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PREFACE

On behalf of the Scientific and Organizational Committee, it is my honor and great pleasure to present the Proceedings of the 2nd EUROSA International Conference, held on 15-18 May 2024 in Vrnjačka Banja, Serbia.

The papers contained in this Proceedings represent current scientific and professional informations in the field of sustainable management of occupational health and safety, environmental protection, fire protection and emergency situations and represent a mix of scientific research and professional opinion, shared with us by participants from academia and industry professionals.

We sincerely thank all the conference participants for their contribution, ensuring the success of the conference. Special thanks to all the participants of the round tables and panel discussions, keynote speakers, chairmen of the sessions and of course the reviewers for their invaluable contribution.

Last but not least, I would like to express my sincere gratitude to all members of the Scientific and Organizing Committee, whose efforts and work led to the successful realization of the EUROSA 2024 conference.

Vrnjačka Banja, May 2024

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INTEGRATED ANALYSIS OF WATER POLLUTION: CASE STUDIES ON NITROGEN TRACING IN ANOXIC AND OXIC GROUNDWATER ENVIRONMENTS

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Abstract: Presented research explores the critical role of water in sustainable development and the challenges it faces, particularly in managing groundwater pollution, with a focus on nitrogen sources. Groundwater, vital for human survival, undergoes increasing strain due to various factors, including agricultural and industrial activities. With less than 10% of wastewater in Serbia undergoing treatment and nitrogen being wastewaters' primary constituent, the research underscores the importance of utilizing diverse scientific methods to effectively trace nitrogen origin and transformations. Given that over 50% of Serbia's water supply is sourced from alluvial aquifers, three case studies demonstrate the integration of hydrogeochemistry, isotopic analysis, and microbiological tests as a comprehensive approach to understanding nitrogen transformations in shallow alluvial groundwaters. Based on physico-chemical data, the groundwater potential for nitrogen conservation or removal can be determined. To evaluate the ability of machine learning models to predict the ammonium concentration in groundwater, four machine learning models were applied: a three-layer neural network (NN), a deep neural network (DNN), and two variants of support vector regression (SVR) models: with linear and with Gaussian radial basis function kernel. Despite the complexities involved, this multidisciplinary approach offers valuable insights for groundwater management, emphasizing the importance of prevention over treatment.

Keywords: **N***itrogen; Nitrate; Groundwater; Isotopes.*

INTRODUCTION

Water is essential for sustainable development and human survival. It serves as the cornerstone of socio-economic progress, ecological health, and disease prevention, plays a crucial role in reducing the effects of climate change and protecting essential ecosystems (UN, 2024). As a finite and increasingly stressed resource, effective management is imperative to ensure its availability for future generations and to harness its potential as a catalyst for resilience in the face of evolving environmental challenges. Groundwater constitutes approximately 99% of the total global volume of fresh water (Shiklomanov and Rodda 2003). Globally, agriculture dominates freshwater withdrawals at approximately 70%, followed by an industry at just under 20%, and domestic (or municipal) use at about 12% (Ritchie and Roser, 2018; UN, 2024).

Higher-income nations utilize more water for industrial purposes, while lower-income countries allocate 90% or more of their water for agricultural irrigation (UN, 2024). In low-income countries, inadequate wastewater treatment largely contributes to poor water quality, while in more prosperous countries agricultural runoff emerges as the primary concern (UN, 2024). Roughly 75% of the EU population relies on groundwater for water supply.

The significance of groundwater in the Republic of Serbia as a water supply source is evidenced by the 75% share of groundwater used for water supply. Over 50% of groundwater utilized for water supply in Serbia originates from alluvial aquifers (SUVRS; Perović and Dimkić, 2021). Maintaining groundwater quality benefits from its slow flow (1 m/day to 1 m/year), enabling natural self-purification processes such as sorption, biodegradation, and redox reactions, along with dispersion, diffusion, and advection effects. Yet, this slow flow also burdens contamination removal, as pollutants persist in the groundwater for a long time, making purification economically challenging. Considering pressures on groundwater quality, the population connected to sewage systems and industrial facilities represents the most significant concentrated sources of water pollution. In the Republic of Serbia, approximately 54% of the total population is connected to public sewage systems. There is a significant disparity in the level of population connection to sewage compared to connections to the water supply network, especially in settlements with fewer than 50,000 inhabitants, posing a threat of groundwater quality, especially considering nitrates (SUVRS). Over the past few decades, over 50 urban wastewater treatment plants have been constructed in settlements with more than 2,000 inhabitants in the Republic of Serbia. Of the constructed plants, only 32 are operational, with only a few operating according to project criteria, while the rest operate with efficiency below projected levels (SUVRS). The overall treatment efficiency for organic load removal is less than 65%, for nitrogen components it's less than 35%, and for phosphorus components it's less than 25% (SUVRS). The Republic of Serbia ranks among moderately developed countries in terms of sewage infrastructure development, while lagging significantly in wastewater treatment capabilities.

Considering that less than 10% of wastewater in Serbia is treated and that nitrogen is wastewaters' primary component of concern, presented research demonstrates the possibilities and necessity of simultaneous application of different scientific methods from various scientific perspectives in order to determine the nitrogen origin in groundwater. The study presents a concise overview of three case studies in Serbia, showcasing the integration of hydrogeochemistry, isotopic analysis, and microbiological tests to trace nitrogen transformations and sources. The study aims to demonstrate that the only approach reducing ambiguity in drawing conclusions is highly complex, comprehensive, financially, and temporally demanding. Therefore, in the context of groundwater management, prevention outweighs treatment.

Environmental and health hazard of nitrogen compounds in water

Since the 1970s, elevated nitrate levels in groundwater have been recognized as a significant health and ecological risk, as highlighted by various reports from European Nations on nitrate contamination (Dimkić et al., 2008; EEA, 2018). Recharging surface waters with nitrate-laden groundwater and agricultural runoff nutrients can trigger eutrophication in aquatic ecosystems. This can harm biodiversity and populations of mammals, birds, and fish, leading to toxin production and decreased levels of dissolved oxygen (Pastén-Zapata et al., 2014). Eutrophication occurs naturally in aquatic ecosystems in response to elevated levels of nitrate and phosphate salts, leading to heightened primary production, specifically the growth of aquatic plants. Increased production of aquatic plants results in increased organic matter content, which is bacterially decomposed, producing unpleasant odors, consuming available oxygen, and affecting the development of other aquatic organisms. It has been found that even relatively low concentrations of N around 4.4-8.8 $mgNO_3/l$ (1-2 mgN/l) can trigger eutrophication in oligotrophic surface waters (Rivett et al., 2008). In nutrient-rich environments, phosphorus concentrations represent the limiting factor for eutrophication.

Increased nitrogen levels in aquifers indirectly contribute to nitrous oxide (N_2O) emissions, a potent greenhouse gas generated either as a necessary intermediate in denitrification reactions or as a by-product of nitrification. About 60% of the total N_2O present in the atmosphere is of natural origin. Natural N_2O emissions occur within the nitrogen cycle, which involves the circulation of nitrogen forms between the atmosphere, plants, animals, and microorganisms (in soil and water), in which nitrogen changes oxidation states from -3 to +5, including the state +1 (nitrous oxide). The main anthropogenic sources of N_2O are agriculture (application of mineral fertilizers and manure), burning of plant residues, fuel combustion, wastewater management, and industrial processes. N_2O molecules persist in the atmosphere for an average of 114 years, and this gas is 300 times more potent as a greenhouse gas than carbon dioxide (USEPA, 2018). Nitrous oxide (N_2O) is mitigated in the atmosphere through bacterial absorption, chemical reactions, or exposure to ultraviolet radiation.

Health problems due to constant intake of food rich in nitrogen compounds and water with elevated nitrogen concentrations have long been considered and well-documented (Canter, 1997; Camargo and Alonso, 2006; IARC, 2010; PSEP, 2018). The International Agency for Research on Cancer (IARC) categorizes nitrates and nitrites in Group 2A (vol. 94) as "probably carcinogenic to humans," potentially resulting in the formation of established carcinogens like N-nitroso compounds under specific circumstances (IARC, 2010). The most discussed disease caused by elevated nitrate concentrations in drinking water is a hematological disorder that occurs when erythrocytes contain more than 1% of methemoglobin - methemoglobinemia. Symptoms include cyanosis, bluish mucous membranes, digestive and respiratory problems, headache, drowsiness, fatigue, tachycardia, convulsions (methemoglobin concentrations 1-10%), brain damage, and fatal outcome (methemoglobin concentrations 50-70%) (PSEP, 2018). Nitrate in drinking water is considered a health threat in the general population when it is present at concentrations of 100-200 mgNO3-N/l, but individual negative effects depend on the amount of nitrates and nitrites ingested (PSEP, 2018). Studies have shown that long-term intake of drinking water containing nitrate levels nearing the maximum allowable limit (10 mg NO_3-N/l) can trigger the production of endogenous nitrosamines (Camargo and Alonso, 2006). There is scientific evidence that ingestion can have mutagenic, teratogenic effects, may contribute to the risk of lymphoma, as well as the occurrence of bladder, thyroid, ovarian cancers (Camargo and Alonso, 2006; IACR, 2010; PSEP, 2018). The presence of nitrates in groundwater can indicate the potential presence of bacteria, viruses, and protozoa, particularly if the nitrates originate from animal waste or septic system discharge (Almasri and Kaluarachchi, 2004). The European Union and the World Health Organization (WHO) have established a standard for nitrate concentration in drinking water at 11.3 mgN/l (50 mgNO_3/l). This same limit for drinking water applies in the Republic of Serbia. United States Environmental Protection Agency (USEPA) has set a standard for drinking water at 10 mg-N/l (45 mgNO_3/l) (Drinking Water Directive 98/83/EC; WHO, 2004). The Nitrate Directive (91/676/EEC) requires the protection of all natural freshwater bodies and sets a limit of 50 mgNO_3/l, which applies to all groundwater regardless of its purpose.

Characteristics and Parameters Relevant to Nitrogen Fate in Groundwater

The role of Hydrogeological characteristics

Hydrogeological characteristics encompass the physical properties of groundwater environment, such as aquifer structures, water table depth, porosity, permeability, and hydraulic conductivity, crucial for understanding groundwater origin, flow, and quality.

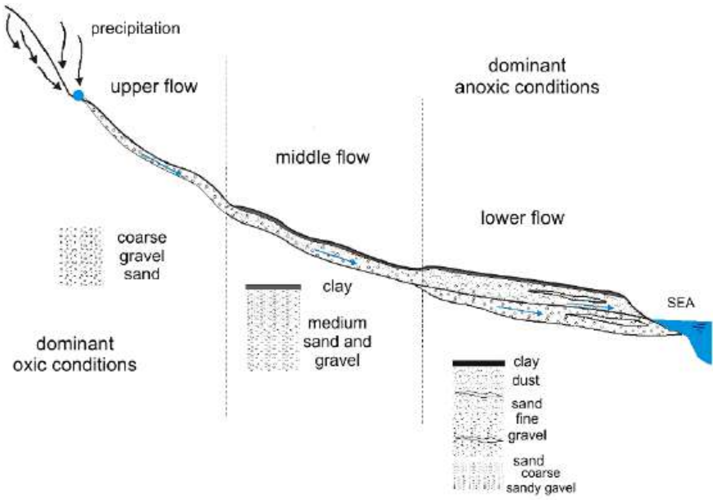

Figure 1. Schematic representation of alluvial groundwater aquifers (Dimkić, 2012)

For a thorough understanding of the vulnerability and protection of water resources, particularly alluvial aquifers, relevant knowledge of the following is essential: geological and hydrogeological composition, hydrological and hydrodynamic relationships within aquifers, knowledge of vegetation cover and plants' water and nutrient requirements, hydrochemical properties of water and soil in lithological layers (Perović and Dimkić, 2021). In the upstream section of the river basins, where water energy is higher, the deposition of fine particles is less pronounced. This results in coarse-grained layers that maintain oxic conditions, reducing the possibility of denitrification processes in the upstream parts of a river basin. As a result, the likelihood of elevated nitrate concentrations becomes more apparent (Figure 1).

Redox processes

The redox potential (R (mV)) is considered a dominant determining factor for pollutant transport, alongside oxygen concentration, and therefore a determinant of the fate of nitrogen species in groundwater. Depending on prevailing redox conditions, redox-sensitive compounds such as O_2, $NO_3^-/N_2/NH_4^+$, $SO_4^{2-}/HS^-/S^{2-}$, Mn^{4+}/Mn^{2+}, Fe^{3+}/Fe^{2+}, As^{5+}/As^{3+}, Se^{6+}/Se^{4+}, Cr^{6+}/Cr^{3+} will exhibit different mobility, degradation rates, solubility, bioavailability, and thus toxicity (Perovic, 2017). Once oxygen is consumed by aerobes, facultative anaerobes start utilizing nitrates as the next energetically favorable electron acceptors. Reduction reactions proceed with the consumption of Mn^{4+} and Fe^{3+}, followed by SO_4^{2-}, then H^+ and CO_2, ultimately leading to methane production. According to the literature review, the highest values of redox conditions where nitrate reduction can be expected are around 150 mV (<250 mV).

Oxygen content

Groundwater can be categorized as follows: oxic if the concentration of dissolved oxygen is greater than 30 μM (1 mg/l DO), suboxic if the oxygen concentration ranges from 1 μM < O2 < 30 μM (0.03 mg/l to 1 mg/l DO), anoxic if the oxygen content is less than 1 μM (0.032 mg/l DO), and anaerobic sulfidic or non-sulfidic (IJČ, 2010a). Feast et al. (1998) specifies the upper limit for denitrification occurrence as 0.2 mg/l, whereas Dimkić et al. (2008) states that the upper limit of dissolved oxygen concentration for denitrification processes is 0.5 mg/l. In aerobic aquifers, the aging of water abstraction facilities occurs significantly slower, and better self-purifying characteristics are expressed for most chemical compounds (Dimkić et al., 2008).

Environmental isotopes

In recent years, the ratio of stable nitrogen isotopes in nitrates has been widely used as a method to identify nitrate sources in water bodies (Nikolenko et al., 2018). Different sources of nitrogen compounds exhibit distinct isotopic signatures, which are used in identifying nitrogen sources

(Table 1). There are over 10 known isotopes of nitrogen, but only two, ^{14}N and ^{15}N, are stable. The atmospheric concentration of the heavier isotope ^{15}N remains relatively permanent, with a constant ratio of $^{15}N/^{14}N$ at 1/272 (0.36%) (Kendall and Aravena, 2000). As a result, the ratio of stable nitrogen isotopes ($\delta^{15}N$) is typically expressed in parts per thousand (‰) relative to atmospheric air according to equation (1):

$$\delta^{15}N_{(vs.air)}=[((^{15}N/^{14}N_{sample})/\ (^{15}N/^{14}N_{air}))-1]\cdot 1000 \quad (1)$$

The isotopic signature of nitrogen can be altered by various complex biogeochemical transformation mechanisms such as volatilization, nitrification, and denitrification, it cannot be exclusively relied upon for source identification, thus it is necessary to understand the influence of nitrogen compound transformation processes on isotopic fractionation (Pasten-Zapata et al., 2014; Perović et al., 2024). The isotope fractionation represents the enrichment of one isotope relative to another during a microbiological, chemical, or physical process, which is quantified by the enrichment factor ($^{15}\varepsilon$). This factor essentially signifies the ratio of enrichment/depletion of isotopes in the reaction product compared to the reactant (substrate). Isotopic fractionation is caused by the presence of stronger chemical bonds by the heavier isotope or due to mass-dependent processes such as diffusion (Sharp, 2007; Nikolenko et al., 2018). Isotopic fractionations are challenging to quantify because they are often metabolically driven, kinetically controlled, and non-equilibrium processes (Nikolenko et al., 2018). In Table 1 there is a review of characteristic isotopic signature results for different sources.

Table 1. The values of $\delta^{15}N\text{-}NO_3^-$ and $\delta^{15}N\text{-}NH_4^+$ for different sources in groundwater (based on data from Nikolenko et al., 2018; modified from Perović, 2019)

	Source	**Range $\delta^{15}N\text{-}NO_3^-$**
$\delta^{15}N\text{-}NO_3^-$	Soil nitrogen	+3 do +8 ‰
	Mineral fertilizers	-8 do +7 ‰
	Manure	+5 do +35 ‰
	Sewage water	+3 do +25 ‰
	Rain	-12 do +11 ‰
$\delta^{15}N\text{-}NH_4^+$	Organic matter	+2,4 do 4,1 ‰
	Rain	-13,4 do +2,3 ‰

	Mineral fertilizers	-7,4 do 5,1 ‰
	Municipal wastewater	+5 do +9 ‰
	Manure	+8 do +11 ‰

Biological activity reaction tests (BART tests)

Semiquantitative and semiqualitative biological activity reaction tests can be utilized to investigate specific bacterial groups involved in various processes in groundwater. The studied groups included bacteria capable of participating in nitrogen transformation processes, including denitrifying bacteria (DN-BART), sulfate-reducing bacteria (SRB BART), and iron-related bacteria (IRB BART). Specialized software, (BART-SOFTv6), was employed to calculate the correlation between the day, specific reaction type, and the quantity of active cells based on the BART test results. The application of BART tests in science is widely used for: assessing the environmental suitability for microbiological transformations, for indicating the potential for biofouling and biocorrosion of underground structures (well aging), as well as for predicting health risks.

MATERIALS AND METHODS

A comprehensive overview of three case studies was provided, covering research on the origin and fate of nitrogen in oxic alluvial groundwater, as well as anoxic alluvial groundwater. State-of-the-art methods were applied for predicting origin, form and nitrogen concentration, including isotopic signature analysis, microbiological activity reaction tests (BART) and machine learning techniques. First case study encompassed 20 groundwater sampling locations during the period 2010-2019, within oxic alluvial source named Ključ. This groundwater source is used for public water supply of the city of Požarevac (approximately 85,000 inhabitants). Within second case study 93 samples from three sampling sites were analysed within five days. Samples were collected from anoxic alluvial aquifer under the drainage system Kovin-Dubovac in Danube alluvium. In the third case study, data spanning a six-year monitoring period from 55 groundwater sampling sites, collected through the state monitoring network, which is part of the national monitoring network managed by the Environmental Protection Agency of Serbia, underwent statistical analysis.

RESULTS AND DISCUSSION

First case study

To solve the problem of increased nitrate concentrations in Ključ groundwater source, in the Velika Morava alluvium, the infiltration-protective system was established in 2006 year. Determined groundwater levels indicated that groundwater recharge depends on Velika Morava water level and on the work regime of extraction wells. The physico-chemical analysis sampling strategy encompassed both - river proximity and the hinterland. The groundwater quality data have shown that examined water is oxic (avg content of DO 5.27 ± 0.37 mg/l), with high redox potential (400.38 ± 17.01 mV). Nitrate concentration was in range from 0.61 mgN/l to 74.27 mgN/l. Statistical data analysis revealed significant correlation between human impact tracers (Na, Cl, NO_3, SO_4, B, pH and el. conductivity), between B and TOC, between pH, NH_4, DO and B. BART tests, along with the isotopic signature results ($\delta^{15}N$ and $\delta^{18}O$ in NO_3^-) were determined. The biological activity reaction tests (BART tests) revealed that nitrification detected in the hinterland alternates with denitrification in the coastal zone. Isotopic signature results showed that the most enriched nitrates with heavier isotope (^{15}N) are determined in the hinterland, while in the area near river the urea hydrolysis signature was observed. Details of conducted research are available in Perović et al., 2024. Based on a comprehensive, simultaneous analysis, zones of different influences were delineated, as depicted in Figure 2 (Perović et al., 2024).

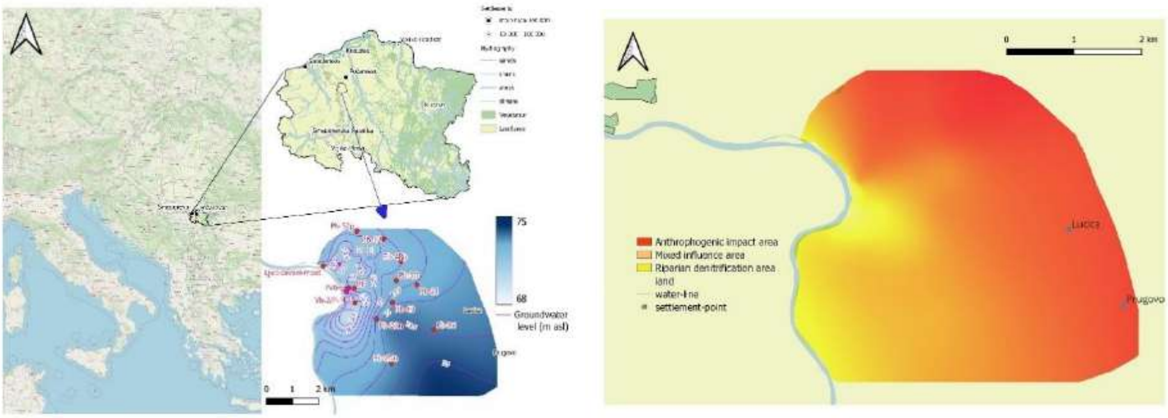

Figure 2. The position of examined area and delineated zone of nitrate origin and fate based on a comprehensive analysis (Perović et al., 2024)

Second case study

The research area holds significance as Kovin-Dubovac represents a potential future regional water supply source, while the area is characterized by the coexistence of intensive agricultural production and an open coal mine. The examined groundwater exhibited an increased concentration of ammonium ions, ranging from 0.02 mgN/l to 4.70 mgN/l and low oxygen concentration, ranging from below the quantification limit to 1.20 mgN/l. The research was conducted in order to determine the fate of nitrates in anoxic groundwater. The nitrate injection experiment ($NaNO_3$) followed tracer experiment (NaCl) and lasted for five days. Groundwater levels, physico-chemistry and BART tests were assessed. Based on conducted research the dominant process in anoxic groundwater environment was conversion of nitrates to ammonium ion by dissimilatory nitrate reduction. The combination of high DNRA (Dissimilatory Nitrate Reduction to Ammonium) and low respiratory denitrification, along with the results of the BART test, indicated that sulfate reducers with DNRA capability as a secondary metabolic pathway were predominant in the process (Perović et al., 2017) (Figure 3).

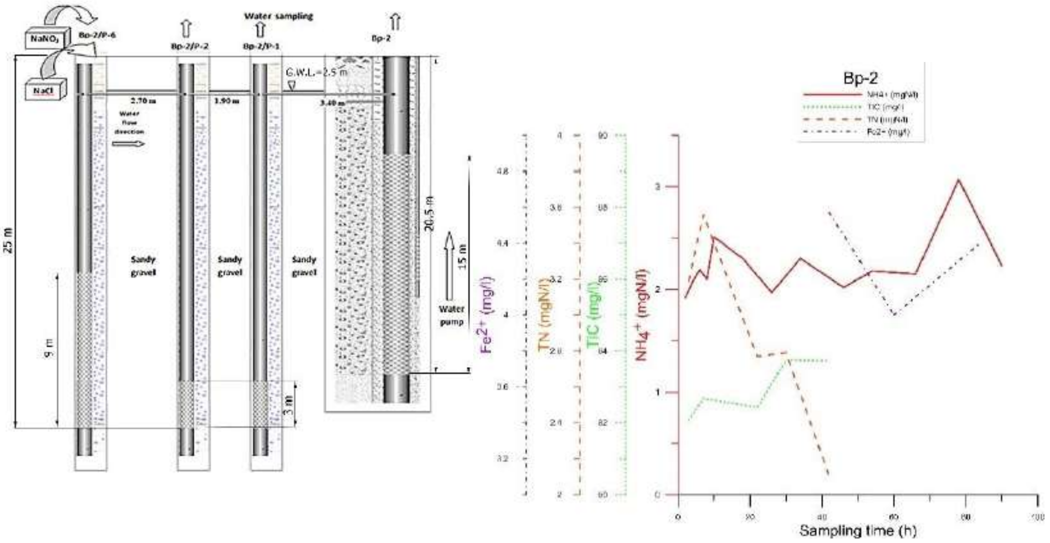

Figure 3. Nitrate and tracer experiment observational objects and observed concentration changes of selected parameters in the well Bp-2 (Perović et al., 2017)

Third case study

The aims of the study were – examination of the correlations between ammonium concentration influential parameters in shallow alluvial aquifers throughout the Serbia; followed by vulnerability map development; and the examination of the possibilities of machine learning models for predicting the ammonium concentration in groundwater in response to predictor variables representing physicochemical conditions in groundwater which are proved to be involved in N transformations (Perović et al., 2021). The map of overall groundwater potential for nitrogen conservation or loss was developed based on threshold values for certain N transformation processes. The figure 4 presents the status of groundwater quality considering ammonium concentrations and marked areas suitable for N conservation - DNRA - low oxygen content (DO) (below 1 mg/L) and C/N ratio over 3.5; denitrification process - places characterised by DO below 2 mg/L and total organic carbon above 3 mg/L and areas with DO content above 3.5 mg/L, which are designated as vulnerable for nitrate inflow. Four supervised learning regression models were applied: support vector regression (SVR) in two variants: with linear and Gaussian radial basis function, kernel, and artificial neural networks in two variants: a three-layer neural network (NN) and a deep neural network (DNN). Based on conducted results the nitrate vulnerability map was developed (Perović et l., 2021). The machine learning models were successfully applied for predicting the ammonium concentration with high determination coefficients (R^2) in tests: 0.84 for DNN and 0.64 for NN, while the SVR did not prove to be adequate with the best R^2 of 0.24 (Perović et al., 2021).

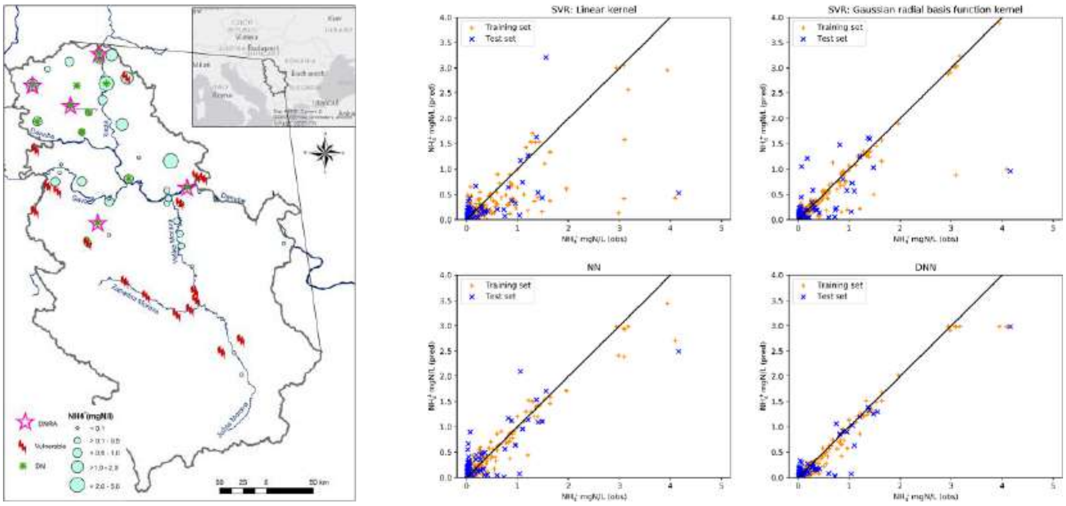

Figure 4. Mapped groundwater potential for nitrogen removal/conservation and Original measured values (NH_4^+ mgN/L (obs)) vs predicted values (NH_4^+ mgN/L (pred)) for ammonium concentration in groundwater compared with the identity line a) SVR model with linear kernel, b) SVR model with Gaussian radial basis function kernel, c) NN model with only one hidden layer, d) DNN model with four hidden layers (Perović et al., 2021).

CONCLUSION

Nitrogen is a unique element due to its abundance and ubiquity, as well as the multitude of oxidation states in which it can be found (-3 to +5) (Perović et al., 2017; Rivett et al., 2008). It provides a compelling example of the challenges in identifying the source of a pollutant that undergoes changes in forms, oxidation states, leading to changes in isotopic signatures, either partially or entirely through microbial metabolism. Methods to identify nitrate sources include isotopic analysis and comprehensive physicochemical, hydrogeological, and microbiological analyses. During the forensic analysis of nitrogen origin in groundwater, it is necessary to - determine groundwater flow and recharge; conduct a physicochemical analysis of groundwater from carefully selected sampling sites; perform microbiological tests to analyse the presence and abundance of bacteria involved in nitrogen transformation; and to extract conclusions with high reliability using appropriate data processing tools. The presented case studies demonstrate the theoretical and practical feasibility of detailed nitrogen source determination and transport and transformation mechanism. First case study showed the complementary analysis for nitrate origin determination in oxic alluvial groundwater. Statistical data analysis revealed significant correlation between anthropogenic impact parameters in the hinterland, where microbiological and isotopic data supplemented drawn conclusions. Second case study revealed that ammonium in examined anoxic groundwater originated from dissimilatory nitrate reduction, conducted by *Desufovibrio*. High determination coefficients of deep neural network and three layer neural network, calculated within third case study, showed that machine learning models could be applied with acceptable accuracy for predicting ammonium concentration in shallow alluvial aquifers.

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PM POLLUTION ON CONSTRUCTION SITES IN SERBIA: CURRENT STATE AND TRENDS, HEALTH AND ENVIRONMENTAL EFFECTS

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Abstract: Particulate matter (PM) pollution from construction activities is a persistent not fully recognized environmental and public health concern in Serbia, particularly in rapidly urbanizing areas like Belgrade and Novi Sad. The paper provides a comprehensive analysis of the current state and trends of PM pollution on construction sites in Serbia, focusing on its environmental and health impacts, mitigation strategies, and workforce trends. Despite limited research data, assessments reveal high PM emission levels on construction sites, with implications for air quality and public health. The paper discusses the sources and dynamics of PM emissions from construction activities, highlighting the multifaceted nature of the problem and its complex correlation with public health and environmental safety. Mitigation strategies, including dust suppression models, use of low-emission equipment, material substitution, and regulatory compliance, are examined to address PM pollution effectively. Furthermore, the paper explores workforce trends, including the influx of foreign labor and the shortage of skilled workers, and their implications for safety and regulatory compliance on construction sites. Analyzing the existing research findings and identifying knowledge gaps, the paper contributes to a better understanding of PM pollution on construction sites in Serbia and defines future research and policy interventions to mitigate its adverse impacts.

Keywords: *Air pollution; PM; Construction site*

INTRODUCTION

Particulate matter (PM) emissions from construction activities pose a significant environmental and public health concern.(WHO 2016) Particularly, in urban environments undergoing rapid development air pollution is significantly noticeable. With urbanization on the rise globally, construction activities have become temporal sources and hot-spots of PM pollution, contributing to the deterioration of air quality and posing risks to both workers and nearby communities.(Stege et al. 2019) The complex correlation between PM emissions, public health, and environmental safety, requires comprehensive scientific approach and effective mitigation strategies. While developed countries have implemented mitigation measures and legislative frameworks to address construction-related PM emissions, challenges persist, especially in developing countries like Serbia.(EEA 2021; National Roads Authority 2011; HKCA 2013; CPCB 2017) Neglect of environmental protection measures in architectural planning and project management deepens the problem, leading to elevated pollution levels in rapidly developing cities like Belgrade and Novi Sad.

Understanding the sources, dynamics, and impacts of PM emissions from construction activities is crucial for formulating targeted mitigation strategies.(Mukherjee and Agrawal 2017) This includes identifying specific construction processes that contribute to PM emissions, considering meteorological factors and material characteristics, and implementing strict regulatory measures to ensure compliance. Furthermore, promotion a culture of environmental awareness and incorporating mitigation measures into architectural practices are essential steps towards addressing this pressing issue. Construction activities are known to emit a diverse mixture of particulate matter (PM) into the atmosphere. These emissions involve fine particles, with sizes ranging from coarse to ultrafine ($<10\mu m$).(Azarmi and Kumar 2016b) PM pollution from construction activities arises from various processes inherent in the construction lifecycle, including site preparation, excavation, material handling, transportation, and different architectural activities. The sources of PM emissions in construction activities are inter and intra disciplinary. Site preparation, involving land clearing and demolition of existing structures, releases significant amounts of dust and particulates into the air. Earth excavation and transport further contribute to PM emissions, as heavy machinery disturbs the soil and releases particles into the atmosphere. Moving equipment and machines on construction sites also generate PM, particularly through the wear and tear of vehicle components and the combustion of fossil fuels. Transport and storage processes, such as loading, unloading, transfer, and storage of construction materials, are additional sources of PM emissions. These activities often involve the handling of bulk materials like sand, gravel, and cement, which can generate substantial amounts of dust. Specific activities performed at construction sites, such as cutting, grinding, and sanding, also contribute to PM emissions by producing fine particles as byproducts. Furthermore, final architectural activities, including painting, plastering, and finishing, can release significant amounts of PM into the air. These activities involve the application of coatings, adhesives, and other materials that may contain volatile organic compounds (VOCs) and other pollutants, contributing to air pollution and PM emissions.

Health Implications of PM Emissions

Prolonged exposure to construction-related PM emissions can have severe health consequences for both construction workers and nearby residents.(Cohen et al. 2017; Kumar et al. 2014) The inhalation of fine particles can intensify respiratory conditions such as asthma, bronchitis, and chronic obstructive pulmonary disease.(Cohen et al. 2017; Mannucci et al. 2015; Wang, Liu, and Zeng 2020) Additionally, PM exposure has been linked to cancer occurrences and cardiovascular diseases, including heart attacks, strokes, and hypertension.(Cohen et al. 2017; O. Raaschou-Nielsen et al. 2016; Ole Raaschou-Nielsen et al. 2013; Requia et al. 2018) Particular concern is caused by the hazardous materials often present in construction-related PM emissions. Silica, commonly found in construction materials like sand, concrete, and stone, can cause silicosis, a debilitating lung disease characterized by scarring and inflammation of the lungs. Asbestos, another hazardous material prevalent in older construction materials, poses serious health risks, including lung cancer, mesothelioma, and asbestosis.

The health impacts of construction-related PM emissions extend beyond the construction site, affecting nearby communities and vulnerable populations, such as children, the elderly, and individuals with pre-existing health conditions. Poor air quality subsequent to the PM pollution can lead to increased hospital admissions, emergency room visits, and premature deaths due to respiratory and cardiovascular diseases.

Table 1. The official stats for issued construction permits and project values yearly in Republic of Serbia for period 2016-2023 (Statistical Office of the Republic of Serbia 2023)

Year	2016	2017	2018	2019	2020	2021	2022	2023
Constr. Permits	12671	18477	19484	21844	22625	30177	29344	31216
Value (million EUR)	2151.85	3532.78	3771.02	7100.84	5105.48	7284.12	8016.65	8777.58

The end of the second and beginning of the third decade of XXI century in Serbia is marked with numerous investment projects. These projects jumpstarted the construction industry in whole country, with significant notice in Belgrade and Novi Sad. The number of issued construction permits has been increasing each year, alongside with the investment value (table 1).

MITIGATION STRATEGIES IN DEVELOPED COUNTRIES

Addressing construction-related PM emissions requires a comprehensive approach that integrates engineering controls, administrative measures, and personal protective equipment to minimize exposure and mitigate health risks. Several strategies can be introduced to reduce PM emissions from construction activities, determined as PM Mitigation Strategy pillars.

Dust Suppression Models

Implementing effective dust suppression measures, such as water spraying, dust barriers, and vegetation buffers, is crucial for minimizing the generation and dispersion of dust particles on construction sites. Water spraying involves the application of water mist or droplets to dampen surfaces and suppress airborne dust. Dust barriers, including temporary enclosures or curtains, create physical barriers to contain dust emissions within the construction site, preventing their spread to surrounding areas. Vegetation buffers, such as trees and shrubs planted along site perimeters, act as natural barriers to trap dust particles and mitigate their impact on air quality. These techniques not only reduce environmental pollution but also contribute to improved worker health and safety by minimizing exposure to harmful particulates.

Use of Low-Emission Equipment

The utilization of low-emission construction equipment, such as electric-powered machinery and vehicles, represents a proactive approach to reducing exhaust emissions and PM pollution on construction sites. Electric-powered equipment operates with zero tailpipe emissions, significantly reducing air pollution and improving air quality in urban environments. In addition to environmental benefits, low-emission equipment offers practical advantages such as quieter operation, reduced maintenance costs, and enhanced worker comfort. By embracing sustainable construction practices and investing in clean technology solutions, construction companies can mitigate their environmental impact and contribute to a greener and healthier future for communities.

Material Substitution

Substituting traditional construction materials with low-emission alternatives is a viable strategy for reducing PM emissions and improving air quality on construction sites. Recycled aggregates, green concrete, and low-VOC paints are examples of environmentally friendly materials that can help minimize pollution and mitigate health risks associated with construction activities. Recycled aggregates, derived from recycled concrete or asphalt, reduce the demand for materials and lower energy consumption during production. Green concrete, made from recycled or renewable materials, reduces carbon emissions and improves sustainability. Low-VOC paints emit fewer volatile organic compounds, reducing indoor air pollution and promoting healthier indoor environments. By incorporating these alternatives into construction projects, stakeholders can create healthier and more sustainable built environments for future generations.

Personal Protective Equipment, Training and Education

Providing construction workers with appropriate personal protective equipment (PPE), including respirators, goggles, and protective clothing, is essential for minimizing exposure to PM emissions and protecting against respiratory and skin-related health hazards. Respirators, such as N95 masks, filter out airborne particles and prevent inhalation of harmful contaminants. Goggles protect the eyes from dust, debris, and chemical splashes, reducing the risk of eye injuries and irritation. Protective clothing, such as coveralls and gloves, shield the skin from direct contact with hazardous materials and prevent skin irritation or chemical burns. By ensuring that workers have access to proper PPE and training them on its correct use and maintenance, construction companies can effectively mitigate health risks and promote a culture of safety on construction sites. Comprehensive training and education programs for construction workers on the health risks associated with PM exposure is essential for raising awareness and promoting a culture of safety on construction sites. By educating workers about the potential hazards of PM exposure and empowering them with the knowledge and skills to protect themselves, construction companies can reduce the incidence of work-related illnesses and injuries and foster a safer working environment.

Regulatory Compliance

Enforcing strict regulatory standards and guidelines for PM emissions from construction activities is essential for ensuring compliance and mitigating environmental and public health risks. Emission limits, pollution controls, and monitoring requirements are among the regulatory measures implemented to regulate PM emissions and minimize their impact on air quality. By enforcing compliance with these regulations, regulatory authorities can hold construction companies accountable for their environmental performance and prevent the release of harmful pollutants into the atmosphere. Regular inspections, audits, and enforcement actions are key components of regulatory compliance efforts, providing oversight and ensuring that construction activities adhere to established standards.

CURRENT STATE AND TRENDS IN SERBIA

Previous researches concerning the PM emission on construction sites in Serbia are scarce. The scarce research data (monitored and modeled) define construction sites as stationary temporal pollution hot spots. (Sunjevic et al. 2023; 2024; Milivojević et al. 2023) Assessment PM emission data, generated by urban transformation on construction sites in the city of Novi Sad, Serbia, unfolded the requirement for additional monitoring and modeling with goal to properly manage the pollution. The researches determine high PM emission levels on construction sites, also indicating that few construction sites are enough to cover city size of Novi Sad with PM pollution vail.(Sunjevic et al. 2023)

Observing workers trends in Serbia, there is a noticeable tendency among the quality construction workers to seek better opportunities in developed countries. Consequently, with the increased number of construction project exhibits shortages of construction workers. To address this deficit, a significant number of foreign workers from Europe and even Asia are being employed in the construction projects. The exact number of foreigner workers is challenging to determine, largely due to a considerable portion operating informally. The Serbian Chamber of Engineers highlights the challenges posed by influx of foreign labor, particularly regarding safety and regulatory compliance. While organized and registered workers typically adhere to safety protocols, those working informally pose significant risks, especially considering language barriers and lack of training. Raw approximations are that up to 40% of construction workers from abroad may be working off the books, presenting regulatory and safety challenges on construction sites. The shortage of construction workers in Serbia is compounded by the outflow of skilled labor abroad, driven by better-paying opportunities.

The research findings depicted in paper concerning utilization of PM mitigation measures on construction sites in Novi Sad reveal a tenacious low level of utilization for most PM prevention measures within the context of construction activities in Serbia.(Sunjevic et al. 2022) While existing legislations lack specific mandates for mitigation measures, certain demands align with environmental protection standards. Notably, measures such as setting up fences, controlled entrances, road definition and marking, and speed limitation are fully implemented, as legislations require defined roads, controlled access points, and speed restrictions of 20 km/h, with closed fences surrounding construction sites. There is a noticeable trend of low utility in adequate material handling, covering stored materials during transport, setting up protective curtains, road watering, and water spraying. Insufficient numbers of qualified workers and an increasing number of construction sites contribute to poor material handling, storage, and transportation practices. The trend over the four-year 2019-2022 observation period suggests stagnation, with only measures defined by legislation showing full compliance.

CONCLUSION

The issue of PM pollution on construction sites in Serbia presents a inter and intra disciplinary challenge that requires attention from policymakers, stakeholders, and the scientific community. The analysis of current state and trends underscores the significant environmental and public health implications of PM emissions from construction activities, particularly in rapidly urbanizing areas such as Belgrade and Novi Sad. High levels of PM pollution on construction sites not only degrade air quality but also pose serious health risks to both workers and nearby communities, increasing respiratory and cardiovascular diseases and potentially leading to premature deaths.

Mitigation strategies such as dust suppression models, the use of low-emission equipment, material substitution, and regulatory compliance are essential for addressing PM pollution effectively. The implementation of these measures remains inadequate, reflecting the need for stronger enforcement mechanisms and greater industry commitment to environmental protection. Additionally, workforce trends, including the reliance on foreign labor and the outflow of skilled workers, further complicate efforts to ensure safety and regulatory compliance on construction sites. Language barriers and lack of training among foreign workers pose significant challenges, highlighting the importance of comprehensive safety protocols and education programs.

Addressing PM pollution on construction sites in Serbia requires a comprehensive and concerted effort from all stakeholders. By taking proactive measures to mitigate emissions, enforce regulatory standards, and promote sustainable practices, Serbia can pave the way for a cleaner, safer, and more resilient future for its citizens.

ACKNOWLEDGEMENT

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ANALYZING THE ENVIRONMENTAL EFFECTS OF MUNICIPAL WASTE MANAGEMENT IN NOVI SAD

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Abstract: The life cycle assessment method is one of the many tools used today to support decision-making in the field of waste management. In order to effectively address the environmental challenges posed by municipal solid waste, it is crucial to implement integrated waste management strategies that prioritize reduction, reuse, recycling, and proper disposal practices. In this research, the impact of municipal waste management on the municipality of Novi Sad was evaluated. The assessment was carried out using the life cycle assessment method. The research delineates 4 waste management scenarios integrating various treatment methods, aiming to assess their respective impacts on mineral consumption, fossil fuel consumption, acidification, and eutrophication. The results show that the greatest impact on the environment comes from waste disposed of in unsanitary landfills, which pose major environmental problems. Examination of impact categories indicates that eutrophication has the highest normalization value, with Scenario 0 displaying a notably heightened impact within this category.

Key words: *Life cycle assessment; municipal waste; scenario.*

INTRODUCTION

Modern society today is confronted with large quantities of waste. Unsustainable production and consumption patterns of natural resources contribute to the generation of more and more waste, and inappropriate waste management leads to the loss of useful components of waste and unforeseeable consequences for the environment and human health (Stepanov, 2018). The implementation of European Union (EU) requirements for municipal solid waste management is a complex problem in Serbia. Until the year 2000, almost all waste collected in Serbia was disposed of uncontrolled landfills or open dumps (Stevanovic Carapina, 2019). Sustainable management of ever-growing amounts of waste has become a major social and environmental concern, as improper management of municipal solid waste leads to significant negative impacts on the environment as well as health and safety problems (Yay, 2015). With the advent of the LCA (Life cycle assessment) method, the possibilities for the optimal selection and application of the most appropriate waste management techniques have expanded considerably.

At the end of the last century, numerous studies began to use LCA as a comparative tool for different waste management options (Boskovic, 2015).

The topic of municipal waste management is widely represented in the world, as evidenced by many scientific papers and doctoral dissertations. Kinshasa, the capital of the Democratic Republic of the Congo, faces several challenges in managing its exponentially growing municipal solid waste. With its 12,000,000 people producing 7,800 tonnes of municipal solid waste per day, the city still struggles with basic services such as waste collection and sanitary landfills. To contribute to the implementation of a better management system in Kinshasa, the study evaluates the environmental impact and cost of the existing waste management framework and proposes 6 alternative scenarios (Haruna, 2022). Research conducted in Turkey aims to determine the environmental aspects of a low-impact municipal solid waste management system through LCA. To achieve the stated objective, a composition study was conducted in Sakarya, Turkey for one year. The results of the first step should be used as a reliable source of data in establishing a complete picture of the environmental performance of the municipal solid waste management system with a life cycle perspective (Moreno Camacho, 2019). The aim of the study by Mondello (Mondello, 2017) was to compare the potential environmental impacts of five scenarios for the disposal/treatment of food waste produced by a mass retail company operating in Messina (Italy) through the application of LCA, and to find the best treatment solution. The results based on the treatment of a functional unit of 1 ton of food waste show that the bioconversion scenario represents the most desirable solution considering all impact categories analyzed by the CML 2 baseline 2000 method, except for global warming, for which higher ecological performances are associated with the anaerobic digestion scenario (Mondello, 2017).

This research is based on previous research (Jovanovic, 2023a, Jovanovic 2023b), and the aim is to analyze the impact of various municipal waste treatments on the environment according to 4 different scenarios using LCA. In contrast to previous research (Jovanovic, 2023a), where only GWP were evaluated, in this research, results from 4 impact categories were calculated: consumption of fossil fuels, consumption of minerals, acidification, and eutrophication, to emphasize the contribution of individual activities for each scenario. The impact categories mentioned not only address current environmental concerns but also underscore enduring challenges in environmental conservation and protection, underscoring the pressing need to address these issues promptly.

METHODOLOGY

The aim of this research is to analyze the environmental impact of different treatment methods for municipal waste using LCA according to the scenarios mentioned (Jovanovic, 2023a, Jovanovic, 2023b):

1. Scenario 0: Current situation, 100% of waste is disposed of in unsanitary landfills. Each municipality disposes of waste in its unsanitary landfill;
2. Scenario 1: All garden waste is directed to composting. 60% to the central composting plant and 40% to household composting. 50% of the waste mass from the fractions paper, cardboard, composites, metal, aluminum and plastic is sent for recycling. The remaining waste is disposed of in a sanitary landfill;
3. Scenario 2: All garden waste is directed to composting. 60% to the central composting plant and 40% to household composting. 50% of the waste mass from the fractions paper, cardboard, composite materials, metal, aluminum and plastic was sent for recycling. Of the remainder, 70% of the waste is disposed of for incineration and 30% for disposal at a sanitary landfill;
4. Scenario 3: All garden waste is directed to composting. 60% is composted at the central composting plant and 40% in households. 50% of the waste mass from the fractions paper, cardboard, composite materials, metal, aluminum and plastic was sent for recycling. 80% of the other biodegradable waste is disposed of in AD (anaerobic digestion) and the remaining waste is disposed of in a sanitary landfill.

The functional unit is 1 kg of waste generated on the municipality of Novi Sad. The geographical area included in the analysis is the territory of the Republic of Serbia for the primary data and Europe for the secondary data taken from the Ecoinvent database. The data that was analyzed had to be within the system boundaries, that determine the process units that must be included in the LCA. The system boundaries for scenarios 0 -3 are shown in Figure 1.

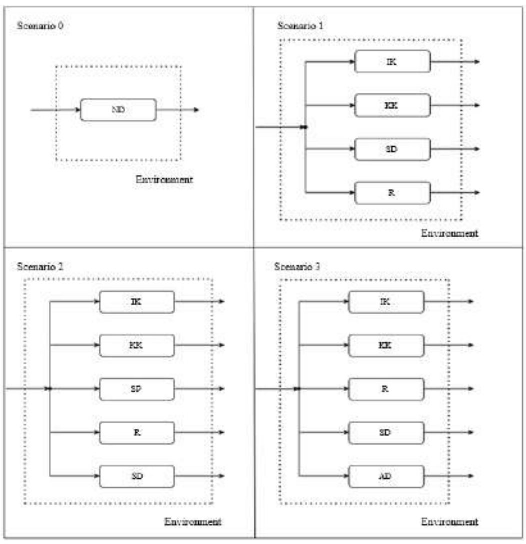

Figure 2. System boundaries (ND - unsanitary landfill, R - recycling, SD - sanitary landfill, AD - anaerobic digestion, KK - home composting, IK - industrial composting, SP - incineration) (Jovanovic, 2023a, Jovanovic, 2023b).

The data required for the preparation of the LCA are taken from the Ecoinvent database (version 3.7). Table 1 shows the type of treatment, abbreviations and the name of the activity in the Ecoinvent database.

Table 1. Type and treatment of waste (Jovanovic, 2023a, Jovanovic, 2023b).

Waste treatment	Abbreviations	The name of the activity in the Ecoinvent database
Industrial composting	IK	treatment of biowaste, industrial composting | biowaste | Cutoff, S - RoW
Home composting	KK	treatment of kitchen and garden biowaste, home composting in heaps and containers | biowaste, kitchen and garden waste | Cutoff, S - RoW
Paper and cardboard recycling	R	treatment of waste plaster-cardboard sandwich, recycling | waste plaster-cardboard sandwich | Cutoff, S - CH
Metal recycling	R	market for ferrous metal, in mixed metal scrap | ferrous metal, in mixed metal scrap | Cutoff, S - Europe without Switzerland
Plastic recycling	R	market for plastic granulate, unspecified, recycled | plastic granulate, unspecified, recycled | Cutoff, S - IN
Glass recycling	R	market for waste packaging glass, unsorted | waste packaging glass, unsorted | Cutoff, S - GLO
Aluminium recycling	R	market for aluminium scrap, post-consumer | aluminium scrap, post-consumer | Cutoff, S - GLO
Sanitary landfill	SD	treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, S - RoW
Unsanitary landfill	ND	treatment of municipal solid waste, unsanitary landfill, dry infiltration class (100mm) | municipal solid waste | Cutoff, S - GLO

Incineration	SP	treatment of municipal solid waste, incineration | municipal solid waste | Cutoff, S - RoW
Anaerobic digestion	AD	treatment of biowaste by anaerobic digestion | biowaste | Cutoff, S - RoW

RESULTS OF LIFE CYCLE IMPACT ASSESSMENT

The openLCA software was used to calculate the results, which expresses the results of the environmental impact based on the impact categories. The LCIA method is CML (version 4.7). Figures 2, 3 and 4 show categories of environmental impact that demonstrate the contribution of municipal waste treatment to environmental pollution.

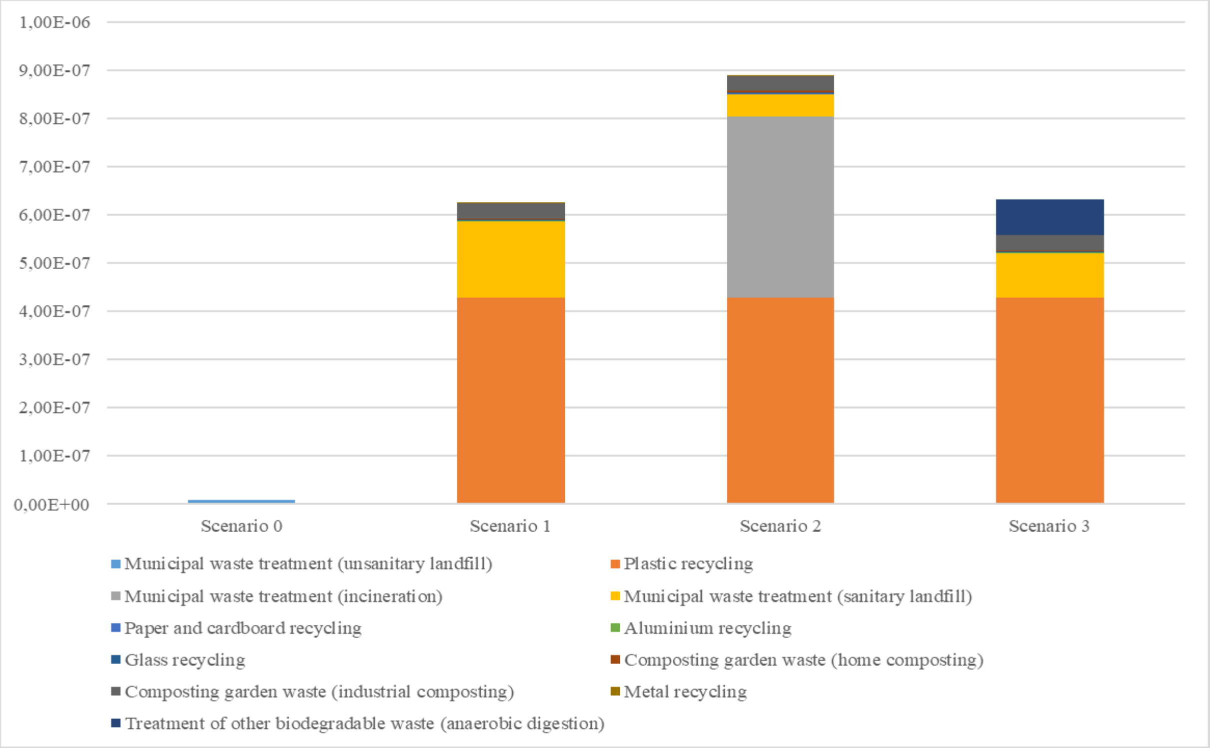

Figure 2. Results of activity impact on mineral consumption (Jovanovic, 2023b).

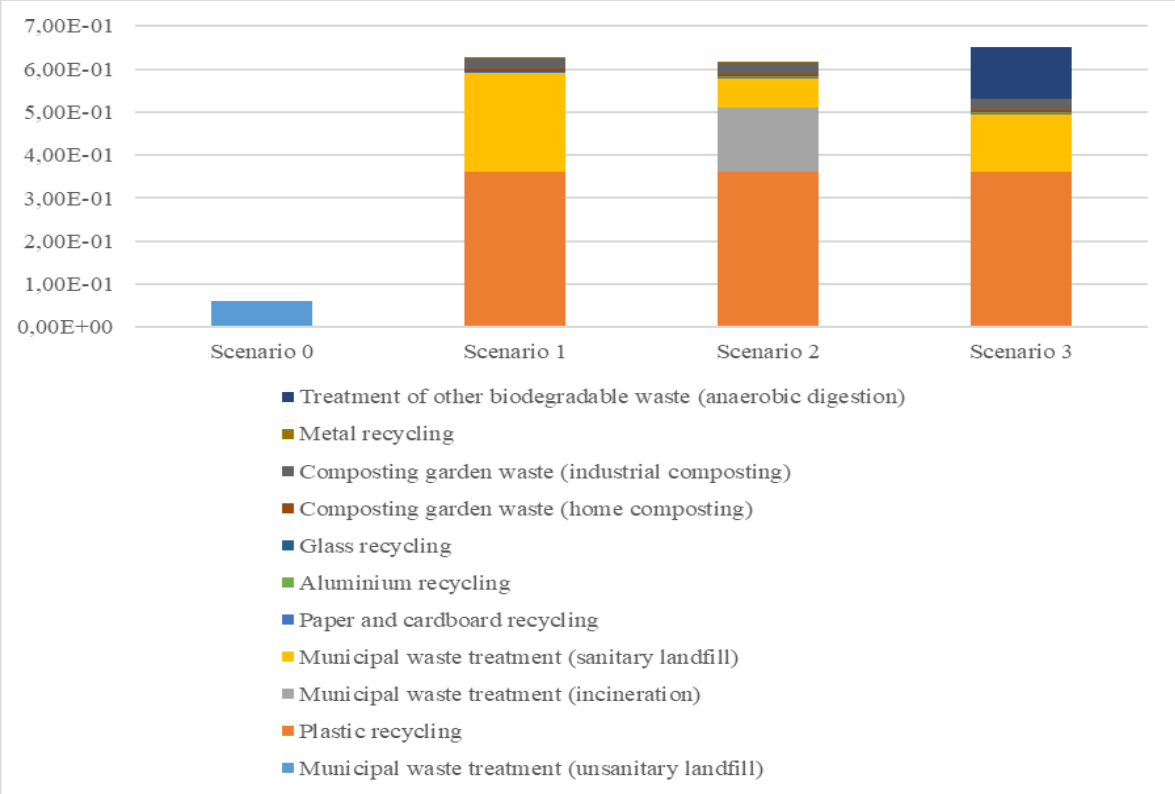

Figure 3. Results of the impact of activities on fossil fuel consumption (Jovanovic, 2023b).

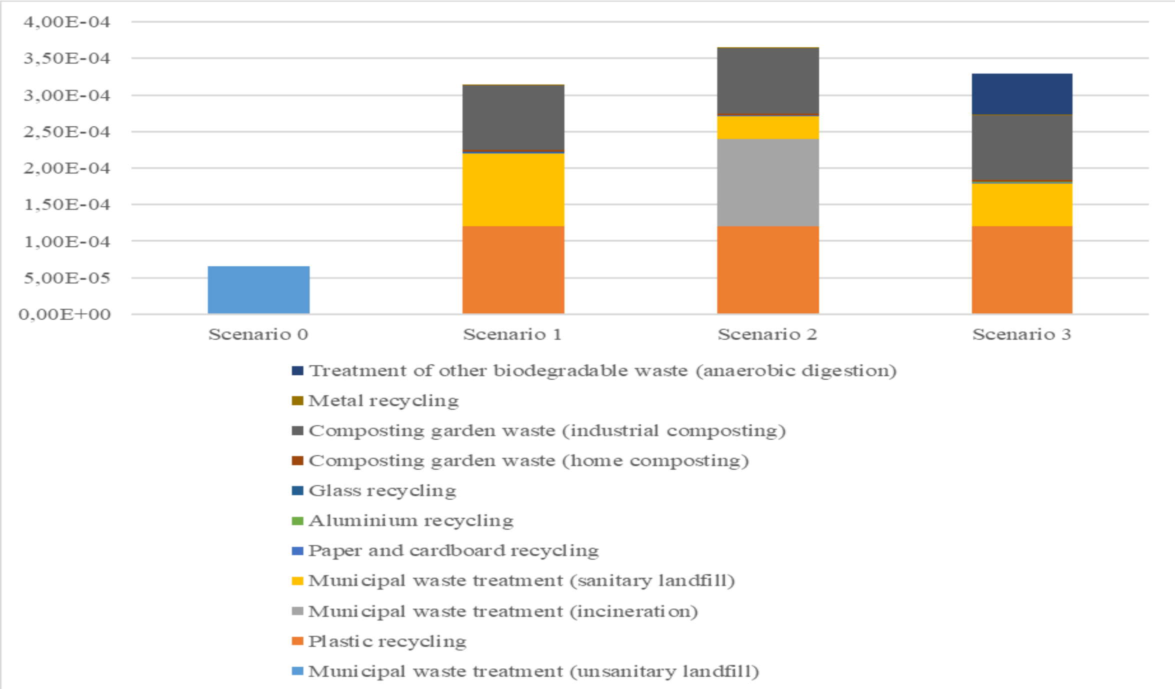

Figure 4. Results of the impact of activities on acidification (Jovanovic, 2023b).

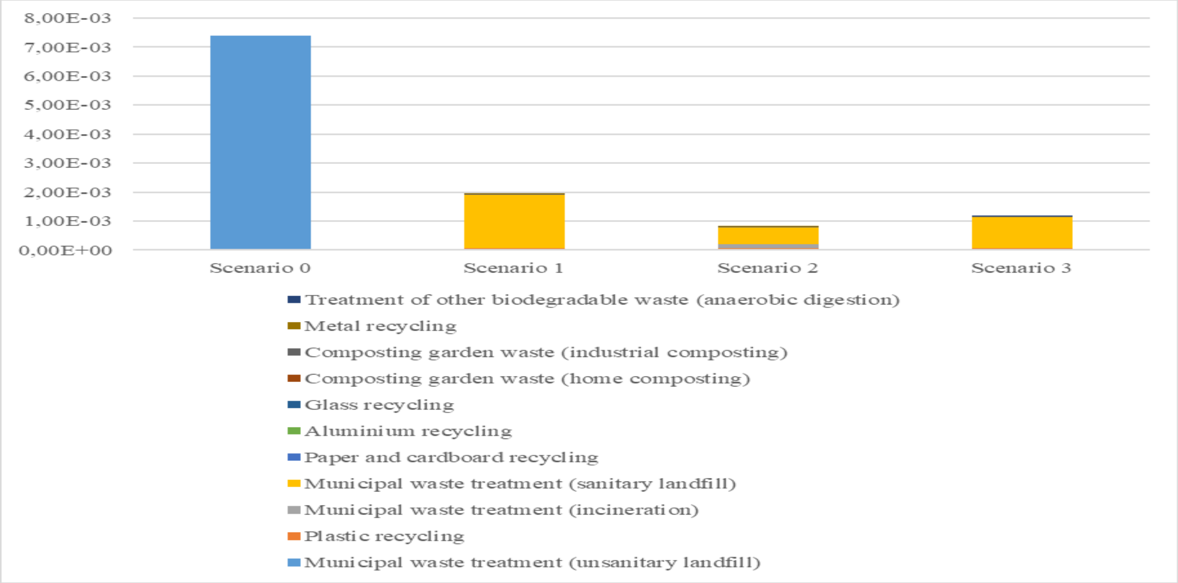

Figure 5. Results of the impact of activities on eutrophication (Jovanovic, 2023b).

In order to be able to compare the values for different impact categories, which are expressed in different units of measurement, the data were normalized. During data normalization, the units of measurement are removed from the input variables and the input variables are converted into a comparable range of values. The normalized values for scenarios 0, 1, 2 and 3 are shown in Figure 6.

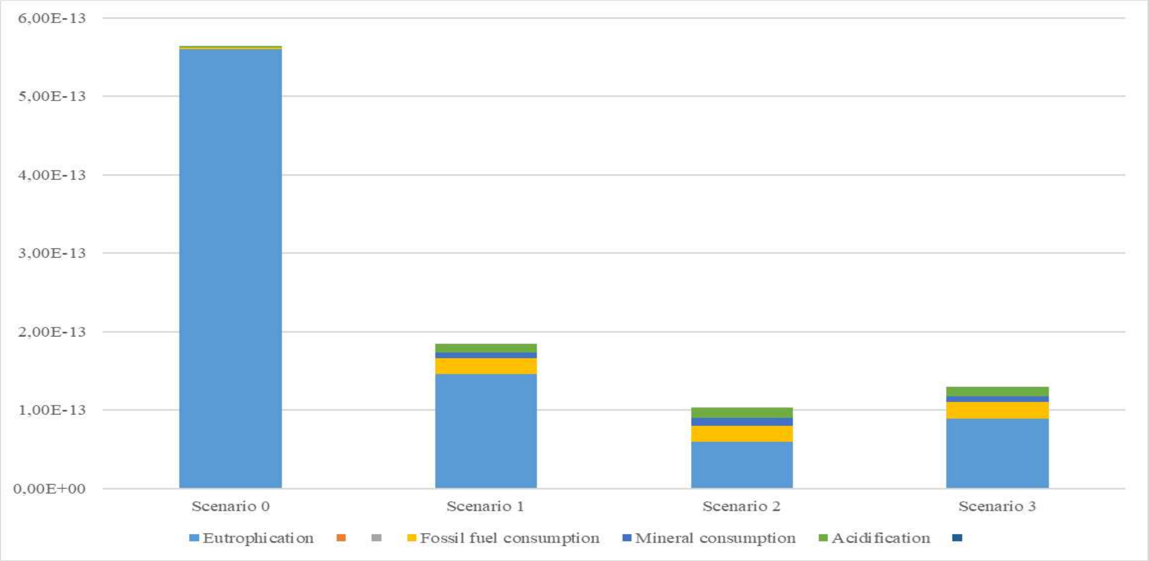

Figure 1. Normalized values of impact categories for scenarios 0-3 (Jovanovic, 2023b).

DISCUSSION

According to scenario 0, the consumption of minerals is municipal waste that is disposed of in an unsanitary landfill. According to Scenarios 1, 2 and 3, plastic recycling has the greatest impact on mineral consumption. According to Scenarios 1, 2 and 3, paper and cardboard recycling has the lowest impact on mineral consumption (Figure 2). In Scenarios 1, 2 and 3, plastics recycling also has the greatest impact on fossil fuel consumption. In Scenario 2, the largest impact on fossil fuel consumption after plastic recycling are incineration and landfilling (Figure 3). Plastic recycling has the greatest impact on acidification, followed by landfill disposal and incineration. Scenario 0 has the greatest impact on acidification, in which all municipal waste is disposed of in an unsanitary landfill, while metal recycling has the least impact (Figure 4). The greatest impact on eutrophication is from waste disposed of in landfills, specifically sanitary and non-sanitary landfills (Figure 5). After normalizing the data, the values for the impact categories mentioned were determined. Scenario 0 has the greatest impact on eutrophication, as do the other scenarios. The lowest values and therefore the lowest impact relate to the consumption of minerals, which is the least jeopardized impact category (Figure 6).

CONCLUSION

The process of determining the optimal waste management system is inherently complex, influenced by a multitude of factors spanning economic, technical-technological, social, and environmental domains. On one hand, waste generation and handling contribute to environmental pollution; on the other hand, waste represents a substantial reservoir of potential secondary raw materials and energy sources. This research aims to enhance understanding of the impacts of municipal waste treatment and disposal activities on various environmental categories. Through the utilization of openLCA software, a more comprehensive assessment of the environmental impact of municipal waste was achieved.

Analysis of impact categories reveals eutrophication as possessing the highest normalization value, with Scenario 0 demonstrating a particularly pronounced impact on this category. Unsanitary landfills present significant environmental challenges, as they allow harmful substances to infiltrate groundwater and soil while releasing methane gas, as demonstrated in prior research (Jovanovic, 2023b). Activities for this research were sourced from the Ecoinvent database. Notably, recycling exhibits negative impacts on certain environmental categories such as mineral consumption, fossil fuel consumption, and acidification. Unlike unsanitary landfills, recycling entails resource and energy consumption, contributing to a greater negative environmental impact. This research underscores the complexity of waste management decisions and emphasizes the importance of informed analysis for sustainable solutions.

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EXPLORING BISPHENOL A CONTAMINATION AND RISK PROFILES IN LANDFILL LEACHATES: EVIDENCE FROM SERBIA

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Abstract: Bisphenol A (BPA) is a synthetic chemical extensively used in the production of various plastics and thermal papers, leading to widespread exposure. Its association with adverse health effects, including impacts on reproductive health, metabolic processes, immune function, and cognitive development, underscores the importance of understanding its presence and distribution. This study conducted three sampling campaigns to assess BPA levels in landfill leachates across four sites in Serbia, focusing on seasonal variations and ecological risks. The findings revealed the presence of BPA in all 14 samples, with individual concentrations ranging from 0.4 to 449.2 µg/L. Comparing across sampling campaigns, higher concentrations were observed in the leachates collected during November compared to February. The calculated risk quotients and BPA concentrations indicated notable variability, with the highest exceedance of the predicted no effect concentration reaching 1871.67 times, and the lowest at 1.67 times. Overall, the risk assessment highlighted significant environmental risks posed by BPA across all landfill sites examined in this study. This paper underscores the critical importance of comprehending exposure routes to BPA and emphasizes the necessity for ongoing monitoring, risk assessment, and implementation of effective mitigation strategies regarding BPA in landfill leachate given its potential to seep into the ground and pose a substantial risk to drinking water sources. Additionally, it draws attention to the hazards posed by unlined landfills in the absence of robust landfill management practices, prompting the evaluation of BPA and other potential contaminants of concern that could endanger public health through this environmental pathway.

Keywords: *bisphenol A; risk assessment; landfill leachate; HPLC; risk quotient; hazardous compounds.*

INTRODUCTION

Landfilling serves as one of the principal practices for the final disposal of most municipal solid wastes, including unwanted/expired household medicines and products. Landfills have become repositories of a variety of emerging organic contaminant residues (Wang et al., 2020). Over the past decades, the occurrence of EOCs such as pharmaceutical and personal care products (PPCPs) and endocrine-disrupting chemicals (EDCs) in the environment has raised environmental and public concern worldwide. They have been detected and reported at trace levels (ng to µg/L or - ng to µg/kg) in surface water, groundwater, and soil (Wang et al., 2020). EOCs are bioactive and persistent in environmental compartments and aquatic organisms (Ojemaye and Petrik, 2019).

Bisphenol A (BPA) or 4,40-dihydroxy-2,2-diphenylpropane is an organic compound consisting of two phenolic rings connected by a single carbon carrying two methyl groups (Allard, 2014). It was first synthesized in 1891, but it was not used widely until applications in the plastic industry were identified in the 1950s (Goodman and Peterson, 2014). Changes in environmental conditions such as temperature, UV radiation, or contact with liquid compounds (solvents, lipids, etc.) and/or acidic/alkaline environments could accelerate its release from the polymer matrix into the various environmental matrices (Duenas-Moreno et al., 2022).

BPA is easy to manufacture; it is also lightweight, clear, and highly durable. Due to its remarkable properties BPA, in its polycarbonate form, is found in a superfluity of common products such as water, milk and baby bottles, eyeglass lenses, sports protective equipment, and compact discs, as well as in medical, dental devices and polyvinyl chloride plastics. Bisphenol A is also found in the thermal paper used for cash register receipts where high levels of free BPA have been detected. The inner walls of cans and the lids of glass jars and bottles for foods and beverages are lined with epoxy resins as a protective coating. Thus, BPA is ubiquitously present in our surroundings and in close proximity to food and drinks (Allard, 2014; Miyagawa et al., 2016; Romani and Banelli, 2019; Czarny-Krzymińska et. al, 2023).

In 1993 came the first report of accidental free BPA leaching of polycarbonate plastics following heat exposure, a major concern in BPA exposure and safety (Allard, 2014). It is likely one of the most common EDCs found in the environment. Animal models showed that BPA crosses the placenta and induces several adverse effects in endocrine, reproductive, and immune systems. It was shown that it increases the risk of prostate and breast cancer (Romani and Banelli, 2019; Cimmino et al., 2020). The toxicological effects of BPA are still controversial, despite numerous studies (ECHA, 2021). Notably, bisphenol A is presently classified as a reproductive toxicant category 1B under the EU CLP Regulation (Regulation 2016/1179) and its use is restricted in numerous consumer products for babies and children (Bousoumah et al., 2021).

This work aimed to broaden the knowledge about the occurrence and fate of BPA in landfill leachate. The landfills are located in Novi Sad, Subotica, Sombor and Zrenjanin, Republic of

Serbia. Specifically, we investigated the potential risks of BPA using a risk quotient. This work would provide insights into the significance of leachates on EDC contamination in the surrounding environment of landfills, as well as the preliminary references for future EDC ecotoxicity research.

MATERIALS AND METHODS

Sampling sites

The sampling sites in Serbia were chosen according to population size, occupation, and way of life to reflect a range of backgrounds. Among them, two are in urban regions known for their fast-paced lifestyle (LS1-1, LS1-2, and LS2), while the remaining pair are in suburban areas primarily focused on agriculture (LS3 and LS4). Throughout 2022, three sampling campaigns occurred in February, May, and November, yielding a total of 14 samples. Table 1 provides an outline of the distinctive features of each site.

Table 1. Landfill sites and sampling points

Landfill site	Operation time, and type of landfill	Collection points
Novi Sad	1983, controlled non-sanitary landfill	LS1-1: 45°18'39.33", 19°50'43.25" LS1-2: 45°18'45.65", 19°50'54.40"
Sremska Mitrovica	2011, sanitary landfill	LS2: 44°56'26.72", 19°41'11.09"
Sombor	1991, non-sanitary landfill	LS3: 45°51'39.18", 19° 6'59.72"
Zrenjanin	1995, non-sanitary landfill	LS4: 45°21'15.92", 20°21'57.01"

Sample collection

Prior to each sampling campaign, we adhered to a defined laboratory protocol for equipment preparation. This procedure involved three fundamental steps: cleansing 2.5 L brown glass bottles with diluted nitric acid, thoroughly rinsing them with Milli-Q water multiple times, and then drying them overnight in an oven. To prevent potential contamination, plastic bottles or plastic laboratory equipment were strictly avoided throughout the entire process.

Determination of organic pollution

All chemicals used in sample preparation were analytical grade. Samples were prepared by liquid-liquid extraction with dichloromethane, then evaporated to 1 mL. All preparation steps were performed under laboratory safety conditions using a fume hood. An HPLC-DAD 1260 (Agilent Technologies, Germany) approach was utilized for quantifying BPA. High analytical purity standards were employed to create the calibration curve. The BPA calibration curve is drawn between 20 and 1000 µg/L. Additionally, an internal standard of concentration 500 µg/L was added to each of the calibration points. The flow rates of the mobile phases were 0.8 mL/min, and the maximum wavelength for BPA was 276 nm.

RISK ASSESSMENT

Risk quotients (RQs) for BPA in raw leachate samples were determined by dividing the measured environmental concentration (MEC) by the predicted no effect concentration (PNEC) (Eq. 1). The methodology employed is deemed robust and advantageous as it furnishes foundational data regarding substances posing elevated risks to environmental organisms when compared with others (Nika et al., 2020; Grobin, 2022; Čelić, 2020).

$$RQ = \frac{MEC}{PNEC} \quad (1)$$

Where MEC represents measured environmental concentration (µg/L) and the lowest PNEC predicted no-effect concentration (µg/L) which was obtained from NORMAN database. To ascertain the degree of RQ, it can be defined as low if $RQ < 0.1$, moderate if $0.1 \leq RQ < 1$, and high if $RQ \geq 1$.

The calculation of RQ is of significant importance, as raw leachates are occasionally discharged to the environment without treatment (e.g., at restored solid waste dumps or at non-licensed closed landfills where no system for the collection and treatment of leachates is available) or inadvertently (in cases of damaged liners in the bottom and side areas of the landfill or improper design/failure of leachates treatment plant) (Nika et al., 2020).

RESULTS AND DISCUSSION

Bisphenol A was quantified in all samples, with ranges of 4.4 - 9.3 µg/L for LS1-1, 2.4 - 7.7 µg/L for LS1-2, 3.9 - 449.2 µg/L for LS2, 3.3 - 18.6 µg/L for LS3 and 0.4 - 4.3 µg/L for LS4. A risk assessment approach was conducted for BPA in all 14 leachate samples using the PNEC value of 0.24 µg/L according to the NORMAN Ecotoxicology Database lowest PNECs. Within the target analysis, MECs at all 4 sampling sites exceeded the PNEC. As all risk quotients with a value higher than 1 are classified as "high risk," and their range in this research was 1.67 - 1871.67, another color gradient was added to the "high risk" category with the goal of further emphasizing these differences. The RQ color gradient, which was implemented in this research, is shown in Figure 1. The darkest red color signifies an exceedance of the BPA PNECs by 1871.67 times, while the lightest shade represents an exceedance range of 1.67 to 10.00. The newly implemented color gradient indicates a rising trend in the concentration of BPA in the leachate, with the highest values observed in the November campaign. However, an exception to this is LS3, where the trend could not be confirmed due to the lack of a sample, as the peripheral canal had dried out. Moreover, the lowest BPA concentrations and lowest RQ values were noted at LS1-2 and LS4 landfill sites, with RQ=10.00, BPA=2.4 µg/L for LS1-2, and RQ={1.67; 9.17}, BPA={0.40; 2.20} µg/L for LS4. At the LS2 sampling site, there is an exponential trendline (R^2=0.9488), suggesting that both BPA concentrations and RQ values rise at progressively higher rates compared to other landfill sites in this study. In contrast, the LS4 landfill exhibits a linear trendline with R^2=0.998, indicating a steady increase in BPA and RQ values.

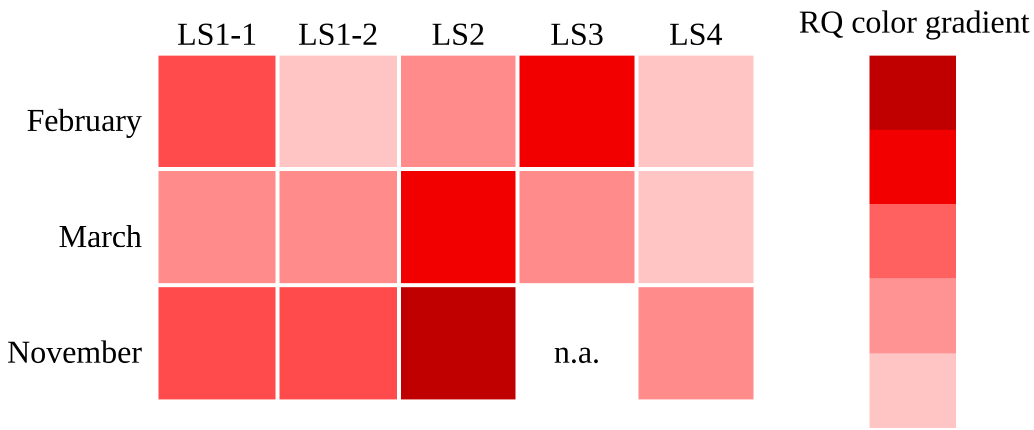
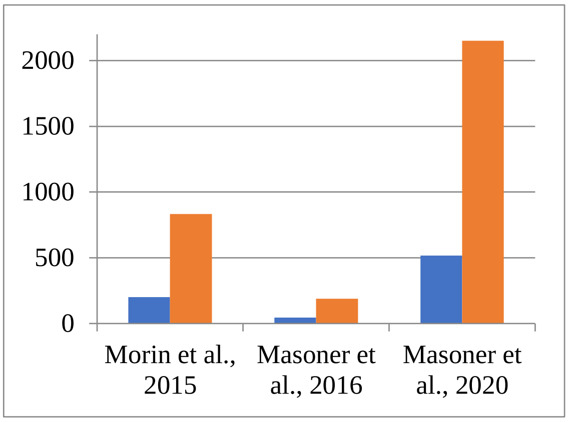


Figure 1. New color gradient scheme for high risk quotients on four landfill sites in Serbia

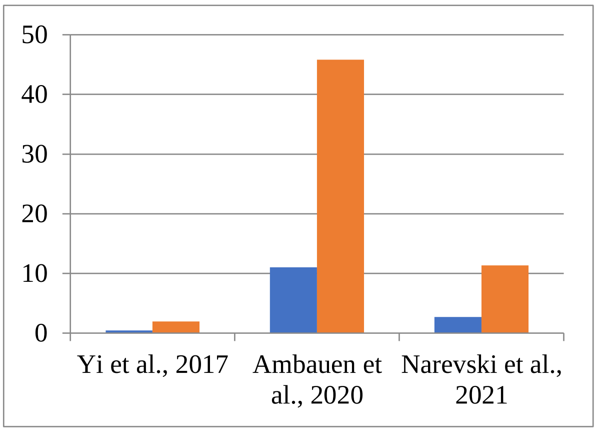
To underscore the significance of monitoring landfill leachate, various studies quantifying BPA were reviewed, and their corresponding RQs were computed using Eq. 1. An overview of the findings is presented in Table 2. The RQ values from these investigations consistently revealed substantial risks. For instance, the research by Masoner et al. (2020) documented the highest PNEC exceedance, surpassing it by 2150 times, whereas the lowest exceedance, at 1.98 times higher than PNEC values, was observed in the study by Yi et al. (2017).

Table 2. Overview of studies quantifying BPA in landfill leachate and their calculated risk quotient (RQ=MEC/PNEC) based on data provided in them.

Study	BPA (µg/l)
Morin et al., 2015	200.00
Masoner et al., 2016	45.40
Masoner et al., 2020	516.00



Study	BPA (µg/l)
Yi et al., 2017	0.47
Ambauen et al., 2020	11.00
Narevski et al., 2021	2.72



The results emphasize the crucial need for further investigation into BPA concentrations in landfill leachates, recognizing them as a pivotal emission source to the environment if released without adequate treatment.

CONCLUSIONS

The current study showed that landfill leachate is an important source of bisphenol A, which was found in concentrations ranging from 0.4 to 449.2 µg/L. The risk assessment for bisphenol A in 14 leachate samples revealed that all sites exceeded the predicted no-effect concentration. The risk quotients indicated an overall high risk, exceeding PNECs by 1.67 to 1871.67 times. The introduction of a new color gradient for the "high risk" category visually highlighted these disparities and confirmed an increasing trend in BPA concentrations over the course of the year in which the campaigns were conducted. The results of this study highlight the importance of further investigation into the seasonal occurrence of EDCs in landfill leachate. In addition, the impact of landfill leachate on the contamination of the soil and water environment surrounding municipal solid waste landfills in Serbia should be fully investigated. Finally, further research is needed on the cumulative eco-environmental risks of uptake of BPA through the water and food chains, as the raw leachate could permeate to groundwater.

ACKNOWLEDGEMENT

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NEW PROMISING CHALCOGENIDE FILMS FOR SOLAR ENERGY UTILIZATIONS: OPTICAL CHARACTERIZATION

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Abstract: The quaternary $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ thin film was prepared by thermal evaporation from previously synthesized bulk samples. Optical characterization of the film was conducted by recording the transmission and reflection spectra. By applying the envelope method, Wemple and DiDomenico model and Tauc's law, relevant geometrical and optical parameters were obtained. The optical band-gap value was calculated from the transmission and reflexion measurements and its value is *1.8 eV*. This value makes the amorphous films of the investigated composition promising from the point of view of its potential for solar energy utilizations, since it corresponds to the zone of high radiation flux in the solar spectrum.

Keywords: *chalcogenides; optical band-gap; solar energy*

INTRODUCTION

Solar energy transformation is a one of the most perspective technologies for reducing the growing environmental pollution and meeting the current clean energy challenges. Cost reduction and efficiency enhancement have always been the essential themes of the development of renewable energy utilisation, forcing the development of novel materials with the enhanced properties. This especially stands for absorber layers of the solar photovoltaics (PV) and the materials for waste water treatment, such as photocatalysts to degrade organic pollutants in water. Optical band-gap (an energetic region with an extremely low density of electronic states) is an important property of materials used for the light into energy conversion, since semiconductors can generate electron-hole pairs when light irradiation energy is enough to overcome the band-gap. Metal oxides and chalcogenides with narrow band-gaps were found as promising materials for solar energy applications, owing to their ability to absorb light in Vis-IR regions, namely form *3.2 eV* to *1.7 eV*. When it comes to the material forms, thin films (thickness <$1\mu m$) play a crucial role in solar cells and modules, since they can be used as an absorber layers, antireflection layers, buffer layer, hole/electron transportation layer and transparent conductive oxide.

The goal of research presented in this paper was to obtain the amorphous quaternary thin film promising from the viewpoint of its potential for solar energy applications and to roughly estimate this potential by determining its optical band-gap and other optical and relevant geometrical parameters, such as thin film uniformity.

MATERIALS AND METHODS

The thin film sample, prepared and investigated in this paper is $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ amorphous film on a glass substrate. The thin film was prepared from bulk components which were previously synthesized in cascade regime from high purity elemental components (99.998%) and air quenched. Thin film was deposited by thermal evaporation technique from the powdered bulks in the tubular quasi-closed evaporator (Figure 1). Thermal evaporation process was conducted under a vacuum of 10^{-5} *Torr* and glass microscope slide with thickness of $d=1.05$ *mm* was used as film substrate. The substrate was cooled during deposition in order to suppress the crystallization with liquid nitrogen. The temperature of the substrate holder was measured with a calibrated PT100 sensor embedded on the substrate holder.

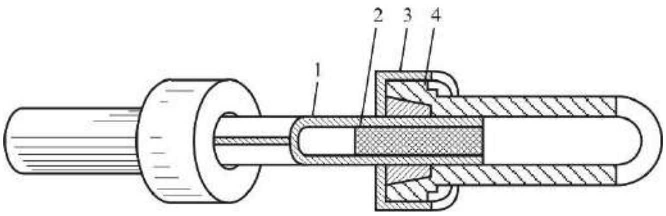

Figure 1. Schematic of a tubular quasi-closed evaporator: 1-thin Ti sheet (heater), 2-thermal insulator (quartz), 3-clamp, 4-sealing cone

As it was already stated, optical band-gap is a crucial property of materials used for the solar energy conversion and it is therefore important to determine their correct values for materials of interest. Among the possible methods, the spectrophotometric is one of the most common. Transmission and reflection spectra of the substrate and the thin film obtained within the presented research were recorded by double-beam UV/VIS/NIR Perekin-Elmer spectrophotometer model Lambda-950. The spectrophotometer was set with slit width of *1 nm*. All optical measurements have been performed at room temperature (*300 K*). The obtained spectra covered spectral region from *400 nm* to *2500 nm*. The method used in this work to determine optical and geometric parameters is based on envelopes of transparent spectra (McClain et al., 1991; Marquez at al., 1995). This method can be used to obtain film thickness and refractive index. The refractive index dispersion can be fitted by the Wemple and DiDomenico model (DiDomenico and Wemple, 1968; DiDomenico and Wemple, 1971) . The dispersion plays an important role in the research for optical materials, because it is a significant factor in optical communication and in designing devices for spectral dispersion. The result of refractive index dispersion below the interband absorption edge corresponds to the fundamental electronic excitation spectrum. Thus, the refractive index is related to photon energy through the relationship:

$$n^2 = 1 + \frac{E_d E_0}{E_0^{\ 2} - (h\nu)^2} \tag{1}$$

where E_0 *is* monooscillator energy (an average energy gap.), E_d dispersion energy (a measure of the strength of interband optical transitions).

The obtained extrapolated values of the refractive index in the region of strong absorption enable the determination of the extinction coefficients of the thin film and absorption. Based on Tauc's law (Tauc, 1974), it is possible to determine the optical band-gap from the dependence $(\alpha\hbar\omega)^{1/2}$ on $\hbar\omega$, as the intersection of the lineart part of the curve that corresponds to high photon energies and the x-axis.

RESULTS AND DISCUSSION

Figure 2. shows transmission spectrum and spectrum envelopes of the amorphous $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ thin film, while figure 3. shows transmission and reflection spectra of the substrate.

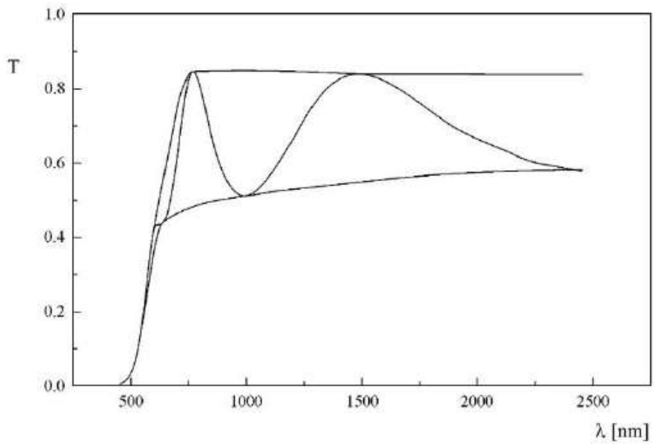

Figure 2. Transmission spectrum of the $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ amorphous thin film on glass substrate.

On the transparent spectrum of the film+substrate system, it can be seen that the envelopes are parallel to each other, which indicates the uniformity of the film thickness, which is an important quality for practical applications.

As can be seen, the transmission curve indicates that the substrate has significant optical losses, especially in the region from *500 nm* to *1500 nm*. Enhanced absorption in this range of wavelengths is often present in substrates that are commonly used for the preparation of thin films for research purposes (Gonzalez-Leal at al., 2002; Štrbac at al., 2007).

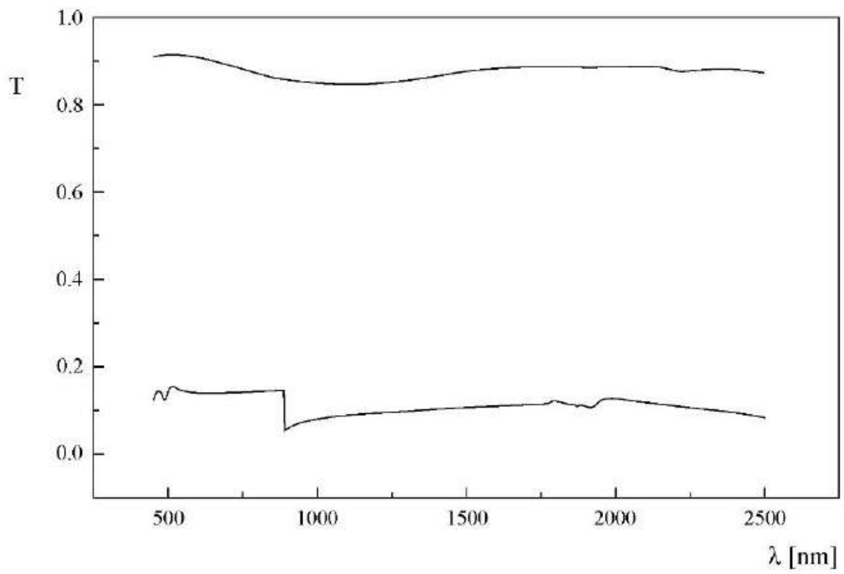

Figure 3. Transmission and reflection spectra of the substrate

The presence of significant absorption indicates the need to use the version of the envelope method, which also takes into account the absorption of a substrate. The jump in reflectance at *860 nm* represents a systematic error of the method and is a consequence of changing the detector.

Table 1 shows the relevant optical and geometrical parameters of the thin film and substrate, obtained by the envelope method, from the experimental data of the transmission of the film + substrate system and the reflection and transmission of the substrate.

Table 1. Values calculated by using the envelope method: n_s-substrate refraction index, n-film refraction index, d-thin film thickness. Values with *0* indexes are first approximations.

λ[nm]	n_s	T_{max}	T_{min}	n_0	n	d_0[nm]	d_1[nm]
1482	1.62017	0.8381	0.5485	2.6911	2.81749		275
1002	1.5351	0.8489	0.5115	2.72956	2.85741	275	275
767	1.75526	0.8456	0.4821	3.19075	2.91635	174	240
638	1.73206	0.5547	0.4404	2.63962	3.03232		

The obtained mean value of the film thickness is: $d_1 = (263 \pm 20)\ nm\ (\ 7.60\ \%\ )$

Figure 4 shows the dependences of $1/(n^2-1)$ on $(h\nu)^2$ and the dispersion of the refractive index based on the Wemple and DiDomeniko model. Figure 5 is absorption as a function of photon energy and extinction coefficient dispersion.

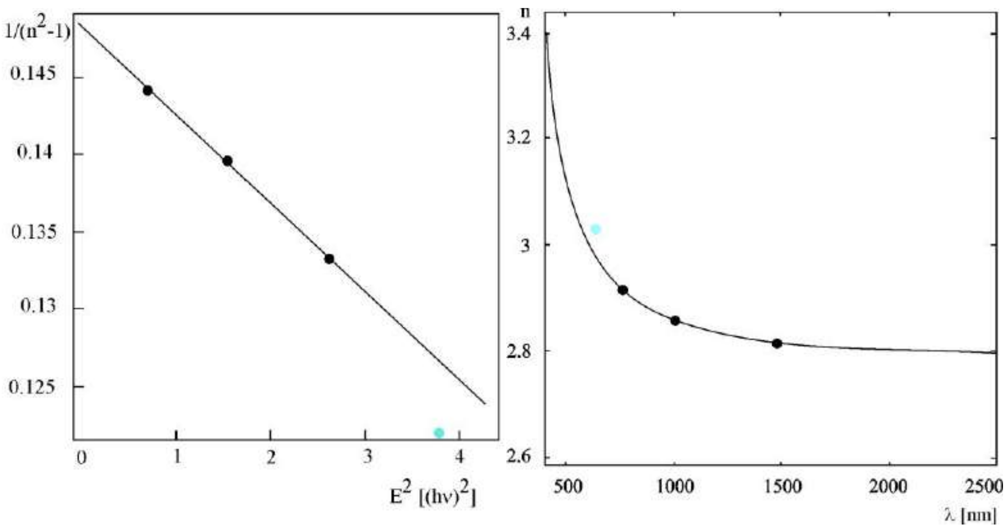

Figure 4. $1/(n^2-1)$ dependende on $(h\nu)^2$ and the dispersion of the refractive index based on the Wemple and DiDomeniko model of the amorphpus $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ thin film

The analytical expression according to the Wemple-DiDomenico model is:

$1/(n^2-1) = 0.148181 - 0.0056964\ h\nu^2$

The values of monooscillator energy, dispersion energy and static (or the long wavelength) refractive index, obtained using the Wemple-DiDomenico model, are respectively:

$E_0 = 5.10 \pm 0.05$ eV, $E_d = 34.42 \pm 0.3$ eV, $n_0 = 2.784 \pm 0{,}0015$.

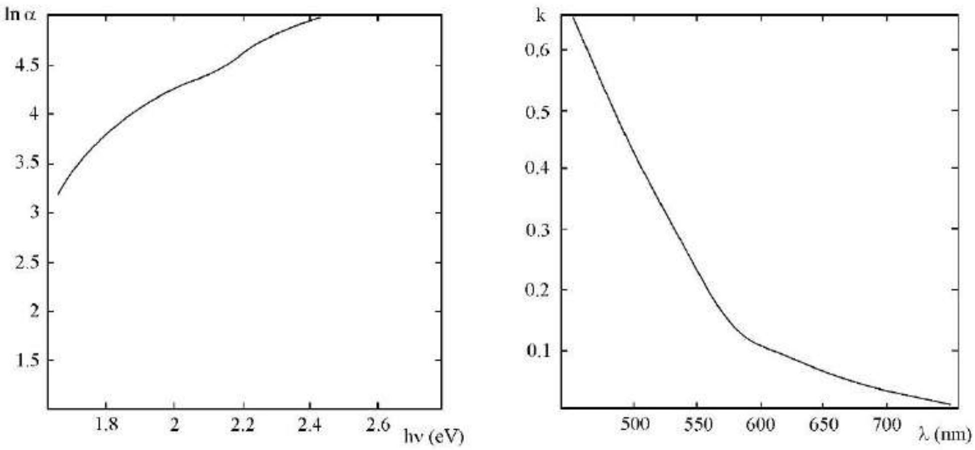

Figure 5. Absorption as a function of photon energy and extinction coefficient dispersion of the amorphous $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ thin film

Dependence of $(\alpha\hbar\omega)^{1/2}$ on $\hbar\omega$, according to Tauc's law is shown in Figure 6. The dashed line is a straight line through the high energy points of the represented dependence, whose intersection with the x-axis determines the optical band-gap for the examined sample. The determined optical band-gap is $E_g = 1.80 \pm 0.009$ eV, and the calculated value of the disorder parameter $B^{1/2} = 751.3 \pm 2.3$ (cm eV)$^{-1/2}$.

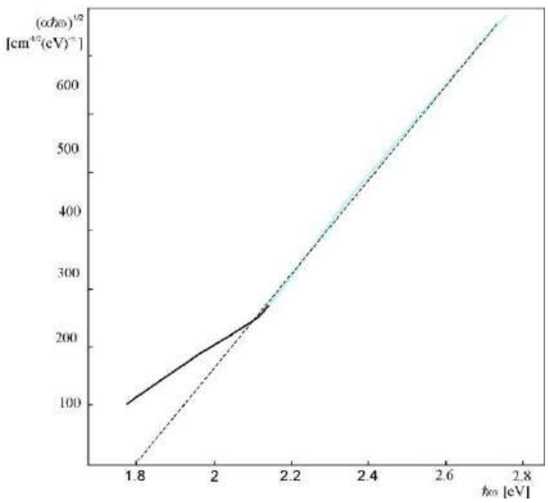

Figure 6. $(\alpha\hbar\omega)^{1/2}$ dependence on $\hbar\omega$ of the amorphous $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ thin film

CONCLUSION

The amorphous thin film $Cu_{20}((As_2Se_3)_{0.9}(AsI)_{0.1})_{80}$ on a glass substrate was prepared from previously synthesized bulk glass, by thermal evaporation technique. The obtained film is uniform in thickness, which proves that the thermal evaporation is a suitable technique for obtaining the films of the investigated composition. The value of the optical band-gap is determined and its value is *1.80 eV*. The results obtained should encourage further experimental exploration of thin film amorphous chalcogenides as candidate materials for use in solar-energy conversion devices.

ACKNOWLEDGEMENT

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PARAFFIN IN THERMAL STORAGE SYSTEMS

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Abstract: Efficient energy storage is fundamental to maximizing energy utilization. Within the spectrum of energy storage methods, latent heat storage using phase change materials (PCMs) stands out as particularly significant. Latent heat storage entails the storage of energy as latent heat at a constant temperature during the phase transition of materials, known as phase change materials. These materials release the stored energy during the crystallization process. Notably, solid-liquid PCMs are integral to latent heat storage systems (LHSS), attracting increasing interest across diverse applications. The text highlights the importance of the thermophysical properties of PCM in latent heat thermal energy storage applications. These properties are critical in determining the effectiveness and efficiency of energy storage systems. Thus, understanding and optimizing the thermophysical properties of PCMs are essential for developing efficient latent heat thermal energy storage systems. These materials, with their varied properties, find wide-ranging applications across various fields. Paraffin, with its numerous advantages, stands as one of the most utilized and important PCMs.

Keywords: *paraffin, phase change material, heat storage*

PCM THERMAL STORAGE

The surge in energy demand and reliance on fossil fuels has spurred the advancement of technologies for energy storage. Among these, thermal energy storage (TES) stands out as a pivotal solution that has been in use for centuries. TES entails the temporary containment of thermal energy, whether at high or low temperatures, offering a means to address energy demands consistently. Through this process, energy can be stored and released as needed, effectively bridging the gap between energy supply and demand while promoting energy conservation.

Thermal energy storage stands as a pivotal concept within energy storage systems. As energy consumption and fossil fuel usage rise, the demand for technologies facilitating energy storage increases. TES fulfills this need by offering a mechanism to store and deploy energy as required. Its historical usage spans centuries, representing the temporary containment of thermal energy at varying temperatures. By bridging the disparity between energy supply and demand, TES significantly contributes to energy conservation, yielding fuel savings and enhancing the economic viability of energy systems through decreased energy wastage.

Integrating TES systems with renewable energy sources enhances their operational efficiency and overall capacity. However, there are potential constraints when coupling storage systems with renewables compared to traditional energy sources. Despite this, TES systems remain a promising option to meet present and future energy requirements. The significance of energy storage has escalated in recent times due to concerns surrounding energy security and the urgent need to combat climate change.

The primary purpose of thermal energy storage is to achieve energy efficiency, which involves three key stages: charging, storing, and discharging. TES systems come in two forms: active and passive. Active systems facilitate forced convective heat transfer to the storage medium, while passive systems typically utilize dual storage mechanisms where the heat transfer fluid cycles through the storage medium only during filling and discharge processes.

A highly efficient method of storing thermal energy is through the utilization of (PCM) in latent heat storage systems. This approach offers benefits such as high energy storage density and an isothermal storage process. TES systems have the flexibility to extract or add heat to storage media for various applications, operating on daily, weekly, annual, or even seasonal cycles, or in rapid serial processes.

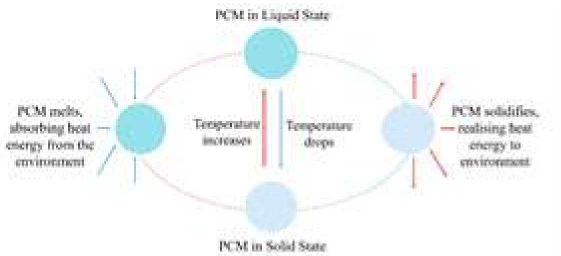

Figure 1. Phase change processes in phase change materials

This systems represents a sophisticated energy technology that holds significant relevance across diverse energy applications. It enhances energy security, minimizes environmental impact, and optimizes the operational efficiency of energy systems. Particularly, TES systems employing PCM present a promising avenue to address the escalating demand for energy storage. Further research and development in this field are imperative to meet both present and future energy requirements.

The advantages of TES are multifaceted. For instance, electricity generated through energy conversion methods can be stored within the system, ready for discharge when demand arises, thereby enhancing energy security and mitigating environmental impact. TES also serves a vital role in addressing short-term fluctuations in energy demand, minimizing reliance on energy generators consuming primary fuel sources. Moreover, it facilitates the redistribution of energy consumption and facilitates the utilization of energy derived from renewable sources, thereby optimizing the operational efficiency of energy systems.

Various types of TES systems exist, categorized as either active or passive. Active systems employ forced convective heat transfer to the storage material, which is circulated through a heat exchanger. These systems can be direct, where the heat transfer fluid serves as the storage medium, or indirect, utilizing a secondary medium for heat storage. In contrast, passive systems typically adopt a dual-storage approach, where the heat transfer fluid only cycles through the storage medium during filling and discharge operations.

An efficient method of storing thermal energy involves the utilization of PCM within a latent heat storage system. PCM-based TES systems offer notable benefits, including high energy storage density and an isothermal storage process. Furthermore, TES systems have the capability to extract or add heat to storage media for various applications. Energy can be charged, stored, and discharged on a daily, weekly, annual, or seasonal basis, or through rapid serial process cycles.

TES systems exhibit promising potential across a broad spectrum of energy applications. They can store energy through sensitive and latent heat, thermochemical processes, or a hybrid combination of these methods. Typically, high-temperature storage aligns with solar energy or heating applications, while cold storage caters to air conditioning, cooling, or even cryogenic requirements. Low-temperature heat storage utilizes materials compatible with the temperature range of the relevant heating or cooling space, whereas medium temperature heat storage employs materials suited for temperatures exceeding human comfort levels. High-temperature heat storage systems leverage molten salts to store and discharge heat energy at exceptionally high temperatures, rendering them ideal for solar power plants.

Thermal energy storage represents an advanced frontier in energy technology, serving as a cornerstone within energy storage systems. Amidst escalating energy demands and the imperative to conserve resources and mitigate environmental impact, TES emerges as a viable solution for storing and deploying energy as needed. Particularly noteworthy are PCM TES systems, offering an efficient means of thermal energy storage. Moreover, TES systems demonstrate wide-ranging potential across various energy applications, further underlining their significance in the evolving energy landscape (Cvetanović, 2022).

Sensible heat storage

In recent years, sensible heat storage (SHS) systems have garnered increasing popularity for their capacity to store thermal energy efficiently, catering to both short-term and long-term energy needs. These systems rely on materials like rock or water as the storage medium, leveraging traditional heat transfer mechanisms such as radiation, convection, and conduction to absorb and retain heat.

Water stands out as a particularly advantageous choice for SHS applications due to its affordability, widespread availability, and high specific heat. Specific heat denotes a material's ability to store heat, with higher values indicating greater heat retention capacity. The amount of heat stored is influenced by both the temperature change and the quantity of the storage material.

Nevertheless, water isn't the exclusive option for SHS mediums. Alternatives such as air, soil, rocks, bricks, and concrete also offer potential, contingent upon factors like their heat capacity and the availability of storage space. Key considerations when selecting a suitable storage medium encompass properties such as density, specific heat, thermal conductivity and diffusivity, vapor pressure, compatibility with container materials, and chemical stability.

Sensible heat can be stored in either solid or liquid states, although gaseous mediums like air storage systems tend to require more space. Current research focuses on innovative materials aimed at reducing energy usage in buildings, such as concrete infused with phase change materials, and the utilization of solid particles for storage in concentrating solar power (CSP) plants.

Concrete incorporating phase change materials represents a notable advancement in SHS. These materials possess the capability to absorb and release substantial amounts of thermal energy through phase transitions, such as melting or solidification. This property renders them invaluable for energy storage within buildings, facilitating temperature regulation and contributing to energy efficiency.

Sensible heat storage systems are an important technology for storing thermal energy for both short-term and long-term use. Water is a common and effective storage medium, but other materials such as concrete with phase change materials and solid particles are being studied for their potential to improve energy efficiency and reduce greenhouse gas emissions. As the world moves towards more sustainable energy sources, technologies like sensible heat storage will continue to play an important role in the transition (Cvetanović, 2022., Cui, 2017).

Latent heat storage

Latent heat storage represents an innovative approach to thermal energy storage that has garnered considerable attention in recent times. This method revolves around the utilization of PCM, such as salt hydrates and organic substances, to store thermal energy. The standout feature of latent heat storage lies in its remarkable energy storage density and the consistent temperature characteristics during heat storage, aligning with the phase transition temperature of the PCM. Within latent heat storage systems, thermal energy is stored in the form of latent heat, which denotes the energy required to transition a material's phase from solid to liquid or from liquid to gas. During this phase transition, a PCM absorbs or releases a substantial amount of energy in the form of latent heat. This energy can subsequently be harnessed to either heat or cool a building, depending on the direction of the phase change. A primary advantage of latent heat storage stems from its high energy storage density. Given that PCM can absorb or release significant energy during the phase transition process, a considerable amount of thermal energy can be stored within a relatively compact volume. This attribute renders latent heat storage systems particularly suitable for application in buildings where space constraints are a consideration. Another notable benefit of latent heat storage lies in its consistent temperature heat storage characteristics. Throughout the phase change process, the temperature of the PCM remains steady, aligning with the material's phase transition temperature. Consequently, the thermal energy stored within the PCM can be released at a stable temperature, simplifying the task of maintaining a comfortable indoor environment. Primarily employed for short-term storage needs, such as daily or weekly energy storage, latent heat storage systems are frequently integrated with other energy storage solutions, including sensible heat storage or renewable energy sources. This amalgamation offers a more holistic and dependable energy storage solution.

In recent years, substantial research efforts have been directed towards the advancement of new PCM materials tailored for latent heat storage systems. Researchers are exploring a diverse range of materials, including salt hydrates and organic substances, to enhance the performance and efficiency of latent heat storage systems. These endeavours aim to develop materials characterized by higher energy storage densities, lower phase change temperatures, and enhanced thermal stability, rendering them well-suited for a broad array of applications. Latent heat storage is a highly efficient method of storing thermal energy that has significant advantages over other forms of energy storage. Its high energy storage density and constant temperature heat storage characteristics make it an ideal solution for short-term energy storage in buildings and other applications. With ongoing research and development, the potential for latent heat storage to revolutionize the energy storage industry is significant (Cvetanović, 2022., Cui, 2017).

PARAFFIN AS PCM

Paraffins encompass a group of saturated hydrocarbons distinguished by varying purity levels and melting points. Among these, technical grade paraffin wax, a derivative of oil refining, emerges as a prevalent choice for Phase change material applications within latent heat storage systems due to its cost-effectiveness. Commercial grade paraffin waxes comprise a blend of predominantly straight-chain hydrocarbons with over 15 carbon atoms, featuring melting temperatures spanning from 22 to 68 °C. These diverse paraffin waxes are readily accessible and economical, offering a spectrum of melting point ranges, facilitating optimal matching with system operating temperatures. Paraffin wax boasts several advantages over alternative PCMs. It possesses a substantial latent heat, moderate thermal energy storage density, minimal or negligible undercooling, low vapor pressure, robust thermal and chemical stability, absence of phase separation, inherent self-nucleating behavior, versatility in phase change temperatures, environmental friendliness, absence of unpleasant odor, non-toxicity, and affordability. Nonetheless, its principal drawback lies in its relatively low thermal conductivity, which hampers the efficiency of heat storage and release during melting and crystallization processes, necessitating a larger surface area. Additionally, its flammability poses a concern, while changes in density throughout heating/cooling cycles to achieve melting/solidification, along with the solid/liquid phase transition, can induce significant volume fluctuations. The thermo-physical characteristics of paraffin waxes, shown in table 1 and documented in available literature, present a range of values owing to incomplete data and limited studies exploring the interdependencies among these properties. Paraffin-based PCMs hold significant promise for energy storage and temperature regulation applications but necessitate stabilization for practical use. Two primary methods for stabilizing the shapes of paraffinic PCMs are encapsulation and microencapsulation. Encapsulation entails shielding the PCM with a shell crafted from polymeric materials boasting enhanced mechanical and thermal properties (Cui, 2017).

Table 1. Thermophysical properties of different n-paraffins

Materials	**Melting point (°C)**	**Latent heat (kJ kg^{-1})**	**Thermal conductivity (W m^{-1} K^{-1})**
n-Tetradecane (C14)	6	228–230	0.14
n-Pentadecane (C15)	10	205	0.2
n-Hexadecane (C16)	18	237	0.2
n-Heptadecane (C17)	22	213	0145
n-Octadecane (C18)	28	245	0.148

n-Nonadecane (C19)	32	222	0.22
n-Eicosane (C20)	37	246	
n-Henicosane (C21)	40	200, 213	
n-Docosane (C22)	44.5	249	0.2
n-Tricosane (C23)	47.5	232	
n-Tetracosane (C24)	52	255	

Macroencapsulation emerges as a simpler and more cost-effective method compared to microencapsulation, involving the formation of capsule shapes such as balls, spheres, cylinders, flat sheets, or tubes. The encapsulation of paraffinic PCMs can be categorized into bulk or macroencapsulation, microencapsulation, and nanoencapsulation. Macroencapsulation finds widespread application across transportation, building construction, solar energy storage systems, and heat exchange mechanisms. Efforts to enhance heat transfer efficiency within these capsules typically involve careful selection of capsule size or the incorporation of suitable modifiers. For instance, aluminum and copper open-cell foams rank among the extensively studied materials for this purpose, while metal oxides, metals, and graphite have also served as enhancers of heat conductivity. Additionally, materials like polyethylene terephthalate pipes and float stones have been utilized both as shell materials and as aids in augmenting thermal conductivity (Rahman, 2012).

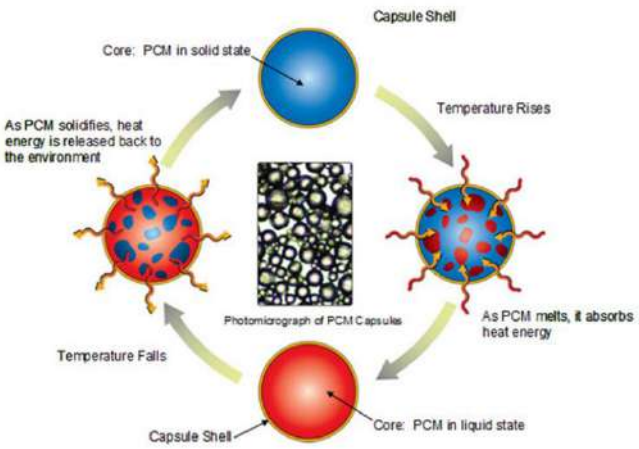

Figure 2. Storing and relising energy in phase change material

Microencapsulation entails encapsulating the PCM within microcapsules ranging in size from 1 µm to 1 mm. This method outperforms macroencapsulation due to its increased contact surface area, shorter discharge and loading times, and enhanced thermal conductivity. Various materials are utilized for the shell component of microcapsules, with two primary physical and chemical methods employed for microencapsulation (Rahman, 2012).

Physical methods include fluidized bed, spray drying, centrifuge extrusion, and similar processes, while chemical methods often revolve around polymerization. These chemical methods encompass in situ suspension and emulsion polymerization, interfacial condensation polymerization, and the sol-gel approach. In the suspension or emulsion polymerization technique, insoluble paraffin is initially emulsified or suspended in a polar medium, primarily an aqueous phase, through vigorous stirring aided by surfactants to stabilize the particles. Lipophilic monomers are then introduced into the medium, and conditions are established for polymerization. The resulting polymer, insoluble in both aqueous and paraffin phases, forms on the outer surface of paraffin particles and ultimately encapsulates the paraffin as a shell. The size of these capsules is contingent upon the size of the emulsion or suspension of paraffin droplets. Occasionally, certain additives are incorporated into the medium to enhance specific polymer properties. For instance, in some studies, polyvinyl alcohol (PVA) has been introduced into the medium alongside methyl-methacrylate monomer, a notable shell material. Consequently, paraffin has been encapsulated by PVA-modified polymethyl methacrylate (PMMA), resulting in the formation of microcapsules with a smooth surface. In the interfacial method, the two immiscible liquids, paraffin, and monomers, are blended together under stirring, resulting in the formation of a thin polymer layer at the interface. The size of these capsules is contingent upon the stirring rate and the quantity of emulsifier used. Through this method, paraffin droplets can be polymerized directly into microcapsules, featuring a slender polymer shell. Recent years have seen a surge in research on polymeric matrix-based shape-stable PCMs, with paraffin-polymer composite materials emerging as particularly appealing options. These composites retain their solid state at paraffin melting point and above, exhibiting no softening. They possess a high-energy absorption capacity and offer versatile applications as stable PCMs with tailored properties. However, common drawbacks such as low thermal stability, modest thermal conductivity, and relatively high flammability can limit their utility, especially in building materials.

Ongoing research endeavors in this domain aim to mitigate these drawbacks and enhance the overall performance of such materials. Various additives have been proposed to bolster thermal conductivity, impart flame retardation, and enhance thermophysical and mechanical characteristics. Notably, the preparation of these composites involves no chemical reactions or bonds between the polymers and paraffin, categorizing them as physical mixtures. Shape-stable PPCMs hold several advantages over other PCMs, as they are thermoplastic, allowing for repeated melting and crystallization cycles. Moreover, they are non-toxic and boast a production process that demands minimal energy consumption. Feldman et al. fabricated plates of shape-stable PCM, showcasing their remarkable thermal energy storage capacity within confined spaces (Feldman, 1985). These polymer-based plates incorporate fatty acids as PCMs, adept at absorbing or releasing substantial heat quantities during phase transitions without altering the composition of the shape-stable PCM. Lee and Choi explored the blend of paraffin and high-density polyethylene (HDPE), presenting it as a viable shape-stable energy storage material (Lee, 1998). Their investigation delved into the morphology of HDPE crystal lattice and its influence on paraffin. Meanwhile, Hong and Xin-Shi synthesized polyethylene-paraffin as a shape-stable PCM, advocating for a composition comprising 75% paraffin for its cost-effectiveness, ease of preparation, and suitability for low-temperature applications. Additionally, Xiao et al. devised a shape-stable PCM by combining paraffin with a thermoplastic elastomer, namely styrene butadiene rubber, and analyzed its thermal properties (Hong, 2000).

Despite their advantages, shape-stable PCMs are not without drawbacks. One significant issue is the softening and leakage of paraffin at elevated temperatures. Seiler addressed this challenge by adjusting the silica and copolymer ratios in the polyethylene-paraffin blend. Additionally, the polyethylene-paraffin compound suffers from low thermal conductivity, prompting extensive research into enhancing this property. Strategies include incorporating expanded graphite, metal particles, and metal oxides into the paraffin, with alumina nanoparticles gaining prominence in recent years as a means to improve thermal conductivity. Nevertheless, shape-stable PPCMs offer unique, customizable structures and find widespread use as stable PCMs with tailored properties. Researchers are actively working to surmount their limitations, necessitating further investigation to overcome drawbacks and enhance their performance. These materials hold immense potential for applications spanning building materials, textiles, thermal energy storage, and numerous other fields. Researchers have observed that the addition of nanoparticles to PCMs can either decrease or augment latent heat, contingent upon the type and quantity of nanoparticles introduced.

CONCLUSION

In conclusion, paraffin wax emerges as a promising phase change material for thermal energy storage applications, offering numerous advantages. However, its low thermal conductivity presents a notable challenge that requires careful consideration and mitigation in the design and execution of thermal energy storage systems. Future research endeavors are essential to comprehensively grasp the properties and potential of paraffin wax as a phase change material for thermal energy storage, paving the way for enhanced efficiency and efficacy in energy storage solutions.

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LAND USE REGRESSION APPLICATION IN THE FIELD OF AIR POLLUTION

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Abstract: Land use regression (LUR) modeling uses geographic information systems (GIS) and various environmental variables to predict spatial concentrations of pollutants. The methodology includes data collection, variable selection, model development, and validation, resulting in high-resolution pollutant concentration maps. LUR models have been extensively developed worldwide, especially in urban regions, using different sampling campaigns and predictors such as traffic and land characteristics. Model development typically uses multiple linear regressions, with validation methods including cross-validation and external validation. LUR offers advantages such as simplicity and interpretability, but generally faces challenges in transferability between urban zones and different research areas. This paper's objective is to describe and discuss the methodology, and progress in land use regression (LUR) modeling for predicting spatial concentrations of air pollutants through a short overview, along with model advantages, limitations, and potential improvements.

Keywords: *LUR; $PM_{2.5}$; NO_2; LUR improvements*

INTRODUCTION

Urban air pollution modeling aims to establish a link between emission sources, atmospheric conditions, and resulting pollutant concentrations. Among various statistical, numerical, and machine learning (ML) methods used for estimation of intra-urban spatial variability of pollutants, the Land Use Regression (LUR) model is notably efficient in capturing small-scale variability with minimal data input (Rodriguez-Villamizar, 2024; Unik, 2023; Zaini, 2022). The LUR methodology establishes statistical relationships between heterogeneous air quality measurements and geographic features to predict pollutant concentrations at unmonitored locations. Widely used in health studies (Mo, 2021), LUR models show high predictive efficiency and estimate pollution levels within and between cities, as well as country-level variations (Das, 2023). The LUR methodology usage involves estimation of the level of target air pollutants in areas without air quality monitoring or where no emission data exist (Azmi, 2023). Given these advantages, the LUR method has been extensively used to assess exposure to various air pollutants globally (Son, 2018).

LAND USE REGRESSION METHODOLOGY

Regression LUR modeling is based on the use of a geographic information system (GIS), which uses geographic, traffic characteristics, land characteristics, and urban topology of the studied area, such as traffic intensity, road length, population density, meteorological parameters, percentage of green areas in buffer zones, combined with air quality monitoring data in the study area to explain variations in spatial concentrations of pollutants at measurement locations (Rodriguez-Villamizar, 2023). The basic steps of the process of developing a LUR model are: 1. Collecting and processing data to select measurement sites, 2. Defining a list of predictive variables, including influence zones, i.e. so-called buffer circular zones of different diameters, 3. Using GIS for extracting predictive variables for influence zones around each measurement site, 4. Exporting data obtained from ambient air quality monitoring, 5. Implementing data obtained from predictive variable monitoring into an appropriate statistical package, 6. Developing LUR model using linear regression, 7. Validating the LUR model and assessing its performance, 8. Applying the LUR model, 9. Obtaining a high-resolution map showing the distribution of predicted pollutant concentrations (Unik, 2023). The measured levels of air pollutants are the dependent variable, while data calculated based on geographic, land cover, and land use characteristics of the studied area are independent predictors (Vyas, 2023). The statistical relationship between pollution and geographic and other characteristics is determined by the least squares method. Pollutant concentration at any spatial point is defined as a set of local sources and regional background concentrations (Jain, 2021). Each model contains unique definitions of one or more classes of variables, depending on the available data and the pollutant for which the model was developed (Ma, 2024).

RESULTS AND DISCUSSION

LUR models have been intensively developed in different regions, such as North and South America, Europe and Asia (especially China) (Ge, 2022; Rodriguez-Villamizar, 2023), as well as Africa (Muttoo, 2018) and Australia (Rahman, 2017). Many methodologies have been developed based on the principles established in the "European Cohort Study of Air Pollution Effects - ESCAPE" (Naughton, 2018).

Sampling campaign

Two types of data collection protocols can be applied, that is short-term or long-term stationary monitoring (Blanco, 2023) and non-stationary or on-road mobile monitoring (Saha, 2019). LUR methodology has been successfully applied to estimate monthly, daily and annual concentrations of NO_X (Rahman, 2017), $PM_{2.5}$ (Das, 2023; Harper, 2021; Shi, 2020; Yu, 2023), PM_{10} (Han, 2020; Karimi 2021), annual VOC concentrations (Bo, 2017), annual O_3 (Huang, 2017), seasonal PM_1, $PM_{2.5}$, PM_{10} and SO_2 concentrations (Chalermpong, 2021; Li, 2020). Seasonal monitoring is often time-limited to a few sampling campaigns (Hsu, 2024; Mo, 2021), or two during the year (Cai, 2020; Chalermpong, 2021), lasting one or two weeks (Cai, 2020; Rodriguez-Villamizar, 2024). NO_2 and $PM_{2.5}$ LUR models developed by Saucy (2018) and Guo (2019) predicted their concentrations during the warm and cold seasons in suburban areas in South Africa, showing good performances in local environments. Annual LUR models may be better than seasonal ones, due to more detailed data and especially the existence of data on crucial predictors for a given study area, near the monitoring site. Within the previous studies of Chalermpong (2021 and Miri (2019), both annual and seasonal models were simultaneously developed, whereby annual ones proved to be more efficient, due to better statistical agreement and robustness than the seasonal models. Studies conducted by Das (2023), who developed annual and monthly $PM_{2.5}$ LUR models, as well as by Thongthammachart (2023), who developed monthly $PM_{2.5}$ LUR models for one year, confirmed better annual performances. As opposed to such coordinated measurement campaigns, the developed $PM_{2.5}$ model can be based on measurements during one day, for example at the time when the greatest pollution is present, in the morning and evening hours (Enkhjargal, 2023). In the case of the mobile campaign, it was found that for a successful LUR model for particle concentration, at least 10–15 days with 1 h of sampling per day is needed to gain a model with good precision and low error (Saha, 2019). In contrast to specially designed monitoring which is exclusively used to assess human exposure to ambient air pollutants, LUR methodology can be applied within routine monitoring for regulatory purposes to measure and monitor pollution (Huh, 2023).

Number of measuring points

The number of sampling sites required to develop a model varies, depending on the scope of the study (Karimi, 2021), and often models are based on a relatively small number of sampling sites, approximately between 20 and 80 sites (Cai, 2020; Miri, 2019; Wong, 2021). For the development of NO_2 LUR models, at least 30 sites were needed to yield better predictions and enhance model stability (Dong, 2021). According to Rodriguez-Villamizar (2024), NO_2 and $PM_{2.5}$ models developed for Bogota needed at least 80 sites for NO_2 and 40 sampling sites for $PM_{2.5}$ models. A model for ultrafine particles in Pittsburgh was developed by measuring on 32 sites with daily sampling duration (Saha, 2019). Research shows that effective monitoring of pollutant concentrations and population exposure in a specific area relies more on terrain properties than on the number of measurement points (Azmi, 2023).

Predictors

Industrial and traffic emissions are major contributors to air pollution in most cities, especially for SO_2, NO_2, and PM_{10} models (Ma, 2024). Traffic is the most significant independent variable in most developed models (Azmi, 2023; Miri, 2019). For the development of hourly PM, SO_2, NO_2, and CO models for Mexico, traffic density data in a buffer > 500m had the greatest influence on explaining air pollution (Son, 2018). Also, the number of medium and heavy-duty vehicles with a buffer size of 500 m was an important predictor for annual $PM_{2.5}$, PM_{10}, and NO_2 models for Hong Kong (Li, 2024). In addition, road length and distance from the nearest road are often used as predictors in LUR studies and are being used as a proxy for traffic since the data are readily available (Shi, 2022; Wong, 2021). In the study for Sabzevar, Iran, annual and seasonal LUR models for particles were developed using data from 26 sites, and distance to major roads and total length of major roads in buffer zones were used as main predictors (Miri, 2019). The applicability of the methodology depends on available and relevant local data, while the effectiveness of each predictor depends on location and meteorological conditions (Enkhjargal, 2023). For example, traffic predictor and its proxy explained from 23-79%, 56-93%, and 31-82% of the variability in annual spatial patterns of PM_1, $PM_{2.5}$, and PM_{10} respectively, in study developed for Sabzevar, Iran (Miri, 2019). Also, within the study conducted by Cai (2020) in China, the developed model for $PM_{2.5}$ explained 65% of the spatial variability of $PM_{2.5}$ with traffic, industry, and agriculture being the dominant predictors. In another study (Zheng, 2022) authors used traffic volume, population density, number of residential buildings, number of households, and distance from main roads in buffers of 100 - 5000 m to build the model. Five classes of predictors, including land use type, population density, length of the road network, distance to major roads, vehicle density, and geographic information, at different radii (500 - 2000 m) around each sampling site were used for the model developed by Karimi (2021). The variability of the buffer radius is determined during model development, conditioned by the characteristics of the research area and the data. $PM_{2.5}$ and NO_2 models developed in Chongqing (Harper, 2021), used dominant traffic predictors as well as surrogate predictors, with buffer radii of 25 m - 1000 m, and for the feature predictor class soils, a buffer of 300 m - 5000 m. For the study conducted in Auckland, New Zealand (Weissert, 2018), the model was developed by monitoring NO_2 at 40 locations, measuring road pollution in buffers of 10 - 100 m and it explained 66% of NO_2 variability.

Model development

The most commonly used algorithm for LUR development is multiple linear regression such as the standardized supervised forward stepwise regression method (Chalermpong, 2021; Jain, 2021; Zeng, 2022), but backward stepwise regression as well (Zhou, 2024). The methodology of model development is based on the principle that is fundamental in studies of this type and is explained in Brunekreef (2008), with certain modifications according to the characteristics of the research (Das, 2023). Linear regression with an automatic variable selection algorithm is often used to maximize the explained variation of measured air pollutant concentrations (Mölter, 2021). Certain linear regression algorithms are also used in some models to consider only predictors that follow the likely direction of the effect, increasing the physical interpretability and potential transferability of the developed model (Karimi, 2021).

Model validation

In the context of validation after defining the final models, few methods are applied to test the performance of the LUR model. The predictive ability of the developed models is evaluated using R^2 and adjusted R^2 values. Mean square error, root mean square error, and mean absolute error are used to confirm the residuals between predictions and measured values (Karimi, 2021; Wong, 2021). Two common approaches are usually applied for model validation, namely internal validation, i.e. method of cross-validation (LOOCV) (Karimi, 2021; Zeng, 2022; Das, 2023) and retention-evaluative external validation, HEV (Harper, 2021; Zeng, 2022), which is applied to independent measurements used for model validation purposes. In addition, "10-fold cross-validation" is also applied (Wong, 2021).

Advantages and limitations of applying the model

The LUR method effectively identifies significant predictors for many pollutants concentration, reducing dimensions of predictor variables in final models (Song, 2019), and offering advantages such as economy, simplicity, efficiency, stability, and interpretability (Ma, 2024). However, careful attention is needed to evaluate assumptions, verify linearity, mitigate multicollinearity, and manage outliers (Thongthammachart, 2023). It efficiently maps and predicts pollutant concentrations in study areas and differentiates population exposure at different distances from the measurement site (Chalermpong, 2021). Beside these advantages, LUR models face limitations in transferability between urban zones (Jain, 2021), requiring redevelopment for different scales (Shi, 2020). However, the automation of spatial analysis by special software can improve model adaptability (Ma, 2020).

Land use regression improvements

Improvements to LUR models include the inclusion of meteorological factors such as wind speed and direction to account for small spatial variability in air pollution (Naughton, 2018). In addition, the integration of satellite data helps predict background concentration levels and improve air pollution forecasts over large areas or entire continents (Unik, 2023). ML methods offer significant advances in pollution prediction by simultaneously considering multiple parameters within a single model and better quantification of complex data (Chen, 2023). Commonly used techniques include artificial neural networks and random forests, along with hybrid models that combine different artificial intelligence algorithms (Huh, 2023; Jain, 2021; Wong, 2021). However, the application of variable selection methods before training ML algorithms is critical in providing interpretable predictors for explaining air pollution variation (Wong, 2021). Recent studies have also refined the models using generalized additive models, principal component analysis, LASSO regularization, and Bayesian probabilities (Yu, 2023). Advanced statistical methods outperform linear models in handling complex data relationships and interactions (Ge, 2022).

CONCLUSION

LUR methodology has proven to be effective in predicting spatial air pollutant concentrations by incorporating diverse geographic and urban data, although it faces certain challenges in transferability between different urban zones. The simplicity and interpretability of the methodology offer quite significant advantages. However, improvements such as the integration of meteorological factors and advanced statistical methods have improved its predictive power and applicability in air pollution research, demonstrating its potential for further progress in this field.

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CONTRIBUTION TO DETERMINING FIRE RISK ZONES IN THE HIGH-BAY WAREHOUSES

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Abstract: Considering that the determination of fire hazard zones in warehouses is not sufficiently researched and studied, this paper aims to present a new methodological approach concerning the mentioned issue. Based on the COPRAS multi-criteria decision-making method, a new method was developed for the precise determination of potential zones where there is a risk of fire. The advantage of the described method is that it allows quick and easy determination of all orientation fire risk zones. The mentioned procedure represents the first step when planning the layout and arrangement in the warehouse itself. The effectiveness of the proposed method was confirmed through a suitable numerical example.

Keywords: *Warehouse; Fire risk zones; COPRAS Method*

INTRODUCTION

Fire represents a serious threat to the aspect of safety of people and property, regardless of whether it is about residential buildings, storage facilities, or industrial facilities, therefore managing the risk of fire outbreaks is a big challenge in urban and rural environments (Alkış et al., 2021). Warehouses, as objects in which some activities and work processes are performed regarding the storage, transportation, and manipulation of goods and materials, are places where various accidental situations can often occur, which can result in the injury of employees, the occurrence of material damage and the endangerment of the working environment, especially in cases of fire.

Warehouses, as an integral part of logistics, are often exposed to various improvements and corrections in the development phase, all with the aim of better performance, capacity, and efficiency of the warehouses themselves. The aforementioned improvements result in larger and higher warehouses, the use of automated systems for storage and retrieval of storage units

(AS/RS systems), increased storage density, and placement of storage units at higher heights (Dinaburg and Gottuk, 2012). The mentioned improvements have made the warehouses efficient, but at the same time, they have introduced potential dangers in terms of fire protection. In modern society, we are witnesses of fires that occur in warehouses in which there are often human victims and large material losses. It is known that most deaths in fires are the result of inhalation of toxic gases (CO, CO2,...), thick smoke, and insufficient amount of oxygen (Martin et al., 2016; D'Evelyn et al., 2022]. The fire that occurred in August 2015 in the warehouse of the port of Tianjin in North China, due to the large number of victims and caused material damage, pointed out the importance of the issue of fire protection in warehouses. In this event, 173 people died, and several hundred were injured (Fu et al, 2016). At least 49 people, including nine firefighters, were killed in a major fire in 2022 at a container warehouse near a port city in southeastern Bangladesh (Tahmid et al, 2022), and more than 100 people were injured in total. The cause of such a large fire was the explosion of a container that was full of chemicals.

Based on the large number of fires in warehouses, which by their scope and consequences can sometimes be considered catastrophic and which occurred around the world at the end of the last century and during this century, a large number of research related to this topic was initiated. The primary goal of these investigations consisted of answering questions related to risk assessment, safe evacuation from the warehouse, effective fire extinguishing and localization, as well as reducing the risk of the fire itself.

MATERIALS AND METHODS

The method developed in this paper consists of four parts. The first part refers to the selection of parameters used in fire risk assessment methods, needed to obtain the weighting coefficients necessary for determining fire hazard zones using multi-criteria decision-making procedures (Bošković et al., 2022; Chanthakhot et al., 2021). In the second part, the COPRAS method is presented, which was selected as relevant for obtaining the weighting coefficients necessary for further calculation, as in the paper (Valipour et al., 2017). The third part describes the characteristics and advantages of the three-dimensional method for determining the parameters related to the contents placed in the warehouse necessary for calculations, fire risk assessment, and determination of fire hazard zones. In the last, fourth part, the 3D COG method (Center of Gravity Method) is presented, which is used to determine locations within the warehouse that are considered potential risk zones in case of fire.

Selection of Parameters for Multicriteria Analysis

The basic concept in the development of the method was to combine factors related to the emission of harmful substances due to the frequency of poisoning in fires, as well as factors related to the process of burning materials in a fire. Due to the limitations of the COPRAS method related to the number of criteria that can be applied, 7 key parameters were selected based on the available literature. The mentioned parameters represent the criteria in the multi-criteria analysis procedure, which are divided into two groups: criteria related to the impact on human health and criteria related to the thermal characteristics of the stored materials.

Determination of Simulation Parameters Using the COPRAS Method

The COPRAS method has a very wide field of applications. It was used for risk assessment in the construction industry, for the selection of materials for solar panels, for the selection of mechanical processing of composite materials, for the selection of the type of robotization in production, etc. In this paper, the COPRAS method was used to determine the weighting coefficients, which also represent input parameters for risk assessment in the case of a high-bay warehouse, as the authors presented in their paper (Bošković et al., 2023). The COPRAS method includes six steps - from the creation and normalization of the decision matrix to determining and ranking the relative importance (weight) of each alternative.

3D method for determining storage parameters

To determine the most precise parameters related to the locations of transport units, flexibility in terms of the configuration of the layout within the facility itself, and using the approach as in the literature, a procedure was developed for the formation of a three-dimensional model of the warehouse with associated elements. The proposed structure of the procedure for determining the parameters of the warehouse, as shown in Figure 1, includes three main phases for the calculation and determination of the necessary parameters related to the storage of materials inside the warehouse.

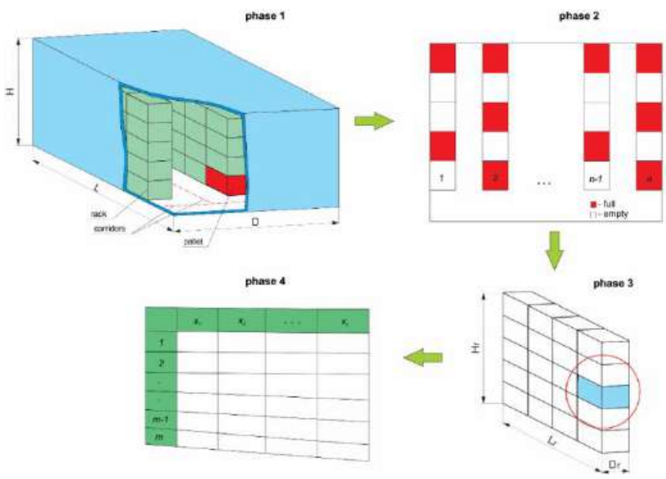

Figure 1. Schematic representation of the formation of a three-dimensional warehouse model and the procedure for obtaining the relevant parameters

The procedure for determining the coordinates of potential risk zones

To simplify the presentation and further calculation, transport units as bodies of appropriate dimensions and characteristics that occupy only a stationary position in the warehouse will be represented by a material point. In this way, the dimensions of the transport units can be considered infinitely small, assuming that each point of the volume has the same properties, ie. that the content of the transport unit is homogeneous.

The procedure for evaluating the center of gravity of transport units represented in the form of a material point and determining the weighting coefficients for materials placed in the warehouse are the main prerequisites for determining the potential fire risk zone. The classical approach to the method of determining the center of gravity (COG method), enables the determination of optimal locations in the two-dimensional coordinate system XoY. To assess potential fire risk zones and their coordinates, an improved version of the COG method will be used.

NUMERICAL EXAMPLE

In the numerical example shown in this section, the parameters of the high-bay warehouse related to dimensions and layout (see Figure 2) given in the paper (Bošković et al., 2023) were used. Based on the considerations given in the previous chapter, to obtain the most accurate data needed for further simulation, it was decided to select 5 types of solid materials (wood, cardboard, chipboard, PVC plastic, and rubber) as alternatives in the multi-criteria decision-making process, which will be the subject of further calculations.

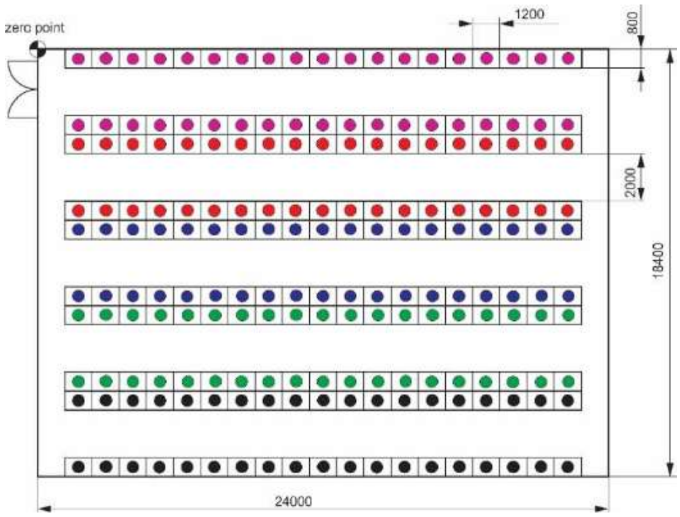

Figure 2. The layout of a high-bay warehouse with associated dimensions and materials (• wood, • cardboard, • chipboard, • PVC, and • rubber)

The list of materials and the numerical values of the seven selected parameters are given in Table 1. The listed characteristics of materials related to combustion shown in the mentioned table represent criteria in the multi-criteria decision-making process (Ch. Varada Rajulu et al., 2013; Ding, et al., 2020).

Table 1. Input parameters in the procedure of determining the weighting coefficients required for the simulation

Material	CO [mg/g]	CO_2 [mg/g]	Smoke density [kg/m^3]	Ignition temperature [°C]	Thermal conductivity [W/mK]	Specific heat capacity [J/(kg K)]	Calorific value [MJ/kg]
Wood	6	1696	100	350	0.15	1360	14.4
Cardboard	0.1	1450	39.8	427	0.061	1400	13.5
Plywood	6	1774	400	150	0.13	2500	17
PVC	71	657	55.03	391	0.185	900	41
Rubber (tire)	600	1911	8000	315	1.85	1880	35

The first three parameters are considered useful because they take into account the emission of harmful gases affecting human health, while the other four parameters (criteria) are declared useless. Following all the steps provided by the COPRAS method, weights for each of the alternatives Qi and the corresponding ranking are obtained as shown in Table 3. Identically, the parameters for case 2 can be determined when the parameters are replaced so that the last four parameters are considered useful, and the first three parameters are considered useless.

Table 2. Calculated weights of alternatives for Case 1 and Case 2

Case 1		Case 1	
w_{ei}	Rank	w_{ei}	Rank
0.14821	0.0566	0.14821	3
0.13642	0.0573	0.13642	4
0.15195	0.0598	0.15195	2
0.11238	0.0768	0.11238	5

0.45105	0.1495	0.45105	1

Each of the materials presented in Table 1 occupies two racks, so the total number of racks in the warehouse is 10, with maximum of 1200 transport units in the warehouse. It is rarely the case that the warehouse is filled to 100%, so testing the effectiveness of the proposed method is done by varying the layout of the transport units in the racks, the warehouse is filled to a maximum of 70% as in (Tahmid et al, 2022), with the rule that the percentage share of each of material should be equal, i.e. is 20% of the total number of transport units (168 units).

To confirm the functionality of the method and the comparative presentation of the results, the coordinates X, Y, Z, and the vector r were calculated for the following variants of warehouse filling:

- Variant 1: The first three racks on the left side of the warehouse are completely emptied and the filling of the warehouse with the remaining 840 transport units starts from rack number 4,
- Variant 2: The last three racks on the right side of the warehouse are completely emptied and the filling of the warehouse with the remaining 840 transport units starts from rack number 1,
- Variant 3: The content of each of the racks on the upper front side is reduced by 30%,
- Variant 4: The content of each of the racks on the lower front side is reduced by 30%,
- Variant 5: The content of each of the racks in the uppermost rows is reduced by 30%,
- Variant 6: The content of each of the racks is reduced by 30% in the initial lower rows,
- Variant 7: The content of each of the racks is reduced by 30% and the arrangement of transport units within the racks is done randomly.

RESULTS AND DISCUSSION

Based on the parameters related to the location of the transport units determined by implementing the procedure shown in Figure 12, the weighting coefficients obtained using the COPRAS method and entering the mentioned parameters into the COG algorithm, the locations of the potential fire risk zone in the high-bay warehouse are obtained.

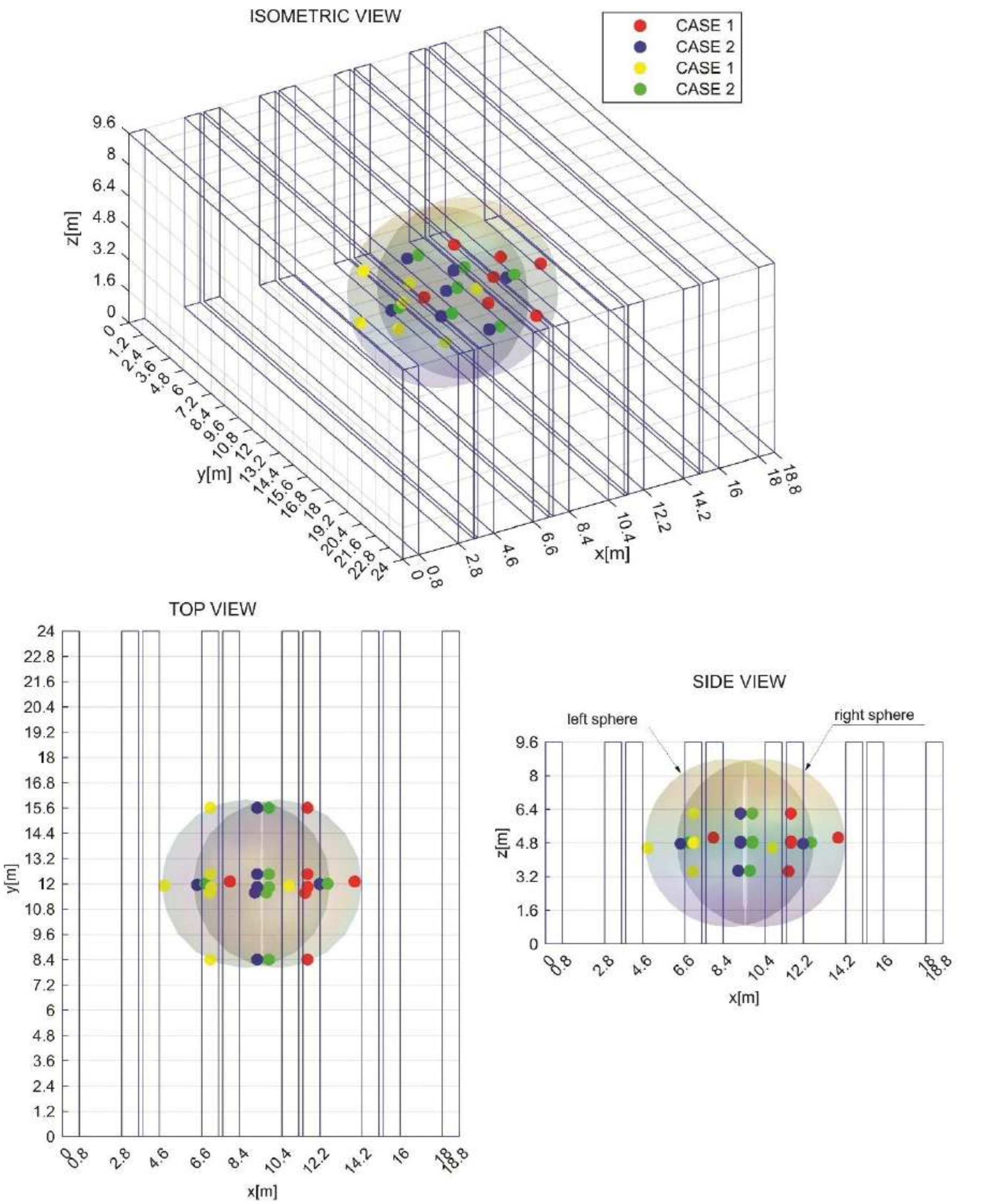

Figure 3. Graphic representation of the fire risk zones in warehouse with isometric view, top view, and side view

Based on the obtained coordinates of spatial points and using a three-dimensional model of a high-bay warehouse, two spheres that define potential fire risk zones, were generated (see

Figure 3). The mentioned spheres represent the space that is considered vulnerable in terms of fire and which includes normal and random variants of material distribution within the space of the observed high-bay warehouse. Considering the symmetrical arrangement inside the warehouse along all axes, the homogeneity of the stored material and the warehouse occupancy, the left sphere (coordinates of center x=8.7 m, y=12 m, z=4.8 m, and r=4 m) and the right sphere (coordinates of center x=10.2 m, y=12 m, z=4.8 m, and r=4.1 m) are generated. Figure 3 shows the deviation in the coordinates of the spheres along the x-axis, which is directly related to the change in the distribution of materials in the racks. Coordinates of spatial points are obtained for the warehouse cases of layout when the tire occupies the first two racks and when it occupies the first two racks, respectively.

About the existing fire risk assessment methods (e.g. Gustav method), in the proposed approach, the simulation results are obtained based on the weight coefficients related to the materials that are stored, the percentage share of storage units, and the parameters related to the dimensions of the warehouse. The practicality and usability of the proposed method are reflected in the simplicity and practicality of application with fewer necessary parameters and resources, simple data acquisition, and the possibility of a three-dimensional display of risk zones in real-time. The described method was not meant to be a replacement for the Gustav method. The Gustav method (Ju et al., 2023)is more complicated and can be more complex. This means that it takes some time to adapt it and use it by the warehouse designer, and it gives broader results. The method described in this paper can be utilized quicker and it provides general guidelines for the warehouse designer, but it does not provide results as detailed as Gustav's method.

CONCLUSIONS

A method for risk assessment and determination of potential fire hazard zones in high-bay warehouses is presented in this paper. Concerning existing methods related to risk assessment in warehouses, the proposed method is based on weight coefficients related to the type of material being stored, the percentage share of storage units, as well as parameters related to the structure and configuration of the warehouse. Weight coefficients related to the type of material represent input parameters in the process of simulation and determination of potential fire hazard zones. They are determined by a multi-criteria decision-making process using the COPRAS method.

Compared to other, mostly two-dimensional methods, this method enables simple data acquisition in the form of data tables and the generation of a three-dimensional model of the warehouse, which contains spatial points that define potential risk zones. By incorporating the mentioned spatial points within the 3D model of the high-bay warehouse, a sphere is obtained, whose radius represents the critical area of the risk of fire. The results obtained by the proposed method can be a good basis during the planning and design of the warehouse, the layout of the object, and also when designing the appropriate fire protection and evacuation systems in the warehouse.

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BLACK SOLDIER FLY'S ABILITY TO REDUCE ORGANIC WASTE

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Abstract: This paper aims to discuss the effectiveness of the Black Soldier Fly (BSF) for organic waste treatment. Due to its ability to accumulate amino acids and fatty acids, it can convert organic waste into protein. Increased amounts of organic waste require solutions such as BSF to reduce the negative impact on landfilling of this waste flow. Results show that BSF is more than effective for organic waste management. Future research should focus on conditions that increase its efficiency and the type of organic waste that is more suitable for waste reduction by BSF. The conclusion of this study stems from the presented papers and indicates varying efficiency of BSF depending on the specific type of organic waste used in the process. Additionally, through the analysis of the papers, it has been determined that the salinity of the substrate reduces the growth of BSF larvae, while statistical tests have shown that the weight of the larvae is significantly influenced by the intensity of light, with the highest degree of reduction occurring under low light conditions.

Keywords: *Black Soldier Fly; BSF; organic waste; treatment.*

INTRODUCTION

The demand for food is increasing due to a growing human population. Additionally, the escalating volume of organic waste generated poses threats to both human health and environmental integrity. (Siddiqui et al., 2022). Approximately 1.3 billion tons, or one-third, of the world's food supply is lost or wasted annually. The importance of finding a way to manage organic waste sustainably is of great importance. Black Soldier Fly (BSF) (*Hermetia illucens*) is one of the potential solutions for appropriate management of organic waste in line with circular economy principles.

The ability of BSF to accumulate amino acids and fatty acids is found to be remarkable (Hosseindoust et al., 2023). By researching the field of sustainable agriculture BSF gain additional attention. Naser El Deen et al. (2023) underline the ability of BSF to convert organic waste into protein. Enhancing our approach to organic waste management is crucial for sustainability efforts, necessitating a concerted effort to discover more effective solutions.

The life cycle of BSF can be classified into five stages such as egg, larva, prepupae, pupa, and adult stages. Larvae are developed from the eggs laid by the BSF in decomposing materials (Kuria & Eyinfunjowo, 2023).

The black soldier fly typically lives for approximately 38-45 days on average (Hall & Gerhardt, 2002). Female BSFs lay between 500 and 900 eggs (Julita et al., 2020), which hatch within a span of 4 days to 3 weeks. Throughout the larval phase, the length of the larvae varies from 5 to 19 mm, containing around 38.86% lipid and 40.96% protein content (Purkayastha & Sarkar, 2022). Initially, during larval growth, protein levels tend to be lower, often around the lower end of the 40% to 50% range. As the larvae advance in their developmental stages, there is a notable increase in their protein content. By the time they reach the pupation stage, fully developed larvae can possess protein levels ranging from 50% to 60%, and sometimes even higher (Abirami et al., 2024).

These larvae efficiently convert waste materials into two valuable resources for the agricultural sector: nutrient-rich residue, known as "frass," and biomass containing high levels of protein. The biomass, which is rich in nutrients, can be gathered and turned into biofuels or fed to fish. In addition, the larvae themselves provide a sustainable substitute for conventional animal feed because they are a high-protein food source (Kuria & Eyinfunjowo, 2023). Vegetables and food waste are among the many organic items that the BSF larvae may decompose into high-protein biomass. Furthermore, it is possible to raise the larvae in a closed system, which lowers the possibility of environmental contamination and encourages the more effective use of resources. The growth, conversion rate, and larval quality of BSF larvae can all be strongly impacted by the meal that they receive, which might include a variety of botanical waste products. By improving their diet, it is possible to improve the amount of protein produced per kilogram of food waste, which makes the production of BSF an economical and sustainable way to provide animal feed while lowering waste and environmental effects (Hosseindoust et al., 2023).

It has been determined that temperature and relative humidity are essential for the growth and development of BSF. BSFs are eurythermal insects that have a broad temperature tolerance range of 15°C to 47°C. With 60% relative humidity and temperatures between 27.5°C and 37.5°C, more than 96% of oviposition took place (Rehman et al., 2023).

BSF is considered to be one of the more sustainable options for achieving the aforementioned goals, especially as an alternative to conventional composting (Amrul et al., 2022). Black Soldier Fly Larvae (BSFL) are high in minerals and amino acids, and their protein content can make up as much as 43% of their body weight.

Using BSF larvae in animal feed might lessen the need for extra supplements. In dry form, BSF larvae have 26 times more calcium than crickets and mealworms, significantly lower sodium levels, and four times more iron. Additionally, BSF larvae provide high-quality protein, matching the essential amino acid profile needed for fish meal (Larouche, 2019). The approximate composition and content of minerals in the larva and transcriptome of the BSF as indicated in Table 1.

Table 2 Proximal composition, polyunsaturated fatty acids and minerals content of the black soldier fly (Hermetia illucens) larvae and prepupae (Larouche, 2019)

Species	**Hermetia illucens**	
Stage	**Larvae**	**Prepupae**
Proximal composition (%, dry basis)		
Crude protein (N x 6.25)	36.2	40.7
Crude lipid	18.0	15.6
Ash	9.3	19.7
Nitrogen-free extract	36.5	24.0
Polyunsaturated fatty acid		
Omega-3 (% lipid)	0.6 – 1.5	
Omega-6 (% lipid)	4.2 – 17.3	
Omega-6/omega-3 ratio	6 – 11	
Minerals content (mg/100 g; dry basis)		
Calcium	2,900	3,000
Phosphorus	350	620
Sodium	100	50
Iron	200	8
Zinc	61	3

Since the larvae of the BSF can grow on a variety of substrates, including manure and organic waste, this makes it one of the most desirable insects for large-scale biotransformation (Rehman et al., 2023). The aim of this paper is to show how effective BSF is found to be in the management of organic waste.

MATERIALS AND METHODS

Based on the analysis of papers focusing on the use of BSF for organic waste reduction, this paper identifies and presents seven studies. By synthesizing individual viewpoints and facts, a general conclusion is reached regarding the benefits that BSF brings in this field.

The criterion by which the papers were selected was the impact of the mentioned insect on organic waste reduction, along with the production of proteins as a byproduct of the process.

RESULTS AND DISCUSION

The seven selected articles are analyzed and presented in Table 2.

Table 2. Overview of results.

Reference	Aim	Methodology	Results & Conclusions
Monita et al. (2017)	This study aimed to investigate the use of BSF larvae as organic waste bio-processors to generate compost and nutrient-rich larval biomass.	The experiment's larvae feed treatments include restaurant organic waste combined with 6% fish silage (treatment A), restaurant organic waste combined with 6% dairy blood waste (treatment B), and restaurant organic waste combined with 6% fish silage (treatment C).	The study's findings demonstrated that treatment B produced the largest larvae growth in terms of length, width, and body weight, with treatments A and C coming in second and third.
Liu et al. (2018)	The purpose of this study was to evaluate the suitability of various organic waste substrates for	Three different forms of organic waste—brewer's waste, solid pig dung, and partially digested grass—were put to the test and contrasted with boll, the	In every substrate that was evaluated, larval survival was high. When the larvae were fed a regular diet or brewer's waste instead of pig dung or semi-digested

	processing by Hermetia illucens, the larvae of the BSF.	typical larval diet made of wheat middling.	grass, they developed faster, gained more weight, and had greater prepupal crude protein and crude fat contents.
Cho et al. (2020)	To evaluate the development of BSFL raised on food waste supplemented with polystyrene (PS), polyethylene (PE), and sodium chloride (NaCl).	Every 2-4 days, the weight of the BSFL was recorded. After the experiment, the pupation ratio, substrate reduction rates, and survival rates were calculated.	The salinity of the substrate reduced the growth of BSFL, not plastics. Further evaluations of the safety of larvae raised on food waste that contains contaminants are required to facilitate the broader use of BSF larvae in vermicomposting.
Khair et al. (2023)	The purpose of this study is to ascertain how well BSF larvae are utilized in the absorption of restaurant trash and to track how the environment—specifically, light intensity—affects larvae development.	The moisture percentage of organic waste from eateries is fixed at 80%. When exposed to three different lighting conditions—12 hours of light and 12 hours of darkness, 24 hours of darkness, and 24 hours of light—the organic waste is employed as a food source for larvae.	The study's findings suggested that BSF may be used to handle restaurant garbage. By varying the amount of light given to the larvae, waste was reduced by 37.77%, 37.78%, and 37.60%. The greatest reduction happened under 24 hours of dim lighting. The weight of the larvae is significantly impacted by light intensity, according to statistical testing.
Santoso et al. (2023)	The study used index calculation and analysis to assess the sustainability of	The scientific judgment of professionals and corporate players in the BSF was used to collect data through focus groups and the completion of	The BSF-producing larvae's sustainability index was 89.69%. When the strengths of each dimension are taken into account, the results

	larvae from the BSF culture.	questionnaires with 31 attributes related to the environment or ecology, economics, social, and technological elements.	indicated that the technique at multiple stages of operation, including trash collecting, planting, harvesting, and marketing, contributed to sustainability development.
Navarro Ferronato et al. (2023)	Through a life cycle assessment (LCA), the research attempts to measure how well the organic fraction of municipal solid waste is treated with BSF larvae.	Using data inventories from published works, this study sought to uncover the potentialities of BSF treatment in both the best-case and worst-case scenarios by offering a broad range of production parameter values. For the analysis, the impact assessment method IMPACT 2002+, the database Ecoinvent3.5, and the SimaPro9 have been used.	Due to the production of BSF larvae, conventional fishmeal can now be substituted with fishmeal. This results in a 100% renewable energy scenario, a 50% reduction in energy consumption, a 15-year equipment lifespan, and locally employed products.
Sari et al. (2023)	The present investigation examined the capacity of BSFL to mitigate grease waste, as well as the impact of feed composition variations on the growth rate of larvae at eight, twelve, and sixteen days of age.	Before the larvae reach the designated age (8, 12, or 16 days), they are fed a concoction of milk and bread that has expired. When BSFL are eight, twelve, and sixteen days old, they are fed either pure grease waste or a mixture of grease waste and past-due milk until they develop into larvae that are twenty days old.	At 16 days old, BSFL showed impressive efficacy in lowering restaurant grease waste. This study emphasizes BSFL's potential as an environmentally friendly method of managing and recycling organic waste, especially when it comes to food waste.

	Next, waste reduction is examined using metrics such as larvae biomass, feed consumption, waste reduction index, and the effectiveness of feed conversion after digestion.	

The researches presented in Table 2 shows that a variety of methods and approaches in researching this topic were applied. It can be noticed that each of them concluded the benefits associated with the usage of BSF in waste management.

A study by Monita et al. (2017) focused on the waste in restaurants and on factors that influence growth. In the same environment research by Khair et al. (2023) was conducted. Sari et al. (2023) emphasized that great effectiveness is achieved with BSF in the reduction of restaurant grease waste.

Liu et al. (2018) showed that BSF is differently effective depending on the concrete type of organic waste used in the process. It provides significant insights for future directions of research and efforts to provide a better understanding of how to reach the best results when it comes to the usage of BSF as a way to manage organic waste. The salinity of the substrate reduces the growth of BSFL, not plastics as determined in the study by Cho et al. (2020). Studies Cho et al. (2020) and Monita et al. (2017) are examples of studies that focused on researching how waste management BSF can be improved and to determine under which conditions better results are achieved.

The contribution that BSF usage in waste management has on sustainability is acknowledged in the study by Santoso et al. (2023). Navarro Ferronato et al. (2023) point out that after conducting an LCA analysis great results with providing fish meals using BSF can be achieved and that it has a great impact on the environment.

CONCLUSION

With an overview of relevant research related to application of BSF in treatment of different organic waste streams, it can be concluded that BSF can be effective solution in waste management contributing to achievement of sustainability and circular economy goals.

Directions for further research should be to find the most adequate conditions that can increase waste reduction by BSF. As well it is also of great importance to determine the type of organic waste that is more suitable for reduction by the BSF.

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REDUCTION OF CO AND NOX EMISSIONS IN THE DISTRICT HEATING SYSTEM OF THE CITZ OF KRALJEVO BY FUEL SWITCHING

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Abstract: The paper presents the analysis of the operation of the boiler room "Higijenski zavod", which operates within the system of the Public Energy Company "Toplana" Kraljevo, in two periods, i.e. 2012-2019 and 2021-2023. In the first period, heavy fuel oil was used as the fuel, whereas natural gas was used as the fuel in the period from 2021 to 2023. The comparison of the measured values of fuel consumption and the emission of flue gases shows that the conversion from heavy fuel oil to natural gas as the fuel resulted in the reduction of carbon monoxide emission by 9.5 times and total nitrogen oxide emission by 19.5 times if compared to the situation before the conversion, at annual level.

Key words: *Emission, Boiler room, District heating, Heavy fuel oil, Natural gas*

INTRODUCTION

The Energy Sector Development Strategy of the Republic of Serbia by 2025 set the priorities and goals of development in the field of energy. The development strategy includes district heating systems (Strategy 2025-2030). One of the most important goals in the field of district heating systems is the reduction of use of solid fuels (coal) and liquid fuels (heavy fuel oil and light oil) by converting to renewable energy sources and natural gas. Figure 1 shows the structure of energy sources used in district heating systems in the Republic of Serbia, with projections until 2030 (Figure 1).

The Public Energy Company "Toplana" (Heating Company) Kraljevo has its boiler plants distributed in four boiler rooms with the total capacity of 80 MW. Two boiler rooms use natural gas and, alternatively, heavy fuel oil, as its energy sources, whereas the other two boiler rooms use exclusively heavy fuel oil.

The subject of this paper is the smallest boiler room within the Public Energy Company "Toplana" Kraljevo, which is located in the part of the city bearing the same name as the boiler room itself - Higijenski zavod. The installed power of the boiler units, the area of the heated residential space and the area of the heated business premises covered by the boiler room are shown in Table 1 (PEC Toplana).

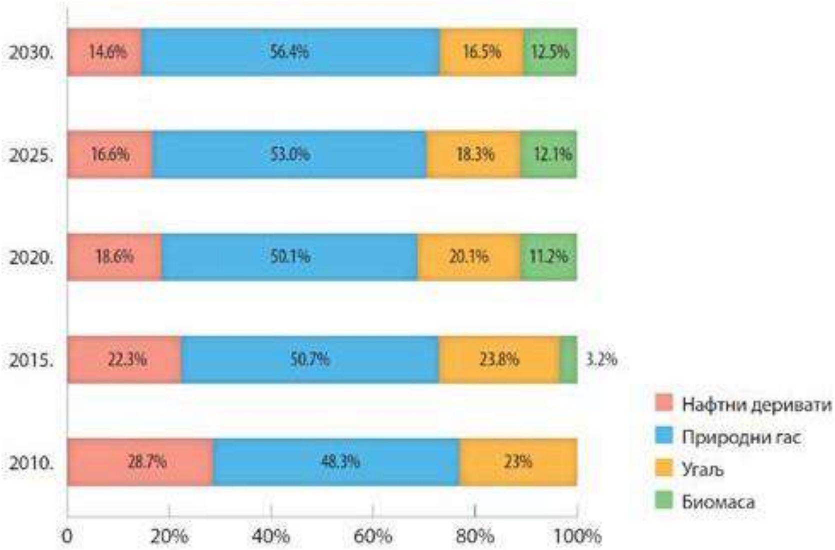

Figure 1. Structure of energy sources which are used for generation of heat energy in the Republic of Serbia, with projections until 2030

Table 1. Technical details about the boiler room "Higijenski zavod" (the data provided from the professional service of the PEC "Toplana" Kraljevo)

Number of boiler units	2
Type and capacity of boiler 1 (kW)	TAM – MARIBOR, TVT ZV – 850 kW
Type and capacity of boiler 2 (kW)	TAM – MARIBOR, TVT ZV – 850 kW
Area of residential space (m^2)	6,785.00
Area of business premises (m^2)	118.00

ANALYSIS OF THE BOILER ROOM OPERATION

Main details about the boiler room

The boiler room "Higijenski zavod" is located in the part of the city positioned directly toward the Kraljevo – Čačak highway.

The boiler room with its heavy fuel oil-fired boilers is accommodated in the cellar room of a residential building in which there are two boiler units with the identical power of 0.85 MW each. The supply and return manifolds with the accompanying regulation, stop and safety valves and fittings are placed in the boiler room.

A new container gas boiler room is situated in the close vicinity of the residential building in which there is the boiler room with its heavy fuel oil-fired boilers, and it is connected with the old boiler room via pipelines. The operation of the natural gas-fired boiler room started in September 2020 and it worked within the system of PEC "Toplana" Kraljevo in this part of the city up to and including the 2023/24 heating season. The old boiler room has not been used any more since the beginning of operation of the new natural gas-fired boiler room.

Consumption of fuel – heavy fuel oil

Based on the data provided from the professional service of the PEC "Toplana" Kraljevo, Table 2 presents the values of fuel (heavy fuel oil) consumption, degree days and the average annual temperature in the heating period from 2012 to 2019.

Table 2. Data about the fuel (heavy fuel oil) consumption, degree days and the average temperature in the heating period provided by the professional service of the PEC "Toplana" Kraljevo

Year	Heavy fuel oil consumption (kg/year)	Degree days	Average annual temperature during the heating season (°C)
2012	152,680.00	2910	4.17
2013	134,236.00	2629	5.79
2014	126,460.00	2365	6.77
2015	141,530.00	2590	5.76
2016	147,040.00	2715	6.75
2017	144,680.00	2789	4.82
2018	137,398.00	2520	5.61
2019	125,281.00	2253	7.39
Mean value	**138,663.13**	**2,596.4**	**5.85**

Consumption of fuel – natural gas

Based on the data provided from the professional service of the PEC "Toplana" Kraljevo, Table 3 presents the values of fuel (natural gas) consumption, degree days and the average annual temperature in the heating period from 2021 to 2023.

Table 3. Data about the fuel (natural gas) consumption, degree days and the average temperature in the heating period provided by the professional service of the PEC "Toplana" Kraljevo

Year	Natural gas consumption (Nm^3/year)	Degree days	Average annual temperature during the heating season (°C)
2021	133,928.00	2572	6.07
2022	115,629.00	2457	5.92
2023	104,050.00	2157	5.31
Mean value	**117,869.00**	**2,395.3**	**5.77**

A NEW PLANT WITH CONDENSING BOILERS

Gas generators, the total of 4 gas condensing units connected into a cascade with the minimum heat capacity of 1.1 MW, are built in the new container boiler room. The characteristics of the installed container boiler room are as follows:

- Nominal heat capacity 1200 kW
- Heat capacity at min / max 50/30 ° C 57.7 /1160 kW
- Heat capacity at min / max 80/60 ° C 51.6 / 1086. 4 kW
- Efficiency at 40/30 ° C 108.8 %

EMISSION PARAMETERS OF THE PLANT

Heavy fuel oil-fired boiler room

Measurement of emission parameters for the subject boiler room is carried out at least once during the heating season (Table 4). The heat capacity of the boiler unit, the fuel used and the connection with the emitter (separate or common) define the type of plant in accordance with the Directive on ELV. According to the mentioned directive, the heavy fuel oil-fired boiler room is classified as a small combustion plant.

Table 4. The measured emission values of carbon monoxide and nitrogen oxides reduced to $NO_{2\ total}$ in the period from 2012 to 2019 (Laboratory of the Faculty of Mechanical and Civil Engineering in Kraljevo, 2012-2015)

Year	CO (mg/Nm^3)	$NO_{2\ total}$ (mg/Nm^3)

2012	21.5	1.295.3
2013	82.5	1.498.0
2014	55.9	1.288.4
2015	64.5	844.5
2016	72.0	568.2
2017	84.3	755.4
2018	89.2	842.8
2019	78.9	789.7
Mean value	**68.6**	**985.3**

Natural gas-fired boiler room

Based on the previously mentioned criteria, the newly built natural gas-fired boiler room is classified as a small plant. The measured emission values of carbon monoxide and nitrogen oxides reduced to $NO_{2\ total}$ in the period from 2020 to 2023 are shown in Table 5.

Table 5. The measured values of carbon monoxide and nitrogen oxides reduced to $NO_{2\ total}$ in the period from 2021 to 2023

Year	CO (mg/Nm^3)	$NO_{2\ total}$ (mg/Nm^3)
2021	7.7	55.1
2022	7.5	64.3
2023	8.9	49.4
Mean value	**8.03**	**56.27**

Reduction of CO and NOx emissions

In order to determine the reduction of CO emission, it is necessary to determine the quantity of fuel gases depending on the fuel consumption. This detail is obtained based on the combustion equations for the known elemental composition of fuel.

The theoretical values for combustion of heavy fuel oil and natural gas are adopted. The quantity of emitted pollutants is determined based on the known values of emission, volumetric flow rate of flue gases depending on the fuel and the amount of fuel consumed during the observed period.

$$N_{CO}^{''} = n_{CO} \cdot V_{ps} \cdot B \quad (1)$$

where:

N_{CO} (kg) – the quantity of the emitted pollutant

n_{CO} (mg/Nm^3) – the measured concentration of the emitted pollutant

V_{ps} (m^3/kg_B) – the volume of flue gases for the air surplus coefficient 1.1

B (kg_B) – the fuel consumption

The value obtained as the difference between the amount of emitted pollutants before and after the conversion of fuel is the reduction of pollution in the given case.

$$N = N_{CO}^{m} - N_{CO}^{g} \tag{2}$$

where:

N_{CO}^{m} (kg) – the quantity of the emitted pollutant when heavy fuel oil burns

N_{CO}^{g} (kg) – the quantity of the emitted pollutant when natural gas burns

The elemental composition of fuels as well as adopted and calculated values necessary for the calculation are presented in Table 6 (NIS, 2023; Kozić, 1995; Todorović, 2006).

Table 6. Calculation of the reduction of emission of pollutants CO and NOx

Elemental composition of fuels			
Heavy fuel oil		Natural gas	
C (%)	83.87	CH_4 (%)	96.6
H (%)	11.41	C_2H_6 (%)	2.0
O (%)	0.30	C_3H_8 (%)	0.1
N (%)	0.30	C_4H_{10} (%)	0.1
S (%)	2.42	C_5H_{12} (%)	0.1
A (%)	0.2	CO_2 (%)	0.2
W (%)	1.5	N_2 (%)	0.9
Average fuel consumption			
Period from 2012 to 2019 (kg)	**138,663.13**	Period from 2020 to 2023 (m^3)	**117,869.00**

Volume of flue gases			
Vps (m^3/kg_B)	11.01	Vps (m^3/kg_B)	11.61
Emitted quantity of pollutants			
N_{CO}^{m} (kg)	104.73	N_{CO}^{g} (kg)	11.02
$N_{NO2\,ukup.}^{m}$ (kg)	1.504.24	$N_{NO2ukup.}^{g}$ (kg)	77.04
Reduction of emission of pollutants			
N_{CO} (kg)	93.74		
$N_{NO2total}$ (kg)	1,427.24		

CONCLUSION

The comparative analysis of fuel consumption and emission of flue gases for the heavy fuel oil-fired boiler room in the period from 2012 to 2019 and for the natural gas-fired boiler room in the period from 2020 to 2023 was carried out. The year 2020 was not taken into consideration because the heavy fuel oil-fired boiler room was used in the first part of the year, and the natural gas-fired boiler room was used in the second part of the year. The analysis showed that the conversion of fuel, i.e. the use of natural gas as the fuel instead of heavy fuel oil, resulted in the reduction of carbon monoxide emission by 93.74 kg, i.e. by 9.5 times and total nitrogen oxide emission by 1,427.24 kg, i.e. by 19.5 times, at annual level. It is important to emphasise that the values of average annual temperatures during the heating season for the two observed periods are similar.

ACKNOWLEDGEMENT

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A REQUIREMENT FOR SYSTEM DEVELOPMENT IN THE OCCUPATIONAL SAFETY AND HEALTH SYSTEM

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Apstrakt: Occupational safety and health is a system created with the aim of creating conditions to reduce, as much as possible, the risks of injuries at work, occupational diseases and work-related diseases at work, and which mainly creates the precondition for full physical, psychological and social well-being of employees. Occupational safety and health risk assessment is acquis prescribed by law, which stemmed from the need to manage processes in a pragmatic way to identify hazards and hazards in real time, in processes and other activities that can cause harm, especially to the employee. Weakness of the national system that does not have mechanisms based on standardized procedures that would familiarize the organization with the ever-changing risk, which would allow the legal entity to improve performance in the field of OH&S by developing and implementing effective policies and objectives. Our intention is to highlight the benefits of management processes, especially if they are based on standardized procedures, which, among other things, unambiguously strengthen the commitment of the management to proactively improve the performance of the "safety and health at work" system of employees.

Keywords: *Risk, risk assessment, risk management*

INTRODUCTION

The system of safety and health at work in the national socio-political space was created on a platform with a preventive essence and has the imperative goal of preserving the health of people at work. The target function is aimed at creating safe working conditions by applying the most modern technical, organizational, medical, social and other measures, all with the aim of eliminating hazards as a cause of injuries and damage to health in order to reduce or minimize risks.

For many years, safety and health at work and the importance of this organizational form in legal entities have been discussed through the lens of reports on accidents and incidents, the number of inspections and data on the number of unregistered workers. The only tool that is absolutely represented in the system in question is the Law on Safety and Health at Work, which is permanently cosmetically innovated and supplemented.

In the period of implementation of the Strategy for occupational safety and health in the Republic of Serbia for the period from 2013 to 2017, the Labor Inspectorate carried out 74,434 inspections in the field of occupational safety and health. In the mentioned period, 22,802 decisions were made to eliminate deficiencies, 2,186 decisions were made to prohibit work at the workplace due to a dangerous phenomenon that could endanger the safety and health of employees, and 170 reports were submitted to initiate criminal proceedings against responsible persons due to reasonable suspicion that they committed the criminal offense of causing danger by not providing safety and health measures at work, as well as 4,921 requests to initiate misdemeanor proceedings. Labor inspectors carried out 5,012 inspections regarding reported injuries at work, namely: 121 inspections regarding fatal injuries at work, 74 inspections regarding serious injuries at work with fatal outcome, 82 inspections regarding collective injuries at work, 4,124 inspections regarding serious injuries at work and 611 supervisions regarding minor injuries at work.

In support of this statement is the activity of the last three years in an attempt to pass a new law on Safety and Health at Work. The proponents, in explaining the objectives of improving the efficiency of the safety and health system at work, impose three groups of reasons for which it is necessary to enact or amend the Law.

1. What stands out as the first and most significant reason for the adoption of the Law is defined in the sense of introducing all relevant secondary sources of community law into domestic legislation, which achieves the compatibility of the legislative system of the Republic of Serbia with EU law. In this regard, the provisions of the Framework Directive 89/391/EEC on the introduction of measures to encourage the improvement of safety and health of employees at work, which have not yet been transposed, are introduced into the domestic legislation. The framework directive 89/391/EEC of June 12, 1989, was implemented for the first time in the national legal system in the Occupational Safety Act of June 18, 1989. VII 1991 which means that thirty years is not enough to harmonize one document into the national legal system

2. Another reason is to, among other things, harmonize the Law on Occupational Safety and Health with the provisions of other laws.

3. The third reason is the regulation of certain issues that are not regulated or have been observed as a problem in implementation and the solution of which requires finding better legal solutions. It is necessary to specify certain provisions of this law, that is, to carry out legal and technical harmonization of certain provisions, in order to implement the law and thus contribute to faster implementation.

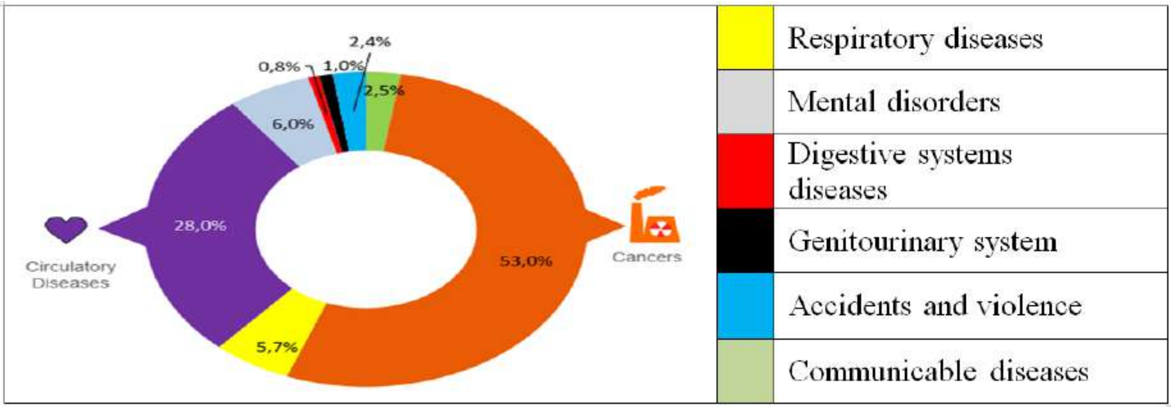
In the draft of the new Occupational Safety and Health Act, the process of harmonization with the provisions of other laws in order to ensure that the organization achieves its business objectives in a safe manner, ignores the fact that in 2018 the Project Committee ISO/PC 283, Safety and Health Management Systems at work, published the ISO 45001:2018 standard, and that on April 5, 2018, the director of the Institute for Standardization of Serbia, by decision no. 1986/2-51-02/2018 adopted SRPS ISO 45001:2018, which is identical to the international standard.

In the procedures for organizing the safety and health system at work, there is no indication of a safety management system or management of health and safety protection at work, which must instill in every legal entity, as well as the responsible social community, the belief that safety performance must be improved and that the management system is actually a tool that ensures that the organization achieves its business goals in a secure manner.

The indicators that describe the state of the Occupational Safety and Health system at the level of the world community are statistically presented from the health, economic or ethical aspect and have a devastating description. The International Labor Organization - ILO estimates that the following were the basis for starting the process of standardizing procedures in the occupational safety and health system:

- 4% of the annual world GDP (2.8 trillion US $) is due to the direct and indirect costs of accidents and illnesses at work (eg lost working time, workers' compensation, production interruption and health costs)
- every year around 2.3 million workers die from accidents or illnesses at work
- during the day alone, 1 million workers suffer an accident at the workplace.

Table 1. Work-related deaths due to disease in the EU-28



In the EU - 28, cardiovascular and circulatory diseases make up 28%, and cancers 53%. of the total number of work-related diseases, responsible for 4/5 fatal outcomes. Occupational injuries and infectious diseases together amount to less than 5%.

The professional and scientific public rightfully asks the question: Why does the model based on SMS not work in national frameworks? Are there mechanisms for establishing SMS? What are the reasons for the existence of the "pathological" management model of the occupational safety and health management system in the century of 4K and 5K technological achievements and approaching a proactive management model. The aim of this work is to try to answer and indicate the directions of modern development of real-time systems.

Looking at the Occupational Safety and Health system from the point of view of the process owner, the general sense of the Safety Management System can be seen, which offers the organization benefits in achieving its business goals in a safe way. Those goals must be met in real time by continuously providing evidence that the organization meets all security requirements that apply to it.

Therefore, developed organizations and the scientific public understand that the effective control of their risks can only be achieved through a process that combines three critical dimensions: the technical component (the tools and equipment used), the human component, and the organizational component (the procedure and method that define the standardized procedure process safety monitoring).

STANDARDS RELATED TO THE "SAFETY AND HEALTH AT WORK SYSTEM"

Standards and standardization can rightly be said to represent the legacy of civilization, primarily because of their invaluable importance for the development of processes in every life situation. If we add to this statement the attitude that standards are among the most important tools used by management structures in organizations, and not only when it comes to products, but also when it comes to technological or production systems or systems for providing services. Standardization, can be also defined as the activity of establishing provisions for general and multiple use, in order to achieve the optimal level of organization.

The standardization of management procedures and the introduction of OH&S management systems aim to enable the organization to ensure the safety and health of employees at workplaces, prevent work-related injuries and ill-health, and constantly improve its OH&S performance. The organization is responsible for the occupational health and safety of its employees and others who may be affected by its activities. This responsibility includes promoting and protecting their physical and mental health.

Developed commonly known SMS or OH&S are based on standards and represent the basis for answering the hypothetical question. Are there mechanisms for establishing SMS? The answer is most easily found in the intention to improve the management mechanisms of the safety and health system at work, which is regulated by law and has the ability to assign legal value to current standards if they are included in a legal act or the legal act refers to standards that are available to the public and which are adopted by some organization regardless of rank (international - interns).

The new OH&S standard ISO 45001 is based on common elements found in all ISO management system standards and uses the unique PDCA (Plan-Do-Check-Act) model, and provides a framework for organizations to plan what they need to establish in order to the risk of damage is reduced. Measures should address problems that can lead to long-term health problems and absenteeism, as well as those that lead to accidents.

David Smith, chairman of the ISO / PC 283 project committee that developed ISO 45001, believes that the new international standard will be a real blockbuster for millions of workers: "We hope that ISO 45001 will lead to a major transformation in workplace practices and reduce tragic number of work-related accidents and illnesses worldwide."

The new standard will help organizations to ensure a safe and healthy working environment for workers and visitors, while continuously improving their OH&S performance. Smith adds: "The world's standards writers have come together to provide a framework for a safer workplace for everyone, regardless of the sector you work in and wherever you work in the world." More than 70 countries were directly involved in the creation of this important document, developed by ISO / PC 283, Management systems for health and safety at work, with the British Standards Institution (BSI) serving as the committee's secretaries.

The interest of society, legal entities and every individual is to achieve the highest level of safety at work in order to reduce unwanted consequences, occupational diseases and injuries to a minimum. Safety and health at work implies the creation of working conditions in which certain measures and activities are undertaken in order to protect the life and health of employees.Today, when the tool ISO 45001 OH&S management systems – Requirements with guidance for use is offered at the world level, for management, a hypothetical question arises. How to optimally apply that tool and achieve the expected goals.

Development of OHS management system standards

The development of standards in the field of risk management began in Australia and New Zealand in 1995 with the adoption of the AS/NZS 4360 standard for risk management. This attempt marked a completely different way of thinking about risk, because it implied an attempt to formalize the entire process of risk management, criticisms and proposals for its improvement soon appeared, so that a new version of the standard appeared in 1999. Five years later, in 2004, the third version of this standard was published. The term risk management is applied in many disciplines and fields. The largest scope of application of general and specific risk management methods is represented in insurance business, banking, and then in the application of ISO 14000 series standards, HACCP concept and OHSAS 18001.

The mentioned standard was the basis and inspiration for the emergence of specialized standards related to risk management in some specific areas. Thus, in 2002, the British Association of Insurance and Risk Managers defined its standard. In the same year, the US National Institute of Standards and Technology defines its standard for risk management in the field of information technology.

The International Organization for Standardization has published its standard in this area - ISO 31000 - Risk management - Guidelines on the principles and implementation of risk management, which is practically a copy of the AS/NZS 4360 standard, adapted to the structure of the ISO 9001 standard. The ISO 31000 standard provides general guidelines for management risk throughout the organization. AS/NZ 4360:2004. With the adoption of the ISO 31000:2009 standard, AS/NZ 4360:2004 has ceased to be valid.

Circumstances in the sphere of safety and health at work in the context of process safety, according to calculations from 2017 by the International Labor Organization, 2.78 million fatal accidents occur annually. This means that almost 7,700 people die from work-related illnesses or injuries. In addition, there are 374 million non-fatal work-related injuries and illnesses each year, many of which result in extended absences from work. These facts paint a picture of the modern workplace - where workers can suffer serious consequences as a result of "doing their job". The burden produced by work-related injuries and illnesses is significant, both for employers and for the macroeconomy, resulting in losses due to early retirements, absenteeism and increases in insurance premiums.

To combat such problems, in 2018 Project Committee ISO/PC 283, Occupational health and safety management systems developed a new standard ISO 45001:2018, Occupational health and safety management systems – Requirements with guidance for use; Management systems for the protection of health and safety at work - Requirements, will help organizations to reduce this burden by providing a framework for improving employee safety, reducing risks in the workplace and creating better and safer working conditions, for the whole world community.

April 2018. director of the Institute for Standardization of Serbia by decision no. 1986/2-51-02/2018 adopted SRPS ISO 45001:2018, which is identical to the international standard ISO 45001:2018. With the adoption of this standard, the SRPS OHSAS 18001:2008 standard is withdrawn and replaced ISO 45001,

The establishment of the OH&S management system is intended to enable the organization to ensure safety and health at workplaces, prevent work-related injuries and health impairments, and constantly improve its OH&S performance.

The goal of the OH&S management system is to provide a framework for managing OH&S risks and opportunities. The goal and intended outcomes of the OH&S management system are: - prevention of work-related injuries and impairment of workers' health and provision of safe and healthy workplaces. It is therefore essential for the organization to eliminate hazards and minimize OH&S risks by taking effective preventive and protective measures.

According to the Law on Safety and Health at Work, risk assessment is the systematic recording and assessment of all factors in the work process that can cause occupational injuries, illnesses or health damage and determining the possibilities, that is, ways to prevent, eliminate or reduce risks. The risk assessment is divided into two categories; general and specific. The general risk assessment refers to all aspects of the observed process. On this occasion, all hazards are taken into account, including those related to the immediate environment. A specific risk assessment deals with one specific hazard, such as, for example, noise, and can deal with this aspect through their organization.

The practically assessed risk expressed in the "risk assessment act" as a result of the management process in this designed system has the property of a tool for managing and conducting operations at a level that can be characterized as a "risk-free process". The experience gained in Serbian business practice shows that this tool does not have any management mechanisms, nor can it be considered a reliable document when determining responsibility and adjudicating disputes that may arise in the process owner-employee relationship.

Development of OHS management system standards

A proactive approach, as a recommendation of the ISO 45001 standard, appears for the first time in one of the documents that regulate the occupational health and safety system in the national professional public. In the last 50 years of the institutional development process of higher education, the scientific community has profiled the professional essence of the safety and health system at work, through the processes of applying various activities, measures and means in the process of creating safe working conditions.

Creating the structure of the safety and health system at work implies the development of a proactive function, which in a defined time period controls the elements of the system and, if necessary, implements corrective actions and/or fine adjustments on individual elements of the system. A proactive approach implies the development of new services in order to check: Is there a possibility that safety and health at work will be endangered? Who or what might be at risk? How to identify danger? Consult all interested parties and document the results of these consultations (often looking at a problem from another "angle" indicates dangers that could not be identified in any other way).

Achieving the achievement of a proactive relationship and the realization of functional requirements implies a built and documented system. This can be realized by implementing standards and developing a management system for safety and health at work. In this way, with proactive support in advance, all system elements can be defined and controlled in the time domain, and if necessary, corrective actions and/or fine adjustments of individual elements and parameters can be implemented with the aim of improvement. The goal of proactive protection is timely detection and elimination of deficiencies before they turn into a serious incident and threaten the process or the entire production system. Risk assessment is certainly a process that creates a platform for achieving the organization's goals, which imperatively implies a documented and regulated system.

A great advantage for our community is that we have the SRPS ISO 45001:2018 standard at our disposal, as a tool that instills optimism in the circumstances in which business systems are located. Above all, a motivated economy that recognizes its business interest through a reliable security system is necessary. At the start, one must keep in mind the fact that small economies, industrially underdeveloped and poor economies cannot equally well apply the universal tool of standards, so expectations must also be realistic.

One certainly perhaps the key hindering factor is the "human factor". The human factor is staff who know and understand the processes that dominate the occupational health and safety system. The personnel picture in the national economic environment "a person with a passed professional exam on practical skills" does not give faith that anything significant can be changed.

The essence of the problem lies in the fact that safety management mechanisms at employers have remained at the level of hypo ethics, with personnel values, that lack professional capacity and a supervisory function that is subordinated to the interests of the process owner. That is why the expectations of the professional public are very pessimistic, due to the fact that the "pathological" model of managing safety and health processes at work is the most prevalent among employers, and they don't have enough knowledge to exploit the tools they practice. Of course, spotting mistakes is important for improving one's own values, but commitment to change for the better is equally important to success.

The management norm ISO 45001 can significantly improve the image of occupational safety and improve the environment for the benefit of the health of employees, if the key levers of management are adapted from the form of "voluntary" to the form of "mandatory". Practice has confirmed that commitment to management standards provides real business benefits. Entities that have adopted the OH&S management system exploit the positive effects in the following spheres:

- 79% improved compliance with regulations
- 64% helped in business risk management,
- 57% inspired trust in our business
- in 55% it helped to protect the business

A successful safety and health management system must be based on:

- Appropriate health and safety management policy at work;
- Identification of risks and legal requirements;
- General and individual goals and programs that ensure continuous improvement;
- Management activities that ensure supervision of risks related to health and safety at work;
- By monitoring the implementation of measures related to health and safety at work;
- Constant reviews, evaluations and improvements of the management system.

CONCLUSION

Management in the system of safety and health at work in order to eliminate dangers or harms that contribute to damage to the employee's health, based on legal regulations, didn't create a prerequisite for proactive process management. The crown of the management tool in this designed system of safety and health at work is the "risk assessment act" in the capacity of a mechanism for managing and managing the process, it can be characterized as a "risk-free process".

The obligation of the process owner to prepare an act on risk assessment formally represents a decision that can be understood as a position to manage risks arising from legal frameworks in an organized manner. The implementation of the decision and the improvement of processes that bring risks to an acceptable level include the procedure of auditing the risk management process. However, risk assessment processes can lead to significant losses in the organization or unnecessary costs for the implementation of security measures, without their effect being justified. The omission of any procedure documenting control over the process, risk assessment as a document has no significance for the validation of the resulting disorders of the employee's health condition.

There are many other reasons for implementing an effective OH&S system to create a framework for increasing safety, reducing workplace risk and improving health, enabling an organization to proactively improve its OH&S performance.

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GLOBAL TRENDS IN DIGITALIZATION IN WORK AND ITS' IMPACT ON OCCUPATIONAL SAFETY AND HEALTH

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Abstract: The ongoing evolution of global digitization trends in the workplace has a profound influence on the work methods and organizational structures in contemporary society. Digitalization in the workplace entails modern technology and digital tools to enhance work processes, streamline communication, manage information, and optimize overall organizational functionality. This shift encompasses the adoption of diverse digital platforms, software applications, process automation, cloud-based solutions, and the development of electronic management systems. The impact of digitalization on individuals' health can be both positive and negative. While digitization remains integral to modern work practices, striking a balance between technology usage and health considerations should remain a constant priority for all individuals operating in digital environments. This paper explains the global trends in workplace digitization and indicates their repercussions on Occupational Safety and Health (OSH), aiming to foster a deeper comprehension of trending digitalization concepts.

Keywords: *Occupational Health and Safety, Digitalization in OSH; Global trends in OSH*

INTRODUCTION

In our increasingly digital world, it is of utmost importance to understand the language of digitization. This includes not only the terms "digitalization" and "digital transformation", but also the technologies and trends associated with them. Not understanding digitalization can cause us to miss important developments and opportunities that can be of great benefit to the work. As we all know, today's world is characterized by increased Internet connectivity, which has also led to rapid digitization. The United Nations International Telecommunication Union (ITU) reveals that approximately 63% of the global population were active Internet users in 2021. We are also aware that the COVID-19 Pandemic has accelerated the process of digital transformation. Without a doubt, especially developed economies are moving towards a rapidly developing digital economy. The size of the global digital workplace market was estimated at $27.33 billion in 2021 and is expected to expand to $92.22 billion by 2027 (EU-OSHA, 2023)**.** Digital transformation has changed the face of every industry. The race for the ultimate digital experience and meeting the ever-changing demands of consumers has been the need for companies in the digital transformation trend. Digital transformation is the adoption of digital processes to achieve strategic business goals (Bachche, 2023). It involves the use of fast, new, and constantly evolving digital technologies to solve business problems. Although a complex and multifaceted process, it has been shown to have positive effects on almost every part of the organization. It can help streamline workflows and improve communications at the very least (Moraru, 2024). Digital technologies for monitoring occupational safety and health are changing the workplace. Smart occupational health and safety monitoring systems can identify and measure data in a more systematic and overall improved way compared to traditional methods. Besides helping to reduce workers' exposure to risks, they can also minimize the harmful consequences of accidents and improve their investigation and reporting (Akyildiz, 2024).

TRENDS IN DIGITALIZATION AT WORK

When it comes to digital transformation, most people will likely focus on the digital part rather than the transformation part. Basically, digital transformation is about improved internal communication and sharing. This includes encouraging employee engagement to achieve a shared vision. This requires assembling teams with diverse knowledge bases and positions, engaging in knowledge sharing, building trust and promoting transparency. With the outbreak of the COVID-19 pandemic, 89% of businesses have adopted a digital business strategy and transformed their technologies to create a digital workplace. A digital workplace is a virtualized form of the traditional office environment, where many elements of collaboration and productivity are performed through some combination of digital applications, computers, and all the rest of today's technology.

Figure 1. Digital workplace characteristics

The digital workplace and increasing digital technology are important in many ways. According to statistical research, 60% of surveyed workers believe that technology is fundamental to productivity while at work, data shows that technology and infrastructure in the workplace do not empower them to achieve their maximum potential. Over 64% of employees would accept a lower paying job over the option to work from home. It has also been observed that organizations with digital workplaces have 87% higher employee retention. Whether employees work at home, in the office, or elsewhere, the technology they depend on to do their jobs is vital to their success at work. Digital technologies are not only affecting the scope of jobs, but they are also transforming the way that work is conceptualized and how people perform their work tasks. The World Economic Forum (WEF) has estimated that by 2025, 85 million jobs may be displaced by the shift in the division of labor between humans and machines, while 97 million new jobs more suited to digitization may emerge. By 2025, humans and machines will spend equal time on work tasks and probably for many workers, the main effect of digitization will be felt through changes in the nature and content of work in a digitally transformed work environment. Digitization in work refers to the application of technology and digital tools to improve work processes, communication, information management and general functioning of organizations or business systems. Some of the most significant trends in digitization are: efficient cloud-based systems, more authorized persons of the company, innovations, continuous progress, data-driven strategies (Hauke et al, 2018).

OPPORTUNITIES, CHALLENGES AND RISKS FROM DIGITALIZATION IN OSH

Opportunities

Digitization will bring new and new challenges for OSH, but also opportunities. Shifting the balance towards enablement will depend on how the technology is implemented, managed and regulated. Digital technologies can advance OSH efforts in a variety of ways, for example by allowing workers to be removed from hazardous work situations, through an innovative way to monitor exposure, or by improving work quality by freeing workers from repetitive or routine tasks. Digital technologies and new forms of work can also enable workers to benefit from higher levels of autonomy and flexibility or facilitate the access of a more diverse workforce to the labor market, particularly vulnerable groups such as disabled people needs and the elderly. Digitalization also offers opportunities for more effective OSH training, advanced workplace risk assessment, communication and OSH inspections. However, depending on how the technologies are designed and implemented, the organizational context and employment status, digitalization may result in some workers being exposed to OSH risks such as ergonomic and safety risks, including functional safety risks. Increased organizational and psychosocial risks, with increasing work-related stress and poor mental health, may also be a consequence of increased performance pressure and work complexity, irregular working hours, less social interaction and work support, blurred boundaries between work and private life, and new forms of work with unclear work status. The digitization of the world of work also challenges and reveals gaps in the current OSH management and regulation mechanisms. This may be the case for example for certain forms of work facilitated by online platforms or in situations where workers are managed by intelligent machines. Maintaining a balance between the challenges and opportunities offered by digitization depends on the correct application of technologies and the way they are managed and regulated in the context of social, political and economic trends such as workforce demographics, the state of the economy, social attitudes, management and skills. Examples of OSH strategies that could help mitigate the OSH challenges presented by digitization include: Development of an ethnic framework of digitization, codes of conduct and good governance, A strong "prevention by design" approach that integrates human factors and worker-centered design, Involvement of workers in the design and comparison of any digitization strategies, collaboration between academics, industry, social partners and governments on research and innovation to digital technologies to properly take into account human aspects, regulatory framework for clarifying OSH obligations and responsibilities in relation to new systems and new ways of working, ddapted education system and training for workers.

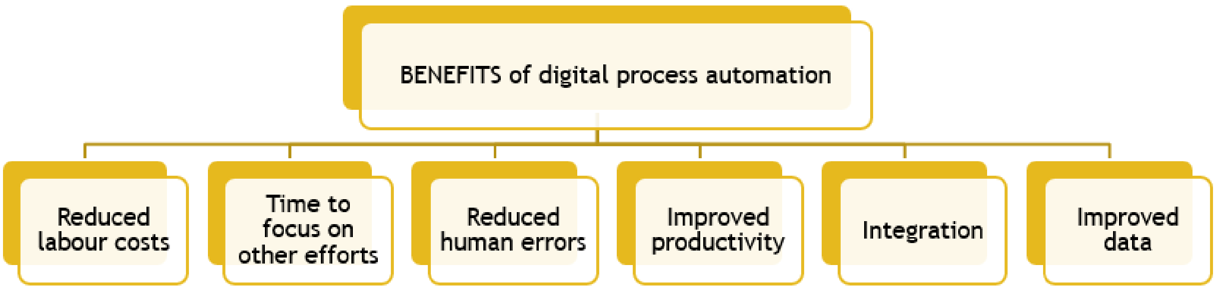


Figure 2. Opportunities of digital process automation

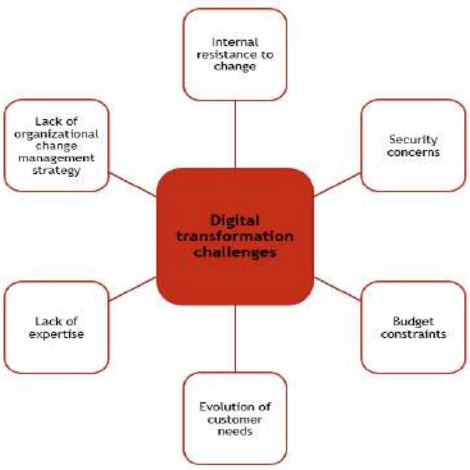
New technologies and a more integrated, globalized world offer many opportunities to create new jobs, improve the quality of existing jobs, and bring previously underrepresented groups into the labor market. Both technological change and globalization create jobs by lowering the price of goods and services, increasing their quality, and hence increasing consumer demand. They're also creating entirely new jobs, like big data managers, social media managers, and drone operators, all occupations that didn't exist a generation ago. The development of VR and AR has the potential to transform virtual work in the future by dramatically changing and facilitating it. It can unite geographically diverse workplaces beyond the current widely used technologies by making it easier for employees to connect with each other digitally. Working from home can make jobs more flexible and accessible to a greater and more diverse number of people, including older workers. It can remove people from hazardous environments, reducing for example physical risks, ergonomic risks, biological risks and exposure to hazardous substances. There are also opportunities to rethink risk assessment and management processes, use Big Data, smart devices and encourage more active participation of workers in these processes. AR can include instructions, which could reduce human error, as workers will not need to refer to separate instructions while their hands are needed for the maintenance activity. It can also improve situational awareness by providing additional contextual information. Some of the benefits of digitalization opportunities are: improved productivity and improved communication.

Challenges

There is clear evidence indicating that digitization, if not implemented in an inclusive, human-centered way, can pose a number of challenges to individuals, organizations, and society. Digitization is now leading to new forms of work and employment, has intensified trends towards new types of dependency and precarious jobs, and has further intensified challenges related to the health, safety and well-being of the workforce. Advances in technology have also led to a negative impact on working conditions, a blurring of the boundaries between work and life, increased monitoring and surveillance of work, as well as the worsening of persistent and the creation of new inequalities in the labor market and workforce. With the increasing use of artificial intelligence, automated systems are able to perform not only physical tasks, but also various cognitive tasks, such as autonomous driving. Automation of tasks may be associated with more sitting and less task variation, leaving workers with repetitive work. While there are significant opportunities for workplace advancement and productivity growth, there are important health, safety and welfare issues that arise as AI is integrated into workplaces.

Figure 2. Challenges of digital transformation

Digital technologies based on artificial intelligence enable new, widespread, accurate and



cheaper forms of monitoring and management of workers based on the collection of real-time data about workers, during and outside of working hours as well as outside the workplace. Collected data may allow employers to increase control over their workers and the workplace, incorporate evaluation systems or other metrics into performance evolution, improve worker performance and productivity, rationalize work organization and production, to reduce the costs of monitoring and supervision, profile workers, influence their behavior, discipline them or improve human resource management (Jeske et al, 2021). Psychosocial risks, work-related stress and harassment are widely recognized as major drivers of health, safety and well-being problems in the workplace. A bad psychosocial work environment can result in absenteeism, reduced productivity, safety, job dissatisfaction, intention to quit the job, etc. Risks can be exacerbated when AI augments existing technological tools or is introduced to workplace management and design resulting in workers being exposed to a number of psychosocial hazards such as loss of control over their jobs.

Risks

The rapid development of technology and the digitization of the business world in the last decade has enabled the opening of new types of jobs, which ten years ago we could not even imagine. The World Economic Forum (WEF) predicts that even more new jobs based on technology and digitalization will be created in the future. For example, jobs like virtual reality specialist, data analyst, artificial intelligence engineer, data analyst, cyber security specialist, social media marketing expert, blockchain technology experts and so on are becoming more popular. However, along with the creation of new jobs, there will also be changes in existing jobs, requiring workers to develop new skills and adapt to new technologies and ways of working and to take advantage of the opportunities and mitigate the challenges associated with the changes. in tasks and processes. The pattern of lower-skilled jobs being replaced by those requiring more advanced digital skills and technical expertise is clear. Overall, automation leads to the suppression or transformation of jobs characterized by a high share of routine tasks, which mainly affect low-skilled workers. In manufacturing, occupations such as production line operators and supervisors, production managers or specialized services and operators are expected to face significant changes that will require upskilling or retraining of affected workers. In general, it can be concluded that digitalization has led to changes in professional structures (Fagerlönn, 2023).

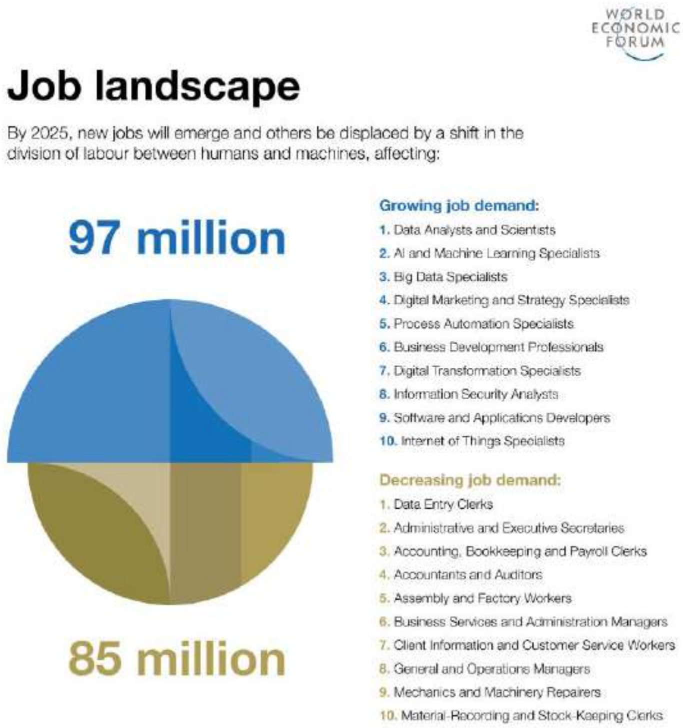


Figure 4. Emerging jobs by 2025 according to WEF

CONSLUSIONS

Digitalization has led to the automation of many processes, resulting in increased efficiency and cost savings. By using digital tools and technologies, companies can optimize their business processes and increase productivity. Digital tools have also simplified communication and collaboration between employees and customers. However, digitalization also has an impact on job security. Companies need to ensure that their employees have the necessary skills and knowledge to perform their jobs in a digitized world of work. To stay safe at work, employers must take the initiative to implement safety measures, such as changing workplace design, using industrial equipment and improving working conditions. It is very important in the future to work towards the creation of safe workplaces in order to reduce the risks brought by digitization and preserve the health of workers in the world. After the workforce's transition to remote work opportunities, have many business leaders fully understood the implications of digital workflows. This transition blurs the boundaries between physical and virtual realms. Conclusively, the recommendations suggest that organizations can start addressing these issues now by prioritizing the five pillars of an intelligent workplace: seamless collaboration, continuous communication, centralized knowledge, streamlined processes and inclusive culture.

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NOISE MEASUREMENT WITH PERSONAL DOSIMETER ON CONSTRUCTION SITE AND PREVENTIVE MEASURES

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Abstract: A wide range of construction activities, including heavy construction machinery, produce high levels of noise on construction sites, and it can be harmful to workers and the environment. This study utilized personal dosimeters to measure workers' exposure to noise generated by hydraulic excavators. An examination was conducted on the operator of the Liebherr excavator on the construction site in Subotica. Since the personal dosimeter records every minute of an eight-hour work shift, values that exceed the permissible level of 85 dB were taken into account. The study's findings indicate that the levels of noise surpassed the acceptable thresholds of 85 dB (A) and 90 dB (A), with the highest Leq exposure recording at 94.7 dB (A). The high value of the peak equivalent sound level (LC_{peak}) indicates the presence of another high-value periodic or impulsive noise. According to the results, it has been found that the operators and the working environment are highly exposed to noise pollution. To ensure a comprehensive approach towards noise assessment in the workplace, it is essential to conduct measurements of noise levels with the personal dosimeter.

Keywords: *Noise, construction, excavators, personal dosimeter*

INTRODUCTION

Noise is defined as every unpleasant and unwanted sound. It is one of the significant pollutants that contribute to stress and hearing loss, raises blood pressure, and impacts lower productivity (Samardžić, 2021; Anees et al., 2017). As there are various noise sources today, the management of noise has consequently experienced a progressive evolution.

Noise from the construction environment is identified as one of the major problems because of its negative impact on the community as a whole. Sounds produced by different construction machinery are one of the main causes of noise on the construction site, and the amount of noise varies depending on the size of the excavator and the operating conditions (Nakashima et al., 2013).

According to the research conducted by Movahed and Ravanshadnia (2022), the majority of construction equipment operators are at risk of hearing damage. Specifically, those who operate bulldozers, excavators, loaders, and mobile cranes are exposed to high noise levels that can lead to hearing loss.

Depending on the type of machine that the operator is handling, OSHA (2012) highlights that working on a heavy excavator can produce noise from 97-107 dB (A). Kantová (2017) states that the main sources of noise on construction sites are those originating from construction machines for breaking concrete, devices for driving piles, etc. In this regard, construction activities, especially earthworks that include clearing, excavation, backfilling, cutting and compaction, have a high level of noise and are directly connected to the machinery used.

Excavation represents the noisiest phase due to its high variability in sound emission and the large difference between the background noise of the machine engines and the noise caused when digging with a spoon (Ballesteros et al. 2010).

To better control and monitor noise exposure, measurements are taken at the workplace and working environment. However, current measurement methods are deemed insufficient since merely measuring the noise exposure level of some equipment operators at construction sites does not provide a comprehensive understanding of exposure. Hence, it is recommended that during the measurement process, audiometric monitoring should be conducted for all employees exposed to noise (Barkokébas et al., 2012). To mitigate the negative effects of noise, the use of personal protective equipment such as earmuffs is recommended (Mučenski, 2018).

Adequate noise control and management within construction environments demands a comprehensive analysis of noise sources, machinery, processes, and human activity. This analysis must be combined with the application of appropriate measures to protect workers from the negative effects of excessive noise exposure and careful attention to prevent any adverse effects on the surrounding environment.

Measuring the noise levels generated by various machinery and processes is a fundamental step in identifying potential sources of excessive noise and designing effective noise control strategies. In this context, a research study was conducted to measure the noise levels produced by hydraulic excavators at a construction site in Subotica. The study investigated the actual extent of noise exposure among excavator operators and highlighted the imperative need to integrate such measurements into the procedure for assessing the working environment. The paper concludes with a set of recommendations and strategies aimed at mitigating high levels of noise pollution, while also prioritizing the protection of workers' health.

MATERIALS AND METHODS

Noise levels at individual workstations were evaluated using a personal dosimeter to assess noise's impact on workers. This approach is especially important in the case of mobile machinery like excavators, where multiple tasks are often performed simultaneously.

Personal noise dose was measured using a Bruel&Kjer tip 444-8B noise dosimeter (Figure 1.), which moves with the worker in order to measure their exposure at their exact location and for their particular behaviour. To accurately assess an employee's noise exposure, it is best to attach the noise dosimeter to the employee at the beginning of their shift and collect it at the end of the shift. This ensures that the measurement is taken over the entire duration of the shift. The personal sound dosimeter is mounted on the shoulder of the person, at least 10 cm from the ear more exposed to noise, with the microphone about 4 cm above the shoulder.

The research presents a case study that measures noise produced by a hydraulic excavator during construction work in Subotica. It was conducted using modern hydraulic excavators, which were part of the machinery used.

Figure 2. A personal noise dosimeter attached to the shoulder of the operator

RESULTS AND DISCUSSION

Throughout the 8-hour work shift, the dosimeter recorded numerous L_{eq} and LC_{peak} values that surpassed the threshold level for one-minute intervals. Notably, values exceeding 85 dB and 90 dB were reported. Consequently, Table 1. and 2. show the values of measured equivalent noise exposure (L_{eq}) and peak equivalent sound level (LC_{peak}) of noise exposure at the construction site. Results show that measured values of noise vary between 85 and 95 dB (A), with the highest value for L_{eq} of 94.7 dB (A), which is 9.7 dB higher than the permissible level of 85 dB (A).

Table 3. Results of L_{eq} measurements which exceed 85 dB and 90 dB using a personal dosimeter at the construction site during the 8-hour shift.

	L_{eq}>85 dB									
L_{eq} (dBA)	86.1	87.1	88.3	85.7	88	85.6	85.1	85.1	86.6	89.8
	85	85.3	85.6	86.7	87.4	89.2	87.2	87.9	89.4	85
	86.4	85.8	86.1	88.5	88.2	88.8	86	88.7	85.3	87.7
	85.5	88.7	89.4	86.1	86.1	88.9	88.8	89.4	87.6	87.2
	89.5	87.9	86.5	88.4	87.9	86.1				
	L_{eq}>90 dB									
	92.2	92.2	91.1	91.2	91.6	91	90.3	93	91	91.2
	92.1	92.5	94.7	92.5	90.4					

Table 4. The results of Lpeak measurements for Leq exceed 85 dB and 90 dB, taken using a personal dosimeter at the construction site during the 8-hour shift.

	For L_{eq}>85 dB									
L_{peak} (dBC)	133.4	135.2	114.7	130.8	131.1	134.3	133.5	129.7	129.4	133.6
	132.9	132.3	132.4	115.4	124.9	143.1	131.3	122.1	122.3	129.7
	132.6	115.5	134.7	124.9	114.9	116.8	133.3	135.2	115.2	131.7
	132.4	114.7	118.3	115.5	111.9	118.2	123.4	117.3	120.6	131
	119	118.2	114.8	119.1	120.2	115				
	For L_{eq}>90 dB									
	129.7	121.9	130	119.4	120.1	118.1	117.4	125.2	118	117.6
	132.6	130.7	125.6	117.3	117.7					

In order to ascertain the mean noise level for values exceeding the predicted threshold, we conducted an analysis of the results obtained, which are presented in Table 3 and depicted graphically in Figure 2. The average noise levels of Leq>85 dB and Leq>90 dB suggest that workers are regularly exposed to loud noise that can harm their hearing health. Moreover, the mean values of L_{eq}=91.80 dB(A) and L_{peak}=125.14 dB(C) indicate that there are instances of even higher noise exposure, which could be problematic. Therefore, it is advisable to implement noise control measures to ensure the safety of workers' hearing health.

Table 5. Mean values and SD of L_{eq} and LC_{peak} measurements for activities of excavator where noise exceeds limits

	L_{eq} (dB)		LC_{peak} (dB)	
	L_{aeq}> 85	L_{aeq}>90	LC_{peak}>85	LC_{peak}>90
Mean	87.21	91.80	125.14	122.75
Std. Dev	1.48	1.13	8.16	5.66

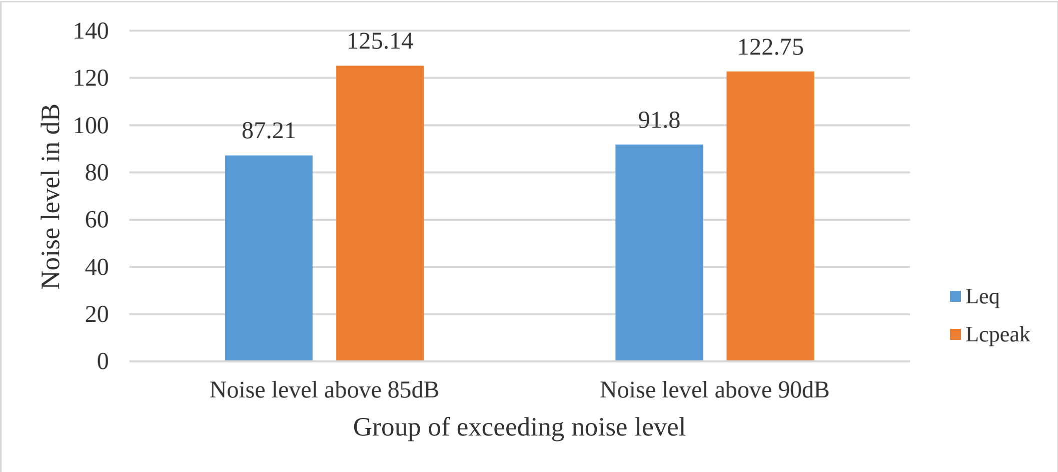

Figure 3. Mean values of L_{eq} and LC_{peak} for noise level exceeded 85 dB(A) and 90 dB(A)

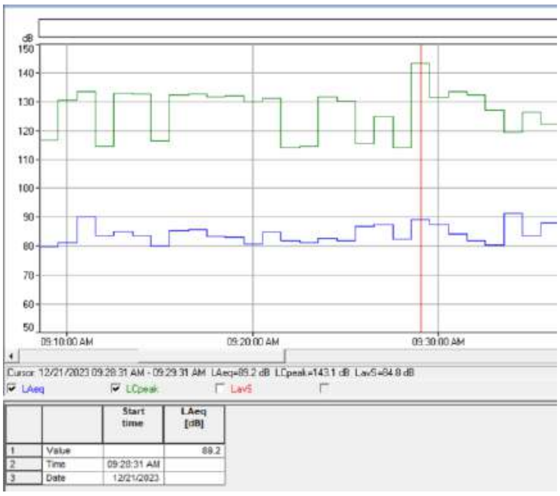

Figure 4. Personal dosimeter readings for an eight-hour working shift

A Pearson's correlation test was conducted in the Statistical Package for Social Sciences (SPSS) to ascertain the potential correlation between L_{eq} and Lcpeak values. To simplify the presentation of personal dosimeter readings (Figure 3.), 32 measured values were obtained by recording 4 data points every hour with a 15-minute interval. Table 4 displays the correlation matrix for two variables L_{eq} and LC_{peak} - along with their mean values and standard deviation. The matrix shows the Pearson correlation coefficients between variables, indicating the strength and direction of the linear relationship between them.

Table 6. Pearson correlation matrix

Variable	Correlations (Personal dosimeter) Marked correlations are significant at p<.05000 N=32 (Casewise deletion of missing data)			
	Means	Std.Dev	L_{eq}	L_{peak}
L_{eq}	77.7125	9.45641	1.000000	**0.857645**
L_{peak}	113.0688	14.97653	**0.857645**	1.000000

The presented table reveals a robust and statistically significant linear correlation between the variables of L_{eq} and LC_{peak}, with a correlation coefficient (r) of 0.86 and a p-value of less than 0.05.

The overall personal dosimeter readings show the following values: L_{eq} = 82.9 dB(A), sound exposure = 0.62 Pa2h, dose = 19.3%, and LC_{peak} = 143.1 dB. Measuring by the personal dosimeter for an eight-hour workday showed that the L_{eq} is close to the permissible limit of 85 dB (A), but LC_{peak} notes a very high value, indicating the existence of high–value periodic or impulsive noise, which demands the use of hearing protection at work. The dose value proposes that in 20% of the workday, the operator of the excavator is exposed to disturbing noise. Figure 2 shows recorded levels of noise when the operator was simultaneously excavating and loading soil material, where the average L_{eq} value was 89.2 dB (A), and L_{peak} was 143.1 dB (C).

Measurements showed that information gathered by a personal dosimeter is more accurate, and it can be useful when managing preventive measures for workers, such as adequate hearing protection devices, and estimating the probability of occupational hearing loss.

ON-SITE CONDITIONS AND PREVENTIVE MEASURES

On-site conditions showed an example of well-placed preventive measures and maximum attention from workers to respect all of their obligations. The operator was provided with adequate breaks during the work, personal protective equipment (ear plugs) and a competitive signalman. Also, the excavator was from the new generation, where the manufacturer had already implemented appropriate preventive measures to reduce the level of noise produced by the excavator during operation. The maintenance book showed that daily, monthly, annual and preventive inspections of excavators are carried out regularly.

Preventive measures for noisy environments include a combination of organizational and technical measures that can prevent injuries at work and occupational diseases. Some of the most used preventive measures are the use of quieter equipment, installation of sound barriers, conducting regular noise assessments to identify areas with high noise levels, regular maintenance and inspection of excavators, training and education of employees and providing workers with personal protection equipment (PPE).

Most of the attention should be put on adjusted training and education of employees. Different educational levels should not be obstacles to assuming knowledge about hazards that can occur in their noisy working environment. Training should contain lectures about how to properly carry out all of the measures, how to properly use PPE and how to recognize potential hazards and defective PPE. Also, it is necessary that employees should be educated about the side effects of noise, how excessive noise impacts health, how to notice the first signs of hearing damage, and how to provide them with a proper medical examination for following their hearing health condition.

Also, it is necessary to provide regular and preventive maintenance of excavators since their parts could lead to excessive noise. That is why it is important to regularly check on key elements such as bearings, gears, engine, and lubrication of all parts and mechanisms, as excavators will become noisier and deteriorate with age.

CONCLUSION

Based on the findings, the noise level exceeded 85 dB frequently during the entire 8-hour workday, and sometimes even reached 95 dB. This indicates that there is a need to improve the examination of working conditions and implement appropriate preventive measures. Often, such measures are not implemented despite being necessary. A consolidated understanding of exposure provides health and safety management to recognize hazardous zones of noise, conduct monitoring exposure over time and implement effective preventive strategies against noise. Throughout these actions, the process of measuring noise in the working environment would be significantly improved, resulting in a safer working environment, reduced noise emissions and improved worker health.

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BIOMECHANICAL RISK FACTORS FOR MUSCULOSKELETAL DISORDERS IN DENTISTRY

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Abstract: Musculoskeletal disorders are among the most frequent medical conditions that dentists are faced with. These conditions can occur in any part of the musculoskeletal system, while the neck, back, and shoulders are the most affected body parts in dentists. The use of painkillers, sick leave, and early retirement are common ways that dentists use in the fight against musculoskeletal disorders. Exposure to various risk factors at the workplace, which can be classified as personal, psychosocial, and biomechanical risk factors, is the main cause of musculoskeletal disorders. Biomechanical risk factors are often considered as one with the biggest impact on the development of musculoskeletal disorders in dentists. Common biomechanical risk factors that dentists are exposed to are awkward postures, repetitive motions, forceful exertion, static postures, and vibrations. Dentists are often exposed to several of these risk factors simultaneously, which increases the risk for musculoskeletal disorders.

Exposure to biomechanical risk factors in dentistry is often unavoidable, however level of exposure can be reduced by using proper ergonomic measures. Managing ergonomic risk factors in the workplace is the best way to lower the prevalence of musculoskeletal disorders in dentistry.

Keywords: *Biomechanical risk factors; Dentist; Musculoskeletal disorders.*

INTRODUCTION

Musculoskeletal disorders (MSDs) are diseases or conditions affecting the musculoskeletal system and are caused by temporary or permanent damage to any musculoskeletal components (WHO, 2022). Modern medicine recognizes more than 150 different disorders/conditions affecting muscles, tendons, joints, bones, ligaments, etc. MSDs pose a serious health problem on a global level, with significant socioeconomic consequences (Russo et al., 2020). MSDs are considered one of the most common work-related disorders, and they often have a dominantly negative impact on an individual's work performance.

MSDs are quite frequent among dentists, mainly due to the exposure to numerous risk factors at the workplace. Dentistry is generally considered a profession with an increased risk of developing MSDs. Chenna et al. (2022) conducted a systematic review aimed at analyzing papers that reported the prevalence of MSDs among dentists. Screening of 234 papers showed that the prevalence of musculoskeletal disorders among dentists varies from 19.4% to 100%, while in the majority of papers, these numbers were higher than 50% (Chenna et al., 2022). The first signs of MSDs in dentists come very early, often during their final years of dental faculty, before they start with clinical practice, and before the start of their career (Garcia et al, 2012).

Working in a dental office puts the whole musculoskeletal system under a lot of stress. Among the most affected body areas, which consequently are most often affected by MSDs, are the neck, lower and upper back, and shoulders (Ohlendorf et al., 2020). Some of the most frequently reported MSDs by dentists are lower back pain, shoulder tendinitis, carpal tunnel syndrome, and disorders caused by hand-arm vibration, (Chenna et al., 2023; Turcot et al., 2023; Gaowgzeh et al., 2015; Alexandre et al., 2011).

MSDs can significantly limit dentists' capacity to work, leading to a serious loss of productivity. Often some kind of treatment is required to deal with the consequences of MDSs, like medical help, sick leave, change of profession, early retirement, etc. However, sick leaves due to MSDs are not that often among dentists, going below 10% per year (Rickert et al., 2021; Šustová et al., 2015). More often, dentists' favorite weapon for fighting against MSDs and musculoskeletal pain is different painkillers, as some studies show that more than 36% of dentists use them (Rickert et al., 2021). Early retirement due to MDSs is not uncommon among dentists, as research conducted in the UK by Brown et al. (2010) showed that 55% of British dentists who retired early stated that MSDs are the main reason for retirement.

Risk factors for developing musculoskeletal disorders in dentists can be grouped as personal, psychosocial, and biomechanical risk factors (Harris-Adamson et al., 2022). Personal or individual risk factors include lifestyle, fitness level, body mass index, age, etc. Psychosocial or organizational risk factors are related to job demand and job control, organization of work, and similar. Biomechanical or physical risk factors for musculoskeletal disorders are awkward postures, static work, repetitive motion, forceful exertion, and others. To reduce or prevent MSDs all three types of factors mentioned above need to be managed adequately. MSDs are mainly caused by the intertwined impact of various personal, psychosocial, and biomechanical risk factors (Figure 1.).

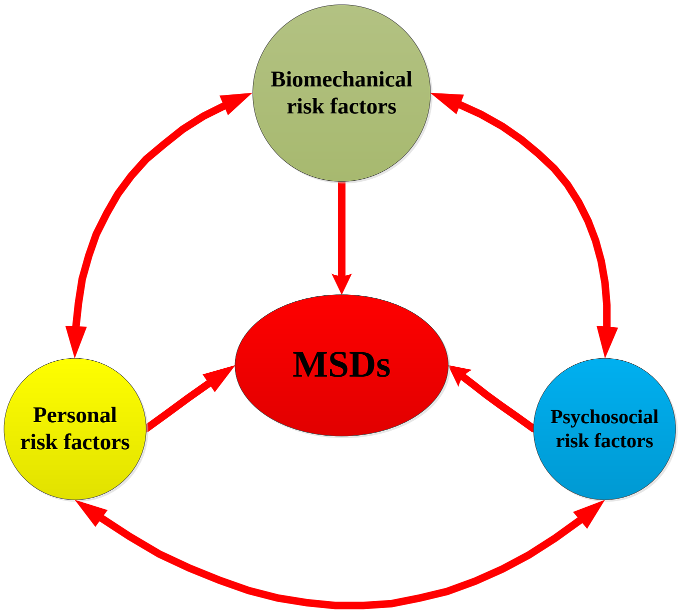

Figure 1. Risk factors leading to MDSs

BIOMECHANICAL RISK FACTORS

The most numerous and most influential group of risk factors that dentists are exposed to are biomechanical risk factors. As these risk factors can't be always eliminated from the workplace, therefore exposure to them should be reduced to a minimum. Among the most significant biomechanical risk factors affecting dentists are awkward postures, repetitive motions, forceful exertion, static postures, and vibrations (Table 1).

Table 1. Biomechanical risk factors in dentistry

Biomechanical risk factors	Body region affected	Significance level
Awkward posture	Neck, upper and lower back, hands/arms, legs	High
Repetitive motions	Hands/arms, neck, legs	Medium
Vibrations	Hands and arms	Low
Static postures	Neck, hands/arms, legs	High
Forceful exertion	Hand/arms	Medium

Awkward posture

Any posture in which there is a significant deviation from the neutral position when performing work activities is considered an awkward posture (Fritz & Fritz, 2020). Working in an awkward posture puts a greater load on the musculoskeletal system, which leads to faster fatigue. Several body parts can be in awkward postures during the dentist' work. Dentist's neck, back, arms, hands, and legs are most often found in awkward posture. Working in awkward posture has a great influence on the occurrence of musculoskeletal disorders in dentists, and these postures can be eliminated by better positioning of the dentist (de Santana Sampaio Castilho et al., 2021). Ergonomic training plays a critical role in eliminating awkward postures, therefore dentists should be trained on the importance of working in neutral positions.

Repetitive motions

Repetitive motions are often made in the dental office, as dentists must make the same moves during their work. Consequently, this means that the same part of the musculoskeletal system is used, leading to cumulative stress on those parts resulting in local pain or discomfort. Repetitive motion leads to quicker fatigue of muscles used, making them more prone to inflammation and injuries (Kohli & Thukral, 2011). The neck, hands, and arms are body parts that are most affected by repetitive motions in dentistry (Dias, Silva & Galvão, 2014). Repetitive motions are present in dentistry regardless if the dentist is working alone or practicing 4-hand dentistry, i.e. working with a dental assistant. Typical repetitive motions made by a dentist are picking up an instrument, positioning of head for a better view of the patient's mouth, foot movement to activate the drill, etc.

Static postures

Any work where a worker stays in the same posture for more than 4 seconds, while muscles are exerting or are under a relatively constant load is considered as a static posture (ISO, 2000). Static postures are typical for sedentary jobs, where workers spend most time sitting or standing. Work in dentistry is considered a sedentary job, as dentists spend quate of their work day in static posture making only minor moves with their extremities. The main disadvantage of static postures is due to isometric muscle contractions, as muscles in isometric contraction do not assist the cardiovascular system which leads to an accumulation of toxic matter in the affected body parts. Consequently, there is a disturbance in the function of the musculoskeletal system leading to quicker fatigue. Static posture in dentistry can happen either when the dentist is working in a standing or seated posture. Static postures when the dentist is standing require 10% more energy than seated static postures, with increased heart rate and disturbed peripheral venous circulation when standing (Anghel et al., 2007).

Forceful exertion

Forceful exertion in dentistry happens mainly when significant force needs to be used to perform some operation. This often happens when removing teeth or similar interventions that require the use of large force. Such tasks put different elements of the musculoskeletal system, like muscles, tendons, ligaments, and joints, under much greater loads compared to their normal loads (Gupta et al., 2014). Serious problems with forceful exertion in dentistry lie in the fact that most dentist will almost always use their dominant hands when performing such tasks. In dentistry is hardly possible to switch between hands during the day for tasks like tooth repair, tooth extraction, and similar. First of all, dental chairs are installed in specific ways for either left-handed or right-handed dentists, and changing these often requires complex manipulation by a trained professional. Secondly, only 1% of the population is ambidextrous so the number of dentists that can use either hand in an equal manner is surely negligible (De Kovel et al., 2019). Therefore, almost all dentist spends their career performing most task only with the dominant hand. This leads to a lifetime exposure of the dominant hand for forceful exertion, which can cause significant neuromuscular deficit in that hand. Forceful exertion is considered a risk factor for carpal tunnel syndrome in dentistry (Haghighi et al., 2013).

Vibrations

Occupational exposure to vibration often happens when using powered machines. Dentists are exposed to hand-arm vibrations due to the use of power-driven handheld instruments. Typically, dentists use numerous different instruments for various tasks like tooth drilling, tooth scaling, and similar. Dental instruments generate very specific vibrations with frequencies above 1000 Hz or ultra-high frequency vibrations. Such vibrations are so specific that findings on vibration exposure from other professions are rarely usable in dentistry. Vibrations are transmitted through small body parts like the fingertips. The effects of vibration on dentists significantly change depending on the position of a tooth that is repaired, as the hand grip or how a dental instrument is held is changed.

Hand-arm vibration syndrome or HAVS is a condition caused by exposure to hand-arm vibrations, while the harmful vascular and sensorineural effect of such exposure is cumulative (Chowdhry and Sethi, 2017). According to the EU directive 2002/44/EC, which sets minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents – vibration, vibration exposure of dentists is assessed as low (Rytkönen et al., 2006). Proper maintenance and regular replacement of dental instruments is an important step to reduce occupational exposure of dentists to vibrations.

DISCUSSION

The nature of MSDs and the way they develop are often complex, with a whole variety of different risk factors as an underline cause. Such multifactorial nature of MSDs has proven to be a great challenge in dealing with this issue. Risk factors for MSDs often can't be eliminated from the work environment, but are controllable to some degree. Generally speaking, biomechanical risk factors are considered as one of the most controllable ones. During their work, dentists can be exposed simultaneously to the effect of almost all the above-mentioned biomechanical risk factors. The harmful effects of most of these factors can be reduced to a greater or lesser extent by applying appropriate ergonomic measures.

Awkward postures are among the risk factors in dentistry that can be eliminated to the greatest extent. To achieve this it's necessary to raise awareness among dentists on the importance of avoiding awkward postures while working. Modern technologies, like the use of sensors or video recording processed by AI, can be used as tools to warn dentists when they work in awkward postures.

Repetitive motions in dentistry can be reduced to some extent. This reduction can be achieved by adequate training of the dentist-dental assistant team. Also, working with the same dental assistant helps in achieving a greater degree of routine, which will consequently lead to a reduction in repetitive movements.

Vibration exposure can be reduced with proper choice of dental equipment, preventive maintenance of dental equipment, and regular replacement of worn-out pieces of equipment. The use of modern equipment, like dental lasers or modern teeth descalers, leads to a significant reduction of vibration exposure.

Static postures in dentistry are probably the most difficult to eliminate due to the nature of the dentist's work. Simply, a dentist's work mainly requires that the dentist stays in one static position for a relatively long period before switching positions. Dentists spend less time in static postures when working without dental assistants, as dentists then have to prepare everything themselves.

Forceful exertions can be reduced by better positioning during interventions and by proper selection of instruments. Forceful exertions in dentistry during procedures like tooth removal are hardly avoidable in full, but they are not considered significant risk factors for the development of MSDs in dentists.

CONCLUSION

Dentists are at greater risk of developing some MSDs during their careers than almost any other medical profession. The prevalence of MSDs is much higher in dentists compared to the general population, with higher rates of sick leaves and early retirement caused by MSDs. The main reason for this is the exposure of dentists to numerous biomechanical risk factors during their work. Significant reduction of risk for MSDs in dentists can be achieved by lowering the exposure to biomechanical risk factors at dentists' workplaces. Risk factors such as awkward postures, static postures, repetitive motions, forceful exertion, and vibrations can be hardly eliminated from the dental offices. Therefore, management of these risk factors sounds like the best solution.

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ASSESSMENT OF INDOOR ENVIRONMENTAL QUALITY IN MODERN OFFICE SPACES: IMPACTS ON HEALTH AND PRODUCTIVITY

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Abstract: In contemporary office settings, individual offices are being replaced by open-plan layouts, highlighting the need for optimal Indoor Environmental Quality (IEQ) for office workers. Given today's imperative focus on indoor air quality and its impact on human health, this article aims to consolidate research on IEQ in modern offices, encompassing air quality (including VOCs, particulate matter, and inorganic pollutants), thermal comfort, lighting, and acoustics, and their influence on health and productivity. The findings reveal that while many offices meet IEQ standards, some exhibit elevated air pollutant levels, inadequate thermal comfort, and insufficient lighting, contrary to guidelines. Evidence shows associations between IEQ indicators and adverse health outcomes, such as sick building syndrome symptoms linked to airborne particles and CO_2. Additionally, poor lighting and acoustics are correlated with worker malaise and stress, while higher productivity is observed under better indoor air quality conditions. This synthesis underscores the importance of monitoring IEQ parameters, mitigating indoor pollution sources, optimizing ventilation, and allowing personalized environmental adjustments to enhance worker health and productivity.

Keywords: *Air quality, Indoor Environmental Quality, Health outcomes, Office environments*

INTRODUCTION

The assessment of indoor environmental quality (IEQ) in modern office spaces has become a crucial area of research, given the increasing emphasis on the impact of the built environment on human health and productivity (Frontczak & Wargocki, 2011; Lan et al., 2014). It has been established that services are the sector that employs more people, followed by industry, manufacturing, construction, and agriculture (OECD, 2021). Currently, many service jobs are carried out in modern office buildings, which are often characterized by sealed facades, increased use of air conditioning and mechanical ventilation systems, and equipped with several sorts of electronic devices, such as computers, monitors, printers, and audiovisual conference equipment (Sakellaris et al., 2016). For instance, office design has been changing throughout the last decades, with individual offices being increasingly replaced by open-plan settings (Candido et al., 2016).

The fact that workers share the workplace with many others during an important percentage of their daily time highlights the importance of providing good indoor conditions for everyone in office environments. The importance of indoor environmental quality (IEQ) on occupants' conditions is well recognized, representing an essential factor that can affect health and well-being (Bluyssen et al., 2011). Occupational health complaints have been reported among office workers, frequently related to sick building syndrome (SBS) symptoms, which prevalence might be dependent on building-related factors, as high indoor temperature and light intensity, low fresh air ventilation, higher than desirable air pollutants levels and poor cleaning (Burge, 2004).

Additionally, IEQ represents a critical aspect of promoting office workers' productivity and decision-making capacity (Satish et al., 2013; Kang et al., 2017). Multiple factors characterize IEQ, including indoor air quality (IAQ, i.e., indoor air pollution levels), ventilation, thermal comfort, lighting, and acoustic conditions (Olesen, 2012; Sarbu and Sebarchievici, 2013). In particular, IAQ is considered acceptable when no chemical and biological pollutants are present at harmful levels in the indoor air, and the majority of occupants do not express dissatisfaction (ASHRAE, 2019). Nevertheless, several air pollutants can occur at exceptionally high concentrations in indoor settings, originating from distinct sources that can be located inside the building and in the surrounding outdoor environment. Focusing on indoor contributions in offices, electronic equipment, building materials and furnishings, occupants' activity and cleaning products can constitute sources of hazardous air pollutants, such as ozone (O_3), volatile organic compounds (VOC), aldehydes, particles ($PM_{2.5}$ and PM_{10}) and ultrafine particles (UFP) (Spinazzè et al., 2020).

Although poor IAQ can result in exposures that may significantly impact workers' health, thermal comfort is identified as the most critical factor influencing overall satisfaction with IEQ (Frontczak and Wargocki, 2011), representing the "condition of mind which expresses satisfaction with the thermal environment" (ISO 7730, 2005). Air temperature, mean radiant temperature, air velocity, turbulence intensity, and relative humidity are the meters typically used to determine indoor thermal conditions (Bluyssen, 2009). Two indices have been developed to characterize thermal comfort conditions in spaces served by heating, ventilation and air conditioning (HVAC) systems: predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) (ISO 7730, 2005).

This paper aims to explore the current state of IEQ in modern offices worldwide, addressing questions regarding IEQ acceptability based on existing standards, associations between IEQ and health outcomes among workers, and links between IEQ conditions and productivity. By synthesizing existing literature, this work seeks to provide evidence-based recommendations for future research and policy initiatives aimed at improving health, comfort, and productivity in office workplaces. Through this endeavor, a comprehensive understanding of the impact of IEQ on office environments can be attained, leading to targeted strategies for enhancing workplace conditions and promoting occupant well-being.

MATHERIAL AND METHOD

The selection of studies assessing indoor environmental quality (IEQ) conditions in office settings, particularly focusing on physical and chemical factors, was conducted through a comprehensive literature search. Air pollutant levels, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), $PM_{2.5}$, PM_{10}, ultrafine particles (UFPs), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2), were evaluated as part of this investigation (Felgueiras et al., 2022). Parameters such as asbestos, mold, and bacteria were intentionally excluded from this review. Furthermore, studies that explored associations between IEQ in offices and workers' health and productivity were identified (Bartzis et al., 2013; Satish et al., 2013; Kang et al., 2017). The discussion specifically focused on studies assessing IEQ conditions within real office buildings, while other study types, such as experimental or intervention studies, were considered solely for analyzing effects on health and productivity. Only studies reviewed by Felgueiras et al. (2022) or published thereafter were included in discussions related to CO_2 and PM parameters. Studies that performed risk assessments based on measured pollutant levels were not included in discussions concerning health effects.

EXAMINING AIRBORNE POLLUTANT LEVELS

Volatile and semi-volatile organic compounds

The presence and characterization of Volatile Organic Compounds (VOCs) within indoor office environments have been extensively investigated and documented. VOCs, known for their high vapor pressure and low water solubility, originate largely from anthropogenic sources, with outdoor air contributing significantly to indoor concentrations, particularly for compounds like benzene, toluene, ethylbenzene, and xylenes (BTEX) (Spinazzè et al., 2020). Indoor environments typically exhibit higher VOC levels compared to outdoor spaces due to various indoor sources such as electronic equipment, furniture, carpets, and cleaning products (Spinazzè et al., 2020; US EPA, 2022). Global assessments of total VOC (TVOC) concentrations in office settings have revealed varying levels, with evidence suggesting that enclosed spaces with recent renovations and poor ventilation can experience elevated concentrations (Liu et al., 2022). While no universally established limit exists for TVOC, some countries have defined limits ranging from 200 to 1000 $\mu g/m^3$ (ISIAQ, n.d.). Studies indicate that certain critical VOC levels in offices remain within WHO guidelines, although formaldehyde levels in renovated offices can sometimes exceed recommended limits (Liu et al., 2022; Spinazzè et al., 2020). Health symptoms associated with VOC exposure include headaches, fatigue, irritation, and skin issues (Sakellaris et al., 2021). Furthermore, studies have suggested potential associations between low VOC exposure and enhanced cognitive function (Allen et al., 2016).

In contrast, Semi-Volatile Organic Compounds (SVOCs), characterized by their partitioning into gas, particle, and dust fractions, constitute another subset of VOCs with lower volatility. SVOCs, prevalent in office environments, stem from sources such as electronics, building materials, textiles, and cleaning products (Ataei et al., 2022). Phthalates, a dominant class of SVOCs, are frequently encountered by office workers (Young et al., 2021). Despite limited investigations into SVOC levels in offices, evidence links SVOC exposure to various health risks (Ataei et al., 2022).

Airborne particulate matter

Airborne particulate matter (PM), including $PM_{2.5}$ (fine particles with aerodynamic diameter $\leq$2.5 micrometers), PM_{10} (coarse particles with aerodynamic diameter $\leq$10 micrometers), and ultrafine particles (UFPs) with diameters less than 0.1 micrometers, are common indoor air pollutants found in office environments. These particles originate from various sources such as outdoor air infiltration, indoor activities like printing, copying, and cleaning, as well as building materials and furniture (Spinazzè et al., 2020).

Particulate matter concentrations in offices vary depending on factors such as ventilation efficiency, occupancy levels, and proximity to pollution sources. Studies have shown that $PM_{2.5}$ and PM_{10} levels can exceed recommended exposure limits in poorly ventilated offices or those located near high-traffic areas.

Occupational exposure to airborne particulate matter poses health risks to office workers. Fine particulate matter ($PM_{2.5}$) can penetrate deep into the respiratory system, causing respiratory diseases, cardiovascular disorders, and exacerbating existing health conditions. Coarse particles

(PM_{10}) can irritate the eyes, nose, and throat and contribute to respiratory symptoms. Ultrafine particles (UFPs) have unique health implications due to their small size and ability to penetrate the bloodstream, potentially leading to systemic health effects (Felgueiras et al., 2022). Chronic exposure to airborne particulate matter is associated with increased risk of lung cancer, cardiovascular mortality, and adverse birth outcomes.

Inorganic Air Chemicals

Inorganic air chemicals commonly found in office environments include carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2). These chemicals originate from various indoor sources such as human respiration, combustion processes, photocopying, and outdoor air infiltration (Satish et al., 2013).

Carbon dioxide (CO_2) concentrations in offices are primarily influenced by occupancy levels and ventilation rates. Elevated CO_2 levels can indicate inadequate ventilation and may lead to symptoms such as drowsiness, headaches, and impaired cognitive function among office workers.

Carbon monoxide (CO) is produced by incomplete combustion of fuels and is often associated with malfunctioning heating systems or poor indoor air quality. Exposure to elevated CO levels can cause symptoms ranging from mild headaches to severe cardiovascular effects.

Ozone (O_3) can enter indoor environments through outdoor air infiltration and is generated by electronic equipment such as photocopiers and printers. High ozone levels can cause respiratory irritation and exacerbate asthma symptoms in susceptible individuals.

Nitrogen dioxide (NO_2) is primarily emitted from combustion sources such as gas stoves and vehicle exhaust. Occupational exposure to NO_2 in offices can lead to respiratory symptoms and exacerbate lung conditions.

Occupational exposure to inorganic air chemicals in offices can have adverse health effects on workers. Symptoms of exposure vary depending on the chemical and concentration levels. Chronic exposure to elevated CO_2 levels may lead to poor indoor air quality-related illnesses.

HYGROTHERMAL, LIGHTING AND ACOUSTICAL CONDITIONS IN OFFICES

Hygrothermal conditions play a crucial role in determining thermal comfort in office environments. Factors such as temperature, humidity, and air movement influence occupants' perception of comfort. Indoor thermal comfort is typically assessed using parameters like air temperature, relative humidity, and air velocity. Inadequate thermal conditions can lead to discomfort, affecting productivity and well-being. Optimal thermal comfort is essential for maintaining productivity and well-being among office workers. Uncomfortable thermal conditions, whether too hot or too cold, can lead to distractions, reduced cognitive performance, and increased likelihood of health complaints such as headaches and fatigue.

Lighting conditions in offices impact visual comfort, task performance, and overall well-being. Factors such as illuminance level, light distribution, and glare affect occupants' visual comfort and productivity. Natural daylighting is preferred for its positive effects on mood and circadian rhythms. Poor lighting conditions can cause eyestrain, headaches, and visual discomfort among office workers. Inadequate lighting levels or excessive glare can impair task performance and increase the risk of accidents or errors. Proper lighting design that considers both visual and biological needs is essential for creating a comfortable and productive work environment (ISO, 2002).

Acoustical conditions, including noise levels and sound quality, influence occupants' comfort and concentration. Factors such as background noise, reverberation, and speech intelligibility impact communication and task performance. Excessive noise levels or poor sound quality can lead to distractions, reduced speech privacy, and increased stress among office workers (ISO, 2005). Chronic exposure to noisy environments may contribute to fatigue, irritability, and decreased job satisfaction. Effective acoustical design and noise control measures are necessary to create a conducive and comfortable office environment that promotes productivity and well-being.

CONCLUSION

The assessment of indoor environmental quality in modern office spaces is essential for safeguarding occupant health, well-being, and productivity. The built environment significantly impacts workers who spend a substantial portion of their day in office settings, highlighting the critical need for optimal indoor conditions.

Studies have demonstrated a link between poor IEQ and adverse health outcomes among office workers, such as sick building syndrome symptoms associated with high indoor temperatures, light intensity, and inadequate ventilation. Additionally, inadequate IEQ can contribute to reduced productivity and decision-making capacity, underscoring the importance of addressing indoor environmental factors. Key components of IEQ, including indoor air quality, thermal comfort, lighting conditions, and acoustics, play pivotal roles in shaping occupant experiences. Monitoring and optimizing these parameters through real-time sensor technologies and advanced assessment methods are crucial steps toward creating healthier and more productive office environments.

Future research should focus on developing comprehensive IEQ evaluation methodologies tailored to office settings and implementing evidence-based strategies to improve indoor conditions. By enhancing our understanding of IEQ impacts on office environments, we can implement targeted interventions to enhance occupant well-being and productivity.

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IMPACT OF CLIMATE CHANGE ON OCCUPATIONAL SAFETY AND HEALTH

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Abstract: The fact that the phenomenon of climate change has implications for the whole world also affects the issue of occupational safety and health. Climate change is an unstoppable process which requires a responsible, quick and effective response from governments all over the world. Also, it is necessary to continuously monitor the situation in the area of climatic changes in order to timely recognize potential risks to the safety and health of employees and prevent them.

The paper analyzes the possible impact of climate change on the world of work, considering the aspects of occupational safety and health. Climate change brings new risks or enhances the existing ones and requires adaptation of all subjects of the occupational safety system - employers, employees and the state. The paper also proposes some measures to protect employees from the risks caused by climate change. One of the important activities of the labor protection policy of each country is the strategic planning of the impact of climate change on occupational safety and health. Serbia has, therefore, addressed this issue in the Proposal Strategy on Safety and Health at Work in the Republic of Serbia with an Action Plan for its Implementation (2023-2027).

Keywords: *climate change, occupational safety and health, action, strategic planning*

INTRODUCTION

Climate change, as a phenomenon of the modern world, affects almost all segments of human lives and work, including occupational safety and health. The world of work faces new challenges emerging from climate change, with workers in numerous industries being affected. They represent an unstoppable process and require a responsible, quick and effective response from governments all over the world. It is necessary to take actions in order to protect the health of workers and the planet, while maintaining economic development, employment opportunities and decent work for all.

The entire world of work can be impacted by climate change. They affect all subjects of the occupational safety and health system - employers, employees and the state. That is why it is important to analyze the potential impacts of climate change on occupational safety and health, precisely observe the risks they bring or enhance, propose concrete mechanisms and measures to protect employees and examine how such measures affect the interests of employers and the state. Based on the above, it can be seen that this issue is complex and requires a detailed and comprehensive analysis of climate predictions.

One of the important activities of the occupational health and safety policy of each state, and the international community in general, is the strategic planning of the impact of climate change on occupational safety and health. Thus, the most relevant international organizations in this field, the International Labour Organization and European Union, address this issue (EU OSHA, 2021). In 2011, the ILO confirmed the presence of climate change and its increasingly large impacts on enterprises and workers, as well as economic and social development. Its most significant long-term impacts will be the increase in average temperatures, the alteration of rainfall patterns and rises in sea level. In the short-to-medium term, the most serious impacts are caused by erratic weather patterns and extreme events such as storms, floods and droughts (ILO, 2011). The European Union explains that in most regions the impacts of climate change on the world of work are negative, causing the disruption of businesses, destruction of workplaces and limitation of income opportunities. In low-income countries and communities it is possible to observe the negative consequences on income generation, employment and social security. Those who have done least to cause the problem seem to lose the most. Considering this issue, the Republic of Sebia addressed the impact of climate change on the occupational safety and health system in the Proposal Strategy on Safety and Health at Work in the Republic of Serbia with an Action Plan for its Implementation (2023-2027) (Ilić Petković, Stratijev, 2023).

CLIMATE CHANGE THREATS IN THE WORLD OF WORK

According to the ILO, nowadays 1.2 billion jobs or 40% of the global labor force are at risk due to environmental degradation. In the period from 2000 to 2015, 23 million working-life years were lost per year because of numerous environmental hazards, caused or exacerbated by human activity. The intensification of global warming will negatively affect infrastructure, business activity, jobs and income. It is a direct threat to the growth of real gross domestic product, labor productivity and working conditions. Nevertheless, addressing these challenges can be an opportunity to boost economies and improve the quality of working lives. ILO studies have shown that implementing the Paris Agreement on Climate Change could create a net gain of 18 million jobs by 2030 (ILO, 2023).

Climate change affects all regions of the world. Such threats include shifting weather patterns threatening food production and water availability, and rising sea levels increasing the risk of catastrophic flooding. There are three crucial aspects which integrate the relationship between climate change and the world of work (ILO, 2018). Climate change threatens the provision of vital services and endangers the jobs which depend on them. Jobs and decent working conditions depend on the mitigation of environmental hazards (e.g. extreme weather events and air pollution) and the maintenance of environmental stability (e.g. normal temperatures and precipitation patterns). Environment-related risks and hazards will mostly affect vulnerable groups of workers, such as women, children and people with disabilities.

Agriculture and forestry, which heavily depend on natural resources, will also be affected by the negative impacts of climate change. For example, fisheries will be impacted by ocean acidification and changing ocean temperatures. Also, natural disasters threaten to destroy critical infrastructure and take lives, thus disrupting energy and water providers, construction, transport and tourism. Consequently, this will increase the pressure on emergency services, healthcare system and other public services. Extreme weather events will also burden banking and insurance companies (ILO, 2023).

POSSIBLE IMPACTS OF CLIMATE CHANGE ON OCCUPATIONAL SAFETY AND HEALTH

Climate change can affect human health both directly and indirectly through the ecosystem and its negative effects can lead to a deterioration of working conditions and decent work. Climate change and environmental degradation also increase the risk of occupational injury, disease and death (Kiefer et al., 2016). Workers are frequently exposed to the risks that the general public can avoid, thus being exposed to the threats for longer durations and at greater intensities. There are numerous health conditions in workers which are associated with climate change, including cancer, cardiovascular disease and respiratory illnesses. Mental health will also be impacted (Charlson et al., 2021).

Apart from workers' well-being, their performance should be considered. Climate change can cause decreased productivity, increased costs of production, accidents and injuries, and absenteeism (Habibi et al., 2021).

Particularly vulnerable groups are workers in developing countries with a large informal sector workforce, inadequate OSH regulations and highly physical jobs. Occupational safety and health risks are also increased for migrant workers due to cultural and language barriers. They are least able to afford the consequences of climate change.

Sectors related to the sound management of chemicals are also affected by climate change. Many chemicals produced and utilized in the world of work can have impacts on the environment and climate, with climate change in turn affecting the ability to safely store, transport and use chemicals. There are seven key impacts of climate change on worker safety and health and the use of chemicals in the world of work. Those are heat stress, air pollution, ozone depletion, pests and pesticides, infertile soil and fertilizers, vector distribution and ecology and major industrial accidents (ILO, 2023).

Heat stress is heat received in excess of that which the body can tolerate without suffering physiological impairment. Heat stress becomes more common due to the rise in global temperatures. It affects the workers in all sectors, especially outdoor workers performing physically demanding jobs and indoor workers inside factories and workshops, where temperature is not regulated. Also workers in heavy clothes or protective equipment will suffer, for example, pesticide spreaders and firefighters. Heat stress can restrict workers' physical capabilities, work capacity and productivity (NIOSH, 2022).

Also, global warming is increased by different air pollutants and it leads to the formation of air pollutants. Higher temperatures can increase ground-level ozone or smog, and also particulate matter. Over 1.2 billion workers all over the world spend most of their working hours outdoors, which increases the risk of exposure to outdoor air pollution (WHO, 2018). Indoor workers are impacted by poor quality air in their work environments. The ILO data shows that air pollution causes numerous health problems, such as lung cancer, stroke, heart disease, asthma (Schulte et al., 2016).

Another major health concern is ozone depletion as it increases the amount of ultraviolet radiation that reaches Earth's surface. This is a particular problem for outdoor workers, who are at an increased risk of sunburn, keratinocyte cancers, melanoma, cataracts and pterygium. Outdoor construction workers, for example, can accumulate sufficient solar UV exposure over 30-40 years of work, to more than double their risk of non-melanoma skin cancer (Cherrie et al., 2021). Lifeguards, power utility workers, gardeners, postal workers and dock workers are other high-risk occupations.

Pesticides also contribute to climate change, both directly and indirectly. For example, fossil fuels are used in their production and transportation. Many different pesticides are classified as carcinogenic to humans and pesticide poisoning has accute effects (ILO, 2023).

In addition, fertilizer use and climate change are co-dependent. Increased precipitation due to climate change can cause soil erosion and decrease essential soil nutrients such as nitrogen and phosphorus, which are essential for plant growth. Loss of fertile soil can pressure agricultural workers to increase use of chemical fertilizers and other agrochemicals, impacting safety and health (ILO, 2023).

Vector-borne diseases are responsible for more than 17% of all infectious diseases and cause more than 700,000 deaths annually (WHO, 2020). Changing rainfall patterns, temperature and humidity can affect vector-borne disease transmission, by impacting the number and survival rate of vectors. For example, higher ambient temperatures are associated with expanded distribution of some vectors, such as mosquitoes, as well as increasing reproduction rate, biting behaviour and survival. Especially outdoor workers are susceptible to vector-borne diseases because they have the highest exposure to vectors such as mosquitoes, ticks and fleas, that can transmit parasites, viruses, or bacteria (Schulte et al., 2016). Sectors such as construction, landscaping, forestry, brush clearing, land surveying, farming, oil field and utility work, natural resources management and firefighting are at risk.

Serious industrial accidents can occur in major hazard installations, such as factories or extraction sites, which use one or more hazardous substances. They occur outside the norms of the operation and include fires, explosions and uncontrolled chemical releases. The severity of industrial accidents is increased by the impacts of climate change. For example, rising temperatures due to climate change can increase volatility of temperature-sensitive chemicals, which could lead to accidents (ILO, 2023).

EU-OSHA recognizes the link between extreme weather events and natural disasters such as floods, forest fires, heat waves, cyclones, and extreme anxiety reactions (EU, 2021). Climate change is one of the acute or chronic stressors that may cause severe mental health problems. Therefore, both direct and indirect effects of climate change on mental health are established. Those include mental distress, anxiety, mood disorders, stress, post-traumatic stress disorder, depression after acute events. Workers in a drought area may experience psychological stress from the weather in general as well as from the effects of heat exposure. When workers lose their homes and property in floods their ability to concentrate and perform their tasks can be reduced. Long periods of high temperatures, heat, and drought significantly affect communities and, consequently, workers' performance.

ACTIONS FOR PROTECTING THE SAFETY AND HEALTH OF WORKERS

After determining that climate change affects occupational safety and health in many different ways, it seems logical to ask what measures can be taken in order to protect occupational safety and health of workers. The answer to this question is very complex, because the effects of climate change are different and far-reaching, and do not affect all areas of work in the same way.

The ILO is very active regarding this issue. For example, information on international labor standards related to climate adaptation and mitigation policies can be found in the 2018 ILO document - The employment impact of climate change adaptation (ILO, 2018). Some possible measures are to integrate climate change issues as a component of occupational safety and health policy and practice. Adaptation measures should be integrated into policies, programmes and risk assessments at all levels. Another possible international measure could be to develop occupational exposure limits for proxy measures of climate change. Some countries have already adopted specific regulations to protect workers from heat exposure and ensuing heat stress. These include maximum temperatures to which workers may be exposed. There are currently no harmonized international standards for work in hot environments or other adverse weather conditions. Also, it is advised to introduce gender mainstreaming into occupational safety and health policy and practice. This should be done specifically in relation to climate change concerns. For example, some workplace consequences of climate change may affect the health of pregnant women. Finally, inspectors should be provided with the means, qualifications and training to fulfil their duties, especially those related to emerging risks due to climate change.

Considering EU-OSHA, there are numerous useful recommendations regarding the process of adjusting the occupational safety and health system to climate changes, which has been adopted in its regulations. Those regulations prescribe that occupational risks related to climate change should be addressed as an integral part of the risk management policy of each company, but businesses may not be sufficiently prepared, empowered, educated, concerned, or compelled to protect their employees from the health impacts of climate change. Workplace preparedness includes devoting resources to the recognition of hazarads, performing vulnerability assessments to determine the categories of workers vulnerable to climate change-related hazards, implementing a control strategy with policies, procedures, equipment, and work organization that eliminates or minimizes the impact of these hazards (EU OSHA, 2021). Emergency planning and business continuity measures in response to natural disasters, such as floods, are also included.

EU-OSHA addresses both organizational and individual measures (EU OSHA, 2021). Organizational measured incorporate adapting work schedules in order to reduce exposure to high ambient temperatures, reviewing working arrangements (e.g. temperature-dependent break times, guidelines for working from home), providing cool drinking water, providing sufficient breaks in a cool(ed) environment, promoting education and training. Individual measures are, for example, introducing smart monitoring of workers' conditions, such as hydration (water consumption) and body heat through the use of smart personal protective equipment, providing suitable clothing for hot weather/UV-radiation (lightweight clothing in light colours, wide-brimmed hat/helmet, sun barrier cream), providing personal protective equipment with cooling function (e.g. cooling vest, cooling cap), etc.

CONCLUSION

The effects of climate change can pose a threat to the progress towards decent work and lead to the deterioration of working conditions. It has the potential to generate new risks to the world of work and influence the use of hazardous chemicals. Several impacts of climate change on worker safety and healthy were identified, including heat stress, air pollution, ozone depletion, increases in pests and vector-borne diseases, soil infertility, and a higher risk of major industrial accidents. Numerous health conditions in workers have been associated with climate change, including cancers, cardiovascular disease and respiratory illnesses.

Emerging risks require priority actions, at both national and workplace levels. Climate change concerns should be integrated into occupational safety and health policy, programmes and profiles at all levels.

International labor standards, EU-OSHA activities, social dialogue and measures of each particular state play an important role in addressing the challenges associated with climate change. Comprehensive workplace programmes and strategies are essential for protecting workers. States, employers and employees should be involved in implementing these measures and activities.

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THE PRESENCE OF BTEX IN THE ENVIRONMENT AND RESULTING HEALTH RISKS

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Abstract: BTEX is a group of volatile organic compounds consisting of benzene, toluene, ethylbenzene and xylenes. The most important natural sources of BTEX compounds include crude oil, gas emissions from volcanoes and forest fires. The main anthropogenic sources include combustion of gasoline and diesel fuels, especially for motor vehicles, as well as emissions from gas stations and small-scale industries that use materials containing BTEX. In addition, benzene, toluene, ethylbenzene and xylenes are common additive to some chemical intermediates, consumer products (cosmetics, inks, paints and lacquers, thinners, rubber products, adhesives), and pharmaceutical products. The BTEX compounds are present in environmental samples like air, water, and soil, which intensity the risk of human exposure. After exposure to BTEX, a number of factors (the amount of BTEX, exposure time, exposure route, as well as the type of BTEX compound) determine possible harmful health effects. In spite of the fact that exposure to BTEX is usually a simultaneous exposure to all its constituents, the impacts on human health are better assessed by considering the individual impacts of each compound.

Keywords: *Benzene; Toluene; Ethylbenzene; Xylenes; Environment; Health Risks.*

INTRODUCTION

Nowadays, there are growing concerns about human exposure to different volatile organic compounds (VOCs). Some VOCs, benzene, toluene, ethylbenzene, and xylenes (BTEX) are of particular concern because of their carcinogenic, as well as and non-carcinogenic properties (CNS dysfunction and narcosis, reduction of red blood cells and aplastic anemia, CNS symptoms include headache, dizziness, fatigue, tremors, in-coordination, etc.). The BTEX compounds are widely present in the environment due to their physico-chemical properties (Table 1).

Table 1. Physio-chemical properties of BTEX

BTEX compound	Molecular weight (g mole^{-1})	Boiling point (°C)	Water solubility (mg L^{-1})	Vapor pressure (mmHg)

Benzene	78	80.1	1780	76
Toluene	92	110.8	535	22
Ethylbenzene	106	136.2.	152	7
o-Xylene	106	144.4	175	5
m-Xylene	106	139	135	6
p-Xylene	106	138.4	198	6.5

Comparing all the compounds from this group, benzene is expected to be the most easily evaporated owing to its low molecular weight, low boiling point and high vapour pressure (Leusch, 2010). Also, benzene is more soluble in water. As mentioned previously, due to their physical and chemical properties BTEX have significant dispersion capacity, and once they are released into the environment, they can volatilize, dissolve in water, or adsorbe to soil particles (Leusch, 2010). Because of the chemical structures and their easy volatilization, BTEX compounds can enter organisms through different routes: the most usual is inhalation, followed by dermal and, at a lower percentage, oral intake through polluted water or food. BTEX are slightly reactive compounds, consequently their toxicity is determined by their biotransformation (phase 1 and phase 2 of biotransformation). All BTEX chemicals can cause neurological impairment via parent compound-induced physical and chemical changes in nervous system membranes. Neurological symptoms including dizziness, headache, confusion, nausea/vomiting, fatigue/tiredness, drowsiness, less concentration/memory, stress/irritability, hand/foot tip numbness, arm/leg weakness, hand shaking, less sexual sensation, and no/less smelling, are the main symptoms associated with exposure to BTEX compounds (https://www.atsdr.cdc.gov). Furthermore, exposure to benzene can result in hematological effects, including aplastic anemia, with subsequent manifestation of acute myelogenous leukemia via the action of reactive metabolites (Spatari, 2021).

ENVIRONMENTAL IMPACT OF BTEX

Benzene, toluene, ethyl benzene and xylenes are significant air, groundwater, and soil pollutants, commonly related with petroleum and petrochemical production and use.

BTEX in atmosphere

BTEX are usually found in air emission of various sources such as refineries, petrochemical industries, storage tanks, chemical plants, vehicle exhaust, etc. (Duan, 2017). They are easily transported to the atmosphere due to the high vapor pressure. The levels of BTEX in air are caused by various factors, such as source type, distance from sources, ambient temperature, air diffusive condition, etc. Also, air pollutant concentrations can vary significantly between seasons (Zhang, 2012). The seasonality of BTEX compounds becomes more critical as, in some months, these compounds affect human health more than in others (Popitanu, 2021). In the atmosphere, BTEX compounds are degraded mainly by photolysis and/or chemical reactions with reactive species such as hydroxyl and nitrate radicals. The products of these reactions, free radicals (organic peroxy and hydroperoxy), favor the transformation of NO into NO_2, contributing to increased tropospheric ozone (Cerón Bretón, 2020). With regard to atmospheric chemistry, BTEX compounds can generate secondary pollutants, such as ozone and peroxyacetyl nitrate (PAN), as well as secondary organic aerosols (SOA) via gas-to-particle conversion processes (Dehghani, 2018). As one of the major environmental concerns, tropospheric ozone brings to numerous respiratory diseases (pneumonia, damaged lung tissues, and respiratory mucous membranes, chronic obstructive pulmonary disease). Long-term exposure to high concentrations of ozone, on the other hand, can cause significant crop yield losses (Nguyen, 2022). Fate and behaviour of BTEX pollutants, as well as formation of secondary air pollutants in the atmosphere depend on meteorological variables such as temperature, pressure, and humidity (Fiore, 2012). Temperature directly impacts ozone formation rates, reaction rates of ozone precursors, and mechanism pathways (Romer, 2018).

BTEX in water

As previously mentioned, BTEX compounds are present in significant amount in either gaseous or liquid media in the environment. As a result of oil spills and oil pipeline leakages, they are often detected in groundwater. Accordin to investigation, one of the most common sources for BTEX-contamination of groundwater are spills involving the release of petroleum products such as gasoline, diesel fuel and lubricating and heating oil from leaking oil tanks. Due to their polarity and solubility, the BTEX components of petroleum products will be able to enter the groundwater systems and cause serious pollution problems (Mitra, 2011). The chemical analysis of water (affter oil spills) in different regions of Brazil was performed (Meniconi, 2002). The study reported that the concentration and persistence of BTEX compounds was high, and directly proportional to the scale and duration of the oil spill. Additionally, other water sources (drinking water, and industrial effluents) have been investigated for the presence of BTEX compounds. In industrial effluents (mostly in the effluents of industries that utilize the BTEX compounds as solvents) they are definetely present (Arambarri, 2004). BTEX pollutants in concentrations that exceeded the permissible limit in drinking water, were detected in farmstead domestic wells, often used as drinking water sources (Goss,1998). Household products (garden pesticides, pharmaceuticals, paints, some detergents and personal care products) contain BTEX compounds, resulting in an increase in the concentration of these compounds in municipal waste streams. These compounds can dissolve in water and reach the surface water bodies, posing significant risks to water resource health, and subsequently human health.

BTEX in soil

Soil was considered as the most important pool of some semi- and non-volatile pollutants. Still, only small percentage of volatile pollutants, including BTEX, released into the environment were stored in soil. BTEX compounds can migrate quickly through soil, with benzene being the fastest followed by toluene, m-, p- and o-xylenes and ethylbenzene. BTEX contamination of soil is generally connected to petroleum leakages and fuel oil from underground storage tanks, production of solvent-based paints, lacquers, etc. BTEX compounds can pose a serious risk to soil due to their toxicity and water solubility (Duan, 2017). The persistence of BTEX compounds in soil, before leaching into groundwater or evaporation, depends on their sorption to soil particulates, which is determined by chemical and physical soil properties, and degradation activity of the native soil microorganisms.

HEALTH EFFECTS OF BTEX

Exposure to these c BTEX compounds may have considerable impact on human health. Table 2 summarize the acute and chronic effects of BTEX in humans. The International Agency for Research on Cancer (IARC) has classified benzene as “carcinogenic to humans” (Group 1) based on sufficient evidence that this compound causes acute myeloid leukemia. Toluene, as well as xylenes have been classified within Group 3 (not classifiable as to its carcinogenicity to humans), while ethylbenzene has been classified within Group 2B (possibly carcinogenic to humans). It is important to note that BTEX compounds also form secondary air pollutants (ozone, peroxyacetyl nitrate (PAN), and ultra-fine particulate matter) that contribute to ill health in humans (Alghamdi, 2014; Masih, 2017; Zheng, 2018; Zhang, 2019).

Table 2. The acute and chronic effects of BTEX in humans (Source: Anigilaje 2024)

Chemical	Routes of exposure	Acute	Chronic	IARC carcinogenicity class

Benzene	Inhalation, ingestion, skin, and eye contact.	Symptoms include drowsiness, dizziness, headaches, skin irritation, respiratory tract, unconsciousness.	Reduced red blood cells. Aplastic anemia. Reproductive function in women.	Group 1: Carcinogenic to humans.
Toluene	Primarily absorbed through inhalation and ingestion.	CNS dysfunction and narcosis, fatigue, sleepiness, headaches, and nausea.	CNS depression. Irritation of the upper respiratory tract and eyes, sore throat, dizziness, and headache. Newborns of pregnant women: problems with attention and mild abnormalities of the head, face, and limbs.	Group 3: Not classifiable as to its carcinogenicity to humans.
Ethylbenzene	Inhalation, ingestion, skin, and eye contact.	Low acute toxicity to humans. Irritation of the eyes and	An increase in the mean number of lymphocytes and a decrease in hemoglobin levels	Group 2B: Possibly carcinogenic to humans.

		throat, chest tightness, dizziness, vertigo.		
Xylene	Inhalation, ingestion, skin, and eye contact.	Irritation of the eyes, nose, and throat, vomiting and diarrhea, and neurological effects	CNS symptoms: headache, dizziness, fatigue, tremors, in-coordination. Affect the respiratory, cardiovascular, and renal systems.	Group 3: Not classifiable as to its carcinogenicity to humans.

CONCLUSION

Benzene, toluene, ethyl benzene and xylenes are ubiquitous air, groundwater, and soil pollutants, commonly related with petroleum and petrochemical production. Also, BTEX concentrations in the general environment are closely related to the human activities, such as combustion of gasoline and diesel fuels, especially for motor vehicles, as well as emissions from gas stations and small-scale industries that use materials containing BTEX. Due to the toxicity, stability, and cumulative properties of these compounds, they can have serious consequences on the environment and human health. For these reasons, continuous monitoring and evaluation of the health risk caused by them are one of the important health issues that should be considered.

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RISK ASSESSMENT IN THE CONSTRUCTION SECTOR IN NORTH MACEDONIA

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Abstract: The concept of risk assessment includes systematic recording of accident data, definition of risk factors used in the risk calculation, and determination of possibilities to prevent risk or reduce it to an acceptable level. The findings presented in this paper are the result of risk assessments conducted in 12 small or medium-sized construction companies (with an average of 20-35 employees) in North Macedonia, where the number of high risks and their share in the total number of risks was analyzed. The largest number of identified high risks (48.28%) refer to injuries due to inappropriate characteristics of the workplace and the working environment. This emphasizes that special attention should be paid to the stability and safety of the terrain, especially in work at height, in depth, scaffolding, suspended platform, excavation or demolition. In addition, the importance of collective and individual measures for protection at work, and the mandatory use of personal protective equipment (PPE) in reducing or eliminating high risks, must be emphasized.

Keywords: *Construction, Risk assessment, Occupational safety and health (OSH)*

INTRODUCTION

The importance of safety workplace and working environment is a crucial factor in an individual's quality of life and in public health at the collective level. Improvement of employees' safety, should be the primary goal in every country. Unfortunately, unsafe and unhealthy working conditions still cause severe human and economic loss, even in the 21st century. Social and cultural development, economic growth, national income, health and safety expenditures, and unemployment are important factors in causing occupational accidents. According to various methodological proposals in the scientific literature (Persechino et al., 2013), risk assessment tools enable companies to comply with the law but also to contribute to better data analysis and comparisons. Risk assessment practice is based on the fundamental Occupational Safety and Health (OSH) Act which lays down general principles concerning the prevention and protection of workers against occupational accidents and diseases (ESAW, 2013). In terms of injuries and endangering the employee's health, according to all statistics on a global scale, the construction industry is among the most hazardous industries (Mahmoudi, 2014). The specificity in this sector requires organization and implementation of specific protection, due to work activities of many contractors with presence of a large number of employees from different profiles and expertise which are usually performed. Especially investigating of potential fall hazards unknowingly built into the construction schedule, as well as identifying and eliminating them early in the planning phase of a construction project is of particular importance to resolving safety issues (Zhang, 2015). On the base of national datasets in the U.S. construction industry analyzed by Dong (Dong, 2013) over an 18-year period (1992-2009), fatal falls from roofs accounted for one-third of fatal falls in the construction sector and disproportionately 67% of deaths from roof falls occurred in small construction establishments (1-10 employees). In this direction, the data from the top 100 construction companies in South Korea show that the accident rate decreased by 67% and the fatal accident rate decreased by 10.3% during the period from 2006 to 2011, which clearly emphasizes the primary role of effective OSH management system implementation (Yoon, 2013). Unexpectedly high incidence rates of deaths, injuries and accidents at work especially in the same sector are revealed in the available data in both, for EU member countries and other non–EU countries in Europe (Amponsah-Tawia, 2016). In North Macedonia, most of all accidents, 22 or 20.37 % out of a total of 108 injuries, that had happened in 2023 (MOSHA, 2023), were in the construction sector.

EXPERIMENTAL

Risk assessment concept which involves a systematic recording, evaluation of risk factors that can cause injury, illness or occupational disease, and identifying possibilities to prevent, reduce, or completely eliminate the risks (Lutovska, 2018), lays down the following principles:

- avoiding risks,
- assessing the remaining risk that cannot be avoided,
- elimination the risk source through the implementation of modern technical solutions,
- adjustment of workplaces by selecting an appropriate technological process, avoiding the work monotony in order to reduce the negative effects on the employees' health,
- choosing of preventive measures and replacing the hazardous technological processes or methods with harmless or less dangerous,
- giving priority to collective over individual safety measures,
- conduct training for employees (general and specific for each workplace) and preparation of safe work guidelines.

Considering that risk assessment is a fundamental step that should consider all potential risks in the risk management process, it must be conducted for every workplace. Due to the demand of a systematic and continuous evaluation, all phases of risk assessment (planning, hazard identification, defining of risk, assessing risks, proposing preventive measures, communication and follow-up the feedback) are equally important (Anttonen, 2010). In addition, some important data needed for conducting of assessment are listed:

- the description and characteristics of the work activities,
- the number, gender, age and level of education of each employee exposed to the risks,
- organization of work in shifts,
- the number and nature of injuries that had previously occurred at the workplace,
- specific working conditions

Majority of deaths that occurred especially on projects undertaken by small or medium-sized enterprises are a result of insufficient implementation of appropriate safety rules or management procedures, as well as lack of training for the employees to carry out these practices. Thus, as the main objective of this study, workplace risk assessments in 12 small or medium-sized construction companies (20-35 employees on average) in North Macedonia were made. The risk assessment activities were carried out by an authorized institution, using a PILZ method and a licensed software package LatiPRO for recording, processing and analyzing the data from terrain work. The estimated risk value is obtained by multiplying the appropriate parameters:

Table 1. Risk rating of total calculated risk

Severity of potential injury (TP)	Frequency of exposure (ZI)	Probability of injury (VP)	Number of exposed people (BL)	**RISK** TPxZIxVPxBL
(0.1÷15)	(0.5÷5)	(0.33÷10)	(1÷12)	**Total**
Estimated risk:				**Risk rating**

TP - severity of potential injury, obtained on a 7-level scale ranging from 1 (scratches) to 7 (fatal injuries)

ZI - frequency of exposure to dangers, obtained on a 6-level scale ranging from 1 (once a year) to 6 (continuously)

VP - probability of injury, obtained on a 7-level scale ranging from 1 (almost impossible to happen, only under exceptional circumstances) to 7 (sure to happen, there is no doubt)

BL - number of exposed people, obtained on a 5-level scale ranging from 1 (1÷2) to 5, (> 50).

The total value of the estimated risk is obtained as a product (multiplication) of the values of previously defined parameters, and is categorized according to the values (Geramitcioski et al., 2015) shown in Table 2:

Table 2. Risk rating of total calculated risk

Risk category **RISK = TP × ZI × VP × BL**				
Negligible Risk	Low Risk	Moderate Risk	High Risk	Unacceptable Risk
0÷5	6÷50	51÷250	251÷500	> 500

Conducting a risk assessment is an obligatory duty of each employer. In accordance with the national Law on OSH (Official Gazette R.M. No.92/2007), every employer is obligated to identify the hazards and risk factors related to work or working conditions, eliminate or reduce them, and assess the effects of the remaining risks, in order to ensure a successful and profitable business. Due to the extensiveness of the risk assessment conducted in the construction sector in North Macedonia, only the identified high risks are shown (Table 3).

Table 3. High-risk hazards from risk assessment in construction sector in North Macedonia

Hazards classification	**Determined hazard or danger**	**Total Risk**
Mechanical hazards due to use of work equipment (free movement of parts or materials	Mechanical hazards that may occur due to the use of construction machinery at the construction site	**400**
	Materials, equipment and elements that are not properly fixed may affect the safety and health of employees	**400**

that may cause injury to the employee)	Dangers of falling objects due to non-coverage of passages or free access of employees to dangerous zones		**400**
	Mechanical hazards of injuries that may occur due to falling of parts and materials that are transported by a hoist machinery		**400**
	Mechanical hazards due to scaffolding	Mechanical injuries due to incorrect installation and use of the scaffold	**400**
Hazards related to workplace characteristics- slipping, stumbling, losing balance, falling	Movement on the rugged, damaged, moldy or slippery floor, i.e. there are damaged surfaces, holes, mugs or cracks, movement on a wet floor or roof		**400**
	Dangers arising from work at height	Dangers due to inadequate measures to prevent the fall of workers and objects from the height	**400**
		Falling from a scaffold due to surfaces by width smaller than a minimum of 80 cm	**400**
	Falling objects due to non-use appropriate personal protection equipment	Injuries due to non-use of appropriate personal protection equipment at work (shoes, helmets, etc.)	**400**
		Danger of falling due to non- use of safety belts for work at height	**400**
	Dangers of work in excavated trenches	Hazards due to falling persons or objects during excavations, underground works, earthworks, work in wells or tunnels because of non-use of supporting constructions or embankments	**400**
		Hazards of flooding or falling persons or objects into mud during excavations, underground works, earthworks, work in wells or tunnels	**400**

	Dangers of work at unstable workplaces at height or depth	Work at height or depth on movable or fixed platforms that are not properly attached and unstable poses danger to employees	**400**
		Possibility of injuries due to the operation of a platform that is not appropriate for the number of employees that perform work on the platform	**400**
		Danger due to work on a platform that is not properly designed to withstand the maximum load	**400**
		Physical instability at the workplace – instability of the supporting construction of the work surface and possibility of accidental or unintended displacement of the entire construction or its individual parts	**400**
	Dangers from demolition works	Dangers of trapping people due to the failure to apply precautionary measures during demolition	**400**
	Dangers of roof works	Danger of working on roofs where height or slope exceeds construction norms	**400**
		Danger of collapse during working on a roof surface made of brittle material	**400**
Hazards from electricity supply installations	There are no measures to protect of dangers due to the presence of buried or overhead high-voltage electrical lines		**400**
	The overhead high-voltage electrical lines are not disconnected from the electrical supply or diverted outside the mobile construction site		**400**

Harmfulness that occurs during the working process (chemical, physical, biological)	The workplace is exposed to an increased dust concentration, concrete particles, cement, earth, gases or vapors	**400**
	Exposure to a toxic substance's atmosphere, harmful or flammable substances, i.e. presence of high-risk atmosphere with insufficient oxygen level	**400**
	Harmfulness due to exposure to external elements - sun, rain, snow, wind, low or high temperatures	**400**
Damages from physical and psychophysiological efforts	Manual transport of load during most of the working hours. An uncomfortable working position during manual lifting of load - away from the body, above the shoulder's height or under the height of the knees	**400**
Other hazards	There are no first aid places on the construction site	**400**
	Construction site is not enclosed and no measures are taken to protect the citizens passing the construction site	**400**
	There are dangerous zones with prohibited access for unauthorized employed persons, and they are not adequately enclosed and visibly marked	**400**
	Hazards arising from insufficiency of fire detectors and fire protection equipment in a case of fire at the construction site	**400**

RESULTS AND DISCUSSION

Out of a total of 65 risks (low, moderate and high risks) identified in the complete risk assessment for the workplace: construction worker at a mobile construction site, 29 or 44.62% are high risks, and appropriate measures for their reduction or possible complete elimination, should be taken immediately. These high risks refer to (Figure 1):

- 17.24% - mechanical hazards and injuries arising from use of work equipment (mechanical hazards due to use of the construction machinery), and free movement of parts or materials (non-fixed equipment elements or falling objects) that may cause injury to the employee,

- 6.90% - hazards from electricity supply installations (presence of buried or overhead high-voltage electrical lines),
- 10.34% - physical (exposure to external climate impacts), chemical (dust concentration, concrete particles, cement, earth, gases or vapors) or biological harmfulness,
- 3.45% - damages from psychical and physiological efforts (manual handling of loads),
- 13.79% - other hazards (lack of marked and enclosed hazardous zones, first aid equipment, fire protection), and
- even 48.28%, or the largest number of risks are related to injuries due to the workplace and work environment characteristics (slipping, stumbling and falling).

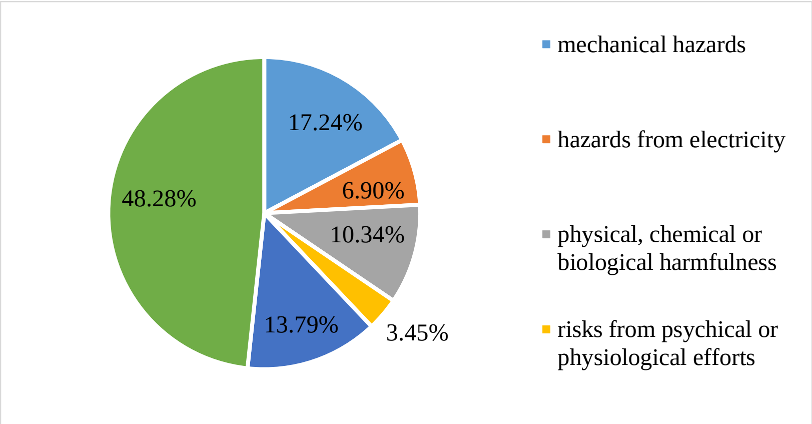

Figure 1. Analysis of high-risks share in risk assessment for the construction sector

Risk management in the construction project is a systematic process conducted with the purpose of identifying, analyzing and controlling the residual risk in achieving the project goals (Adeleke et al., 2017). This study aims to identify the number of high risks during works at the construction site and to determine their participation in the narrower areas of the construction worker risk assessment.

CONCLUSIONS

Risk assessment data, obtained from the various construction companies involved in the study, gives an identical result in most of the cases. The conducted analysis indicates the presence of even 29 or 44.62% high risks out of a total of 65 risks identified in the complete risk assessment for a construction worker at a mobile site. Given the fact that the largest number or 14 out of 29 (48.28%) of these high risks, are related to injuries due to the workplace and working environment characteristics, special attention should be paid to the terrain stability and safety of the workplace, especially at work at a height (scaffolding or work at a platform), in depth (work in a trench), in confined space (shafts, trenches, placement of reinforcement, drainage works, cable installation works, etc.), excavation or demolition work. All of the indicators lead to a single conclusion that construction in North Macedonia is a high-risk sector.

Identified hazards primarily occurred due to both insufficient individual and collective employee's protection during terrain work, as well as the low level of OSH education and awareness among employees. Thus, measures for reduction of the high risks to an acceptable level, or possible complete elimination should be taken immediately. Leading indicators of safety performance as measures of the safety process applied to the construction work, consist of both: passive measures, which can be predictive over an extended period of time and active measures, which can initiate corrective steps in a short period of time. Since it is impossible to completely remove all risks in construction projects, the use of professional personal protective equipment (especially safety belt for work at height, protective construction helmet and professional metal cap shoes) is of particular importance.

Modern economies require a critical examination of OSH costs and a balance with the responsibilities of employers to manage the risks they create, simultaneously considering their existing motivation to ensure efficient, successful and profitable business. It is estimated that well planned and systematically carried out OSH measures, deliver economic returns 3-10 times greater than the monetary investment.

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ADVANTAGES OF SIMULTANEOUS INTRODUCTION OF ISO 45001 AND ISO 14001 STANDARDS - COMMON REQUIREMENTS

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Abstract: This paper explores the significant advantages and synergies gained through the concurrent implementation of ISO 45001, focusing on Occupational Health and Safety (OHS), and ISO 14001, cantered on Environmental Management System (EMS). The study emphasizes the common requirements shared by these standards, presenting a strategic approach to integrated management systems. It provides an overview of the requirements of individual points within the standard. Through an in-depth analysis, it elucidates how organizations can streamline efforts, optimize resources, enhance sustainability, and fortify their commitment to employee well-being and environmental protection. The paper highlights the strategic advantages that arise from aligning OHS and EMS within a unified framework, ultimately fostering a more comprehensive and efficient organizational management approach.

Keywords: *ISO 45001; ISO 14001, Standard requirements.*

INTRODUCTION

Occupational Health and Safety Management System - ISO 45001 is an international standard that specifies the requirements for an occupational health and safety management system (OH&SMS). The purpose of this standard is to provide organizations with a framework to proactively improve occupational health and safety performance, prevent work-related injuries and illnesses, and create a safe and healthy workplace. ISO 45001 has gained significant attraction globally since its release in March 2018. Many organizations around the world have recognized the importance of ensuring a safe and healthy work environment for their employees and have adopted or are in the process of implementing ISO 45001 (Perović and Todorović, 2023). In Serbia, the adoption of ISO 45001 has been part of a broader global trend towards enhancing occupational health and safety standards. Many companies, especially those aiming to compete in international markets, have shown interest in aligning with ISO 45001 to demonstrate their commitment to providing a safe working environment for their employees. The adoption of ISO standards is encouraged with the aim of improving workplace safety and ensuring compliance with international norms.

Environmental Management System - ISO 14001 is an international standard that specifies the requirements for an environmental management system (EMS). It provides a framework for organizations to manage and continually improve their environmental performance, considering aspects like resource usage, waste management, and carbon footprint (Perović et al., 2023). ISO 14001 is one of the most widely adopted ISO standards globally. It's utilized by a broad range of organizations, including manufacturing industries, service providers, government agencies, and more. The global adoption of ISO 14001 reflects a growing awareness and commitment to sustainable and environmentally responsible practices. In Serbia, environmental concerns and sustainability have gained prominence in recent years. Organizations in various sectors have been looking to align their practices with ISO 14001 to demonstrate their dedication to environmental responsibility and meet regulatory requirements. This includes efforts to reduce environmental impact, improve resource efficiency, and engage stakeholders in sustainable practices. The adoption of ISO 14001 in Serbia is influenced by factors such as international trade requirements, corporate social responsibility initiatives, and regulatory frameworks aimed at promoting sustainable development.

Considering the ISO introduction in company businesses is not mandatory, but highly recommended and desirable, the aim of the presented research is indicating and highlighting the common requirements of these two standards, facilitating the process of simultaneously introducing these standards into company operations.

MATERIALS AND METHODS

Within this part of the research the concise overview of the clauses' requirements for both standards are presented. Annex SL is a framework that provides a common structure and core text for the development of management system standards. It enhances the consistency and alignment among various ISO management system standards. The purpose of Annex SL is to ensure that different ISO management system standards have a similar high-level structure, terminology, and core requirements. Annex SL establishes a common structure with ten clauses for management system standards, making it easier for organizations to align their management systems regardless of the specific standard. The core text in Annex SL provides fundamental requirements that are consistent across all ISO management system standards. This includes sections on context, leadership, planning, support, operation, performance evaluation, and improvement. It promotes the use of consistent terminology and definitions across different ISO standards, ensuring clarity and ease of understanding. By following Annex SL, organizations can more effectively integrate multiple management systems, into a cohesive and efficient integrated management system (IMS). With this structure, the standard is formed adhering the plan-do-check-act cycle. Due to their similar structure, it is simple to compare the two standards side by side and see their differences.

ISO 14001 and ISO 45001 certification demonstrates the commitment to environmental sustainability and occupational health and safety, ensuring a safer workplace and a reduced environmental impact. There are 10 standard clauses that both standards contain. The standard requirements are listed from the fourth to tenth clause.

Briefly presented the fourth Clause present the Context of the organization. The context includes defining influences of various factors on the organization and how they impact the EMS and the ability to achieve the intended outcomes of the OH&S management. It encompasses understanding the needs and expectations of interested parties, defining the scope, and establishing of the EMS and OH&S management system.

The fifth Clause refers to the responsibilities and obligations of management, covering defining of the Policy. The Policy would, for both standards, among other, include commitment to provide safe and healthy working conditions, considering the environmental impacts of its activities, setting the framework for defining of EMS and OH&S objectives, commitment to fulfil legal requirements. The first difference between these two standards is in Clause 5.4 Consulting and participation of workers, at all applicable levels and functions and workers representatives in the OH&S management.

Within the Clause six Planning is defined. Within this Clause the risks and opportunities, and environmental objectives must be considered, identified, and assessed. The planning to achieve objectives must be defined. The determination of legal and other requirements is also an integral part of the Clause 6. The second difference between these two standards is that within the Clause 6.1.2, of ISO14001, the recognition, identification, and evaluation of the environmental aspects is required.

The Clause seven present Support covering: resources, competence, awareness, communication, and documented information within organization.

The Clause eight – Operation, probably presents the most extensive Clause of these standards. It encompasses operational planning and control and emergency preparedness and response. Especially in ISO 45001 the emphasis is placed on measures to eliminate hazard and reduce OH&S risks, management of change, and procurement.

The Clause nine - Performance evaluation considers monitoring, measurement, analysis, and evaluation of its environmental performance and identified hazards, risks and opportunities, effectiveness of operational and other control. The important part of this Clause is Internal audit (Clause 9.2). which ensures each requirement of the standard is implemented and maintained within the occupational health & safety management system and environmental management system and includes the ability for the company to add additional questions to suit additional company needs. The Management review (Clause 9.3) considers that top management shall review the organizations environmental and OH&S management system, at planned intervals, ensuring its continuing suitability, adequacy, and effectiveness.

The last tenth Clause – Improvement indicates that organization determines its opportunities for improvement and implement needed steps to accomplish the planned outcomes of its OH&S and EMS management system. The requirements for ongoing improvement in the OH&S and EMS management systems involve recognising nonconformities and taking corrective action to prevent them from recurring repeatedly by removing the underlying cause of the nonconformity.

With the aim of facilitating the simultaneous adoption of these two standards and providing a useful tool for their concurrent implementation, which would demonstrate their common requirements and differences, this research was conducted.

RESULTS AND DISCUSSION

In addition to previously stated common format, many of the processes included are the same for all management systems. For processes such as internal audit, determining interested parties, competence and awareness, control of documented information or management review, there is a common way of performing these activities. Both standards require identification, analyses, and assess the risks of processes. For the EMS, this refers to the aspects of the processes (how it interacts with the environment) and the impacts on the environment. For the OH&S, this refers to the OH&S risks of the process and the hazards they pose to workers. Both standards include requirements to determine what are the legal requirements for either the OH&S or EMS and remain updated of changes. This can be achieved through common format for review and recording, while also providing compliance with these legal obligations. The OH&S or EMS requirements comparison is presented in Figure 1. The common requirements are marked as cross-section listed below with arrow, while the differences are listed within the ellipses (orange - ISO 45001 and green - ISO 14001).

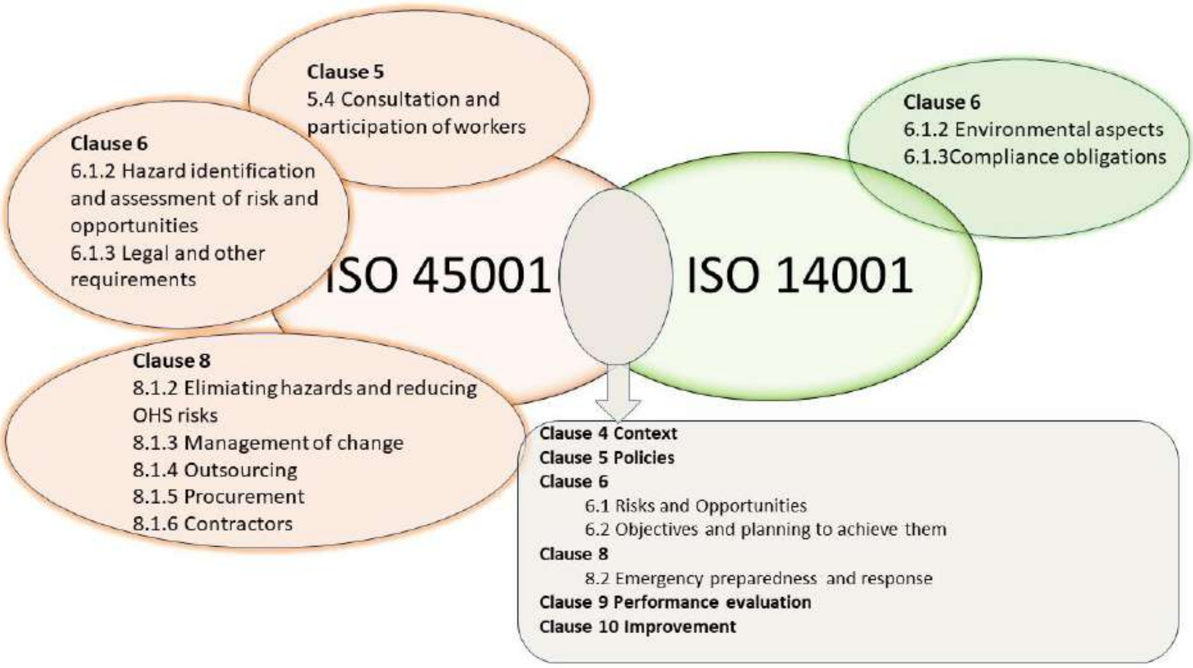

Figure 1. The differences between the ISO 45001 and ISO 14001 requirements and the common requirements

The good example of the cross-section between EMS and OHS is an emergency simulation exercise. During this exercise, a company can simulate various emergency scenarios that could impact both the environment and the safety of its employees. Within the environmental aspect the simulation could involve a mock scenario where a hazardous chemical spill occurs within the facility. This addresses an environmental aspect as it assesses how the organization responds to mitigate the environmental impact, containment measures, and proper disposal of the hazardous materials to prevent pollution.

Within the Occupational Health and Safety aspect, simultaneously, the scenario considers the safety of employees. It tests the company's emergency response procedures, evacuation protocols, provision of safety gear, training effectiveness, and the efficiency of communication and coordination among employees to ensure their well-being during the incident. By combining these aspects, the exercise helps the organization assess its preparedness and response capabilities holistically, aiming for a well-coordinated and effective response that safeguards both the environment and the health and safety of its workforce.

If a fire scenario is an emergency exercise, the environmental aspect assesses how the organization handles a fire incident concerning environmental concerns. This includes evaluating the potential environmental impact of the fire, such as air and water pollution due to the burning of materials, and devising strategies to minimize or prevent environmental damage. Proper containment measures, safe handling of firefighting agents, and minimizing runoff that could contaminate nearby water sources are key considerations. Occupational Health and Safety aspect primarily tests the safety of employees in the event of a fire. It evaluates evacuation procedures, fire safety training, availability and functionality of firefighting equipment, emergency communication, safe routes for evacuation, and overall preparedness to protect employees from harm and potential health hazards associated with fire and smoke inhalation. This simulation exercise serves as a comprehensive evaluation of the organization's readiness to address fires, ensuring that the response not only protects the environment but also prioritizes the health and safety of the workforce. It allows for the integration and alignment of EMS and OHS strategies to achieve a more effective and coordinated emergency response.

CONCLUSION

The common concepts for ISO 45001 and ISO14001 standards are: common format, common management system processes, risk management and focus on legal requirements. The differences could be summarized as distinctive ISO 45001 requirements, focusing on those affected most directly by activities to improve occupational health & safety in the workplace. These can be summarized as focus on workers participation, incident inclusion in the process for taking corrective action, focus on hazard elimination and risk minimization, and requirements for procurement. Several sections of the ISO 45001 standard include requirements to include workers in the creation and functioning of the OHSMS. This includes consultation of workers when determining the processes that need to be included in the implementation of the OHSMS, and worker participation in the running of the OHSMS after it is implemented. The ISO 45001 standard specifies the requirement for corrective action when an OH&S incident happens at work to prevent repetition and protect workers in the future, while all management system standards provide a mechanism for taking corrective action when a process has some nonconformities. Working to obtain elimination of risks in the organisation is one of the ISO 45001 operation requirements. The OH&S risks reduction makes the workplace safer by attempting to eliminate hazards. The procedure of procurement (ISO 45001) enables that any goods or services obtained from contractors or through outsourcing must adhere to OH&S Management System procedures. As a result, a threat of a contractor working on company's property using the different safety procedures from the ones accepted as adequate, will be minimized. Distinctive requirements exclusive to the ISO 14001 standard encompass determination and recognition of environmental aspects, alongside specific compliance obligations.

ISO 14001 places a strong emphasis on environmental performance improvement and sustainability. It mandates proactive measures for pollution prevention, resource conservation, and waste management. Additionally, the standard prioritizes stakeholder engagement, requiring organizations to consider the interests and concerns of relevant parties in their environmental management practices.

Furthermore, ISO 14001 promotes a lifecycle approach to environmental management, encouraging organizations to consider the environmental impacts of their products and services from design and development through to end-of-life disposal. It also emphasizes the importance of continuous improvement, requiring organizations to regularly monitor and review their environmental performance and take corrective action as necessary.

When integrating diverse management systems, the synergy without doubling costs can be achieved. Commonalities between systems allow joint processes, saving time and money while reaping the benefits of both. This approach enhances continual improvement from dual perspectives without doubling expenses, offering the organization added value and efficiency.

ACKNOWLEDGMENT

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PERMIT TO WORK SYSTEM FOR HIGH-RISK OPERATIONS

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Abstract: The system for issuing work permits, as an integral part of the occupational health and safety system, is one of the elements for enhancing risk management in high-risk activities. Permit issuance is a systematic process for approving specific controlled work in potentially hazardous conditions to prevent workplace injuries. The new legal regulation emphasizes the issuance of permits before commencing work at heights, in depth, in confined spaces, in potentially explosive atmospheres, on energy facilities, when using hazardous chemical substances, working in areas where there is a serious, unavoidable, or immediate danger or harm that may endanger the health of employees and contractors. Since the employer is required to establish the permit issuance procedure, the subject of work is the procedure for implementing the system for issuing work permits for high-risk operations.

Keywords: *permit to work; high-risk operations; occupational health and safety system*

INTRODUCTION

In accordance with the provisions of the Occupational Health and Safety Act, it is stipulated that employees should be provided with work in workplaces and environments where safety and health measures have been implemented. The occupational health and safety system entails the interaction of various factors such as legislation, inspection, insurance, education, technical knowledge, occupational medicine services, information dissemination, scientific research, and others. In this regard, the national legislature has introduced a legal obligation for issuing work permits for high-risk activities in the new edition of the Occupational Health and Safety Act.

In the literature, various guidelines and regulations have been established for the effective implementation of permit to work systems. These regulations and guidelines are primarily applied in the United States, the United Kingdom, and Australia. HSG250 Guide to Permit to Work Systems for the Oil, Gas, and Petrochemical Industries was developed by occupational health and safety experts in the United Kingdom and provides general guidelines primarily for the oil industry. In this guide, high-risk activities such as hot work, cold work, confined space entry, working at height, and electrical work are recognized (HSG250). On the other hand, the work permit system in Australia has been heavily influenced by the mining industry, which was also the case in the Republic of Serbia until the adoption of the new Occupational Health and

Safety Act. In neighboring countries, there is a practice of issuing work permits in Slovenia and Croatia due to their alignment with EU regulations and examples of good practice.

The work permit system is a formal written document adopted to control specific types of work identified as potentially hazardous (Mehdi, 2016). Additionally, the work permit system serves as an effective means of communication between managers, occupational health and safety advisors/partners, and employees performing hazardous work activities (Enya, 2016). The work permit system also defines the safety measures that need to be taken for a characteristic hazardous activity. Furthermore, it represents an essential part of the occupational health and safety system as it allows work to commence only after safe procedures have been defined (Lliffe, 2002). The work permit involves both the issuer (occupational health and safety advisor/partner) and the recipient (employee). Therefore, both parties must agree on conditions and preparations before work commences. The permit defines safety procedures that must be followed to ensure safe work (Lliffe, 2002). The objectives and purpose of the work permit system are to properly assess hazards and risks associated with any high-risk activity, ensure the implementation of protective measures, and enhance communication among all stakeholders (Andy, 2012). To achieve the best results from implementing the work permit system, it should be easily adaptable to the circumstances of performing high-risk activities and the individual needs of employees (Enya, 2016). Accordingly, the aim of this work is to outline the procedure for issuing permits for high-risk work activities.

PURPOSE AND RESPONSIBILITY FOR IMPLEMENTING PERMITS TO WORK

The employer is obligated to ensure the issuance of work permits before commencing work at heights, in depths, operating vehicles for internal transport, in confined spaces, in areas with potentially explosive atmospheres, at energy facilities, when using hazardous chemicals, and when working in zones where there is a serious, unavoidable, or immediate danger or harm that could endanger the health of employees.

The basic characteristics of the work permit system are:

- Clear identification of who can be authorized to perform high-risk tasks and who is responsible for defining necessary safety and health measures at work.
- Instructions for using the permit.
- Monitoring and review to ensure that the permit issuance system fulfills its intended role.
- Identification of the types of tasks considered potentially hazardous.
- Identification of responsibilities for implementing controls for applied safety and health measures (HSG250).

For consistent implementation of this procedure, the employer and the occupational health and safety advisor/partner are responsible. Their specific responsibilities include:

- Ensure the development and implementation of the work permit system.
- Ensure clear roles and responsibilities are identified for all employees involved in the work permit system.
- Appoint a competent authority to oversee the work permit system.
- Ensure that employees are familiar with the work permit system.
- Ensure that information in the work permit is explained in a language understood by the employees.
- Monitor the work permit system to ensure it is effective and properly implemented.
- Provide resources to enable the proper application and control of the work permit system (OSHJ-GL-16).

On the other hand, the occupational health and safety system requires employees and contractors to adhere to work and safety procedures. Accordingly, the responsibilities of employees and contractors are:

- Perform work activities without endangering oneself or others.
- Adhere to safety measures to ensure that work activities are carried out safely and without risk to health.
- Collaborate with the responsible person for occupational health and safety regarding adherence to procedures and instructions, supervision, and training.
- Report any activity or deficiency related to the use of the work permit that may jeopardize the safety of employees. (OSHJ-GL-16).

PROCESS OF ISSUING PERMITS TO WORK

The purpose of a work permit is to provide an appropriate control system for identified hazards and risks that arise during the performance of high-risk work activities. Additionally, it serves as a means of communication between responsible parties and employees, ensuring control over the safe execution of high-risk activities and creating conditions for employees to clearly understand the measures necessary to prevent unwanted events before, during, and after the performance of high-risk work activities.

Issuance of work permits

Depending on the duration of exposure to hazards and risks that arise during the performance of high-risk work activities, a work permit may be issued:

- for one working day (one shift/maximum 12 hours), with the possibility of extension if there have been no changes in the conditions that existed at the time of issuance;
- for one month (for less frequent high-risk work activities);
- for one year (for more frequent high-risk work activities - after undergoing periodic medical examination and practical and theoretical training for occupational health and safety).

If it is necessary to extend the duration of the issued work permit beyond the prescribed period, the issuer of the work permit must, upon completion of the job, inspect the workplace and ensure that the work environment is left in a tidy and safe condition. The work permit can only be extended if there have been no changes in the conditions that existed at the time of issuance.

A change in conditions involves a change in identified hazards and risks and the defined measures at the time of issuing the permit, or a change in the way the activity is performed, the tools and equipment used, the work environment (e.g., presence of other contractors, work equipment, etc.), materials used, weather conditions, etc.

The issuer of the work permit must conduct an inspection of the work area before the commencement of work and approval for the permit extension. They need to verify compliance with the prescribed conditions. Only after this inspection, and if all prescribed conditions are met, can the issuer extend the permit.

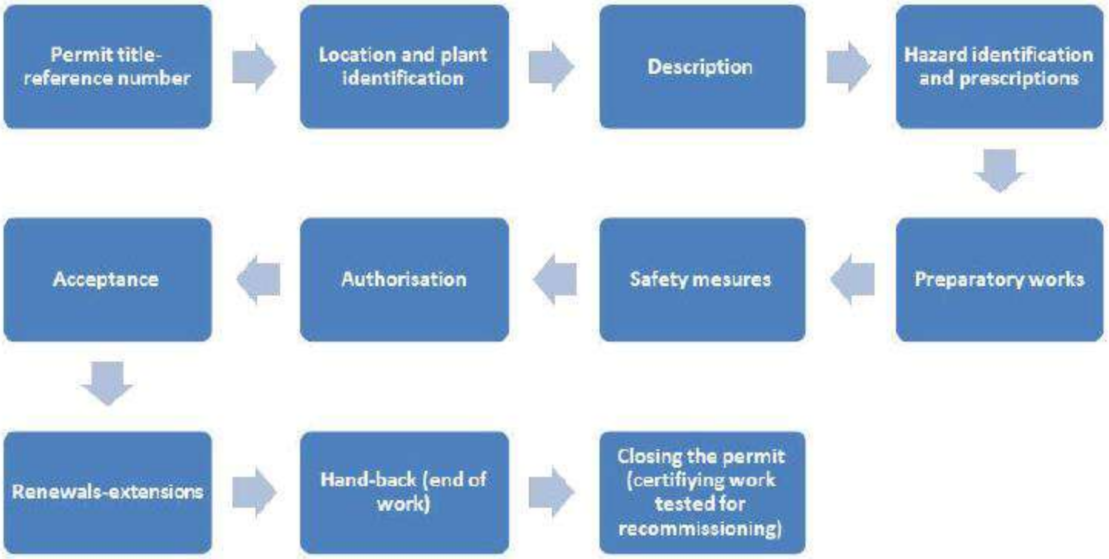

Figure 1. Work Permit Issuance Procedure (MAHB, 2014)

A work permit expires and must be closed in the event: expiration of the permit; completion of the work; change in the working conditions that existed at the time of issuing the permit.

Work on carrying out activities for which a work permit has been issued must not continue if the permit has expired. The issuer of the permit maintains records of issued work permits.

If there is an emergency situation involving serious, fatal, or collective workplace injuries, all work permits will be suspended until normal operations resume. Work permits are reissued before work recommences.

The content of work permits

The work permit should contain the following information (figure 2):

- Basic information: permit number, job title, employee's name, issuance period, name of the high-risk activity, location of the high-risk activity;
- List of specific work equipment;
- Specific measures for the characteristic high-risk activity;
- Specific personal protective equipment for work during high-risk activity;
- Permit verification.

1. BASIC INFORMATION

Permit number:	
Job title:	
Employee's name:	
Issuance period:	☐ daily ☐ monthly ☐ yearly
Name of the high-risk activity:	☐ work at height ☐ work in depth ☐ internal transport ☐ work in confined spaces ☐ work with hazardous chemicals ☐ work in explosive atmospheres
Location of the high-risk activity:	

2. WORK EQUIPMENT

Work equipment:	☐ ☐ ☐ ☐ ☐

3. SPECIFIC MEASURES

Safety measures at work:	☐ ☐ ☐ ☐ ☐

4. SPECIFIC PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment:	☐ ☐ ☐ ☐ ☐

Place, date M.P. Permit issuer

Employee

Figure 2. Sample Work Permit for High-Risk Activities

Control of prescribed occupational health and safety measures in the work permit

Based on risk assessment, insights into the workplace conditions, and data from the Work Permit, the Permit Issuer defines risk control measures necessary for the safe implementation of planned high-risk activities. If necessary, when prescribing measures, the Permit Issuer consults with department heads, activity executors, or other experts. After prescribing risk control measures, employees confirm their acceptance of the prescribed measures by signing the permit.

The occupational health and safety advisor/partner informs employees about specific measures for characteristic high-risk activities, as well as other measures defined in the Risk Assessment Act. Control by the occupational health and safety advisor/partner, in collaboration with department heads, is conducted continuously during the performance of high-risk activities. It can be organized as continuous, periodic, at specific time intervals, or at certain phases of activities assessed as critical.

COMPETENCY TRAINING IN THE WORK PERMIT ISSUANCE PROCESS

Development of the work permit issuance system is a complex process. Responsible individuals are required to consider all aspects of occupational health and safety to determine those requiring a work permit. Considering that the permit issuance system is essentially a tool that grants employees appropriate access to high-risk tasks, it must be agile enough to evolve with the environment and detailed enough to ensure alignment with occupational health and safety policies. Therefore, developing competency is essential to achieve quality and consistency in the use of the work permit system. The responsible party should provide training to all employees involved in and contributing to the work permit system in languages and formats understandable to them, including:

- Principles of the work permit system;
- The necessity of work permits;
- Understanding the types of permits and other required documentation;
- Responsibilities and competencies required for work permit issuers;
- Employee responsibilities in the work permit system;
- Control of high-risk work activities;
- Conclusions from incident investigations related to work permits and findings from audits.

Training should focus on using the work permit system, but it must also ensure that employees understand the work environment, associated hazards and risks, and the measures required for effective risk management. Periodic training should be conducted to ensure the maintenance of employee competency in the following cases:

- When the training certificate has expired;

- Where it is identified as part of the training needs analysis;
- Where risk assessments identify training as a risk control measure;
- When there are changes in legal requirements;
- Where incident investigations recommend training as a corrective measure.

CONCLUSION

The work permit issuance process is of great importance as it contributes to preventing workplace injuries and safeguarding the health of employees. The work permit system is an essential part of occupational health and safety control when performing high-risk activities. The advantages of using a work permit system include improving workplace safety conditions, reducing costs associated with workplace injuries, and potentially enhancing productivity on-site. Another significant benefit is improved communication. The work permit system aids in improving communication among employers, responsible parties, and employees. Therefore, this system can help prevent misunderstandings by establishing an efficient system of consultation and employee involvement at all levels and functions when conducting high-risk activities.

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THE CONCENTRATION OF CU^{+2} IN THE SOIL AND PARTS OF JUNIPER THE SASTAVCI SURFACE MINE AND ITS VICINITY

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Abstract: Plants have the ability to accumulate heavy metals present in the soil, and due to their capability, their tissues are often used as indicators of environmental pollution in studies of heavy metal contamination from various sources. This research was conducted to examine the accumulation capacities of Cu^{+2} in the soil and parts of juniper (root, branches, needles, and fruits) at the Sastavci surface mine and its vicinity.

Keywords: *Cu^{+2}; ICP-MS; Phytoremediation; Juniperus communis.*

INTRODUCTION

Common juniper, scientifically known as Juniperus communis L., is a coniferous tree or shrub belonging to the cypress family (Jocienė, 2023). Common juniper can be found in various types of habitats, including dry and warm deciduous forests, steppe vegetation, dry and warm coniferous forests, as well as areas with impoverished soil. It is often seen in devastated beech forests or in areas where beeches mix with firs (Adams, 2008; Vidaković, 2004; Lakušić, 1980; Šilić, 1990; Jovanović, 1992). Juniper is a highly resilient and densely branched evergreen shrub or tree that can vary from 1-3 m for shrubs and 8-12 m for trees. It is a dioecious plant, meaning that male and female flowers can exist on the same juniper, although they are often found on separate plants. Female specimens have a wider crown, while male specimens have a narrower one. Juniper needles are common, light green in color, and have an elongated-oval or rounded shape. Juniper berries represent berries that form after the fertilization of female flowers. They can have a brown or bluish color, with or without a blue coating. These berries typically ripen in the second year, usually during autumn (Serebryanaya, 2015). Research has shown that juniper possesses certain characteristics that make it a good candidate for phytoremediation (Ahrens, 2011). Juniper has demonstrated promising features for phytoremediation due to its specific abilities to accumulate heavy metals and its rapid growth (Li, 2017). Previous studies have indicated that juniper can be used for the phytoremediation of uranium (Schwitzguébel, 2002; Muske, 2016). Its ability for phytostabilization is particularly pronounced due to its deep root system, high tolerance to heavy metals, intense transpiration, and capacity to grow in nutrient-poor soils (Pulford, 2003). In the vicinity of Raška, since the 1920s, the first explorations of lead-zinc ore deposits began. The Pb-Zn ore deposit of Sastavci (Badanj) is located on the northwest slopes of Kopaonik, east of the town of Raška in Serbia. The Ibar River is situated on the western side of these deposits. Although mining is no longer the dominant industry in the region, significant issues remain, such as tailings, which represent unusable material that remains as residual toxic waste after useful ore extraction. Surface mines are the cause of intensive soil degradation and loss of natural habitats for plants and animals. They often contain harmful and hazardous chemicals, such as heavy metal cations, which can accumulate through the food chain. These heavy metals can cause toxicity and ultimately seriously threaten animals and humans who consume from these systems.

MATERIALS AND METHODS

Research Area: The Pb-Zn ore deposit of Sastavci (Badanj) is located near the Semeteško Lake, situated at the foothills of the Kopaonik mountain, representing a tourist attraction of the municipality of Raška. Soil and plant material sampling was conducted in three zones, each containing three sampling sites for juniper with varying degrees of pollution. The sampling sites were selected based on the assumption that the content of selected elements would gradually decrease with increasing distance from the surface mine. Soil samples were collected using a stainless steel probe at a depth of 20 cm. Juniper was chosen for sampling for several reasons: it is a perennial plant that thrives in various conditions and is valued for its use in medical purposes and nutrition. Samples were collected from three different zones: Zone I represents a sample collected directly from the surface mine, which is the primary source of pollution. Zone II includes a sample collected from the immediate vicinity of the surface mine, which is a secondary source of pollution. Zone III encompasses a sample collected at a distance of 1700 m from the surface mine, which is a tertiary source of pollution. The control zone, located at coordinates (43.328406, 20.656260) and situated 5 km away in a straight line from the Pb-Zn surface mine near the village of Kneževići, represents an uncontaminated area. This zone serves as a reference point for assessing the degree of pollution compared to samples from zones exposed to the influence of the surface mine. Samples were collected during the juniper fruit harvest (September-October), under conditions without rain and wind. The samples used for analysis were in good condition, without visible signs of disease or pests. At a depth of 20 cm, sampling of juniper roots and soil was performed. At a height of 50-70 cm from various sides of the juniper, 4-5 grams of needles approximately 1 cm thick were sampled. From the same branches, juniper fruits in a mature phase, similar in color and shape, were also sampled. Trace element analysis was determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). To assess the level of soil and plant material contamination in the area, the Enrichment

Factor (EF) is used for comparison with uncontaminated reference areas (Oliva, 2007; Enuneku, 2017; Berghof Products, 2023). The Bioconcentration Factor (BCF) represents the ratio of metal cation concentrations in plant roots to their concentrations in soil. When BCF is greater than 1, it indicates the accumulation of soil elements in plant roots (Christou, 2017; Hasnaoui, 2020; Radojevic, 2017; Li, 2023). The Biological Absorption Coefficient (BAC) represents the ratio of element concentrations in plant leaves to the concentrations of the tested elements in the soil (Favas, 2013). The Translocation Factor (TF) is the ratio of the total concentration of a specific element in a plant's roots to the concentration of the same element in its above-ground parts (Nouri, 2011; Mendoza, 2015).

RESULTS AND DISCUSSION

The obtained copper concentrations are compared with the maximum permissible values and the remediation values (RV) proposed by the regulations of the Republic of Serbia. The maximum permissible value (MPV) prescribed by the Regulation of the Republic of Serbia (Regulation No. 30/2018-50) for copper is 36 mg/kg, and the remediation value (RV) is 190 mg/kg. The world average concentration of copper in soil is 38.9 mg/kg (Kabata-Pendias, 2011). The concentrations of copper in the soil root zone of juniper are shown in Figure 1. The copper concentrations in the soil from the juniper zone were below the maximum permissible values according to the Regulation of the Republic of Serbia, as well as below the world average values. Based on the obtained values of the soil enrichment factor for copper (Table 1), it can be concluded that there is no enrichment of this element in the investigated area.

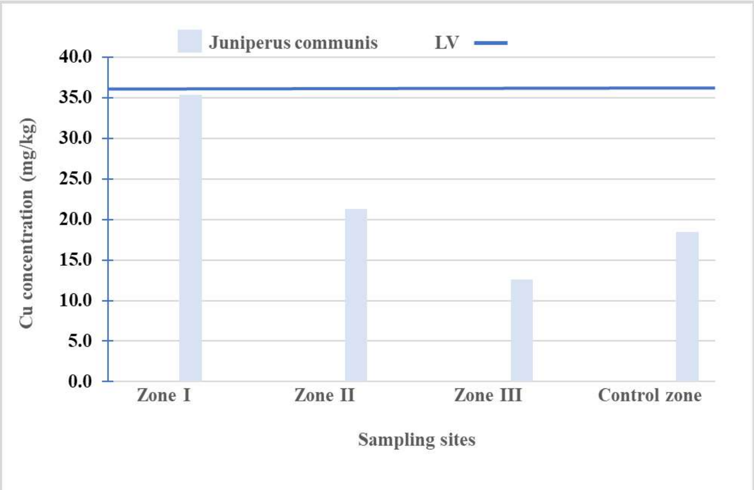

Figure 1. Concentrations of metal cations Cu in the root zone of juniper at 3 sampled locations (solid line represents the threshold value according to the Regulation of Serbia (Regulation No. 30/2018-50, 2018))

Table 1. Enrichment factor for soil in the Juniper Zone Sastavci (Badanj)

Elements / Sampling site	Zone I	Zone II	Zone III
	Sample 1	Sample 2	Sample 3
Cu	1.9156	1.1513	0.6826

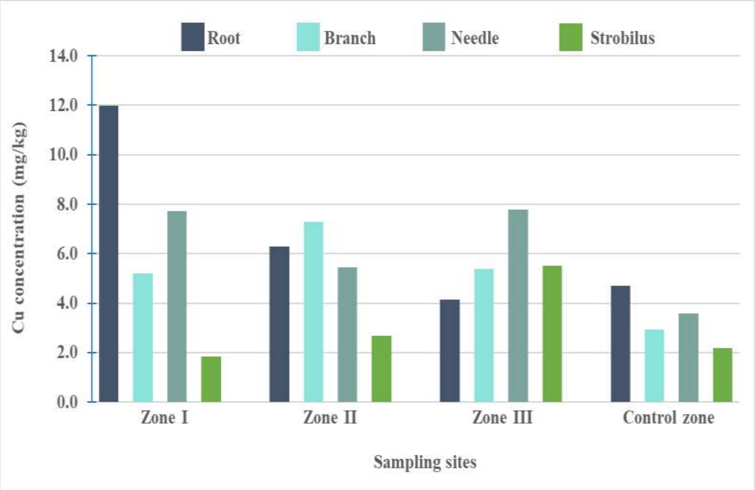

Figure 2. Concentration (mg/kg) for Cu in the root zone and above-ground parts of the Juniperus communis

The concentrations of Cu are shown on the surface mine of Sastavci (Badanj) and its vicinity, in different parts of juniper, including roots, branches, needles, and fruits in Figure 2. The highest copper concentration was observed in the roots of juniper in the first zone (11.9829 mg/kg), while the lowest copper concentration was observed in the fruit of juniper in the first zone (1.8564 mg/kg). The results of the enrichment factors of juniper are presented, indicating that the enrichment with copper is moderate (Table 2). It can be concluded that there are enrichments with copper in certain parts of juniper. In sample 1, enrichment with copper is observed in the roots and needles. In sample 2, there is enrichment with copper in the branches, and in sample 3, enrichment with copper is observed in the needles and fruits. These findings indicate variations in copper concentrations in different parts of juniper in the investigated area.

Table 2. Copper enrichment factor of juniper plant material at Sastavci surface mine (Badanj) and the immediate vicinity

Sampling zones	Sampling sites	Root	Branches	Needle	Strobilus
Zone I	Sample 1	2.5388	1.7859	2.1646	0.8555

Zone II	Sample 2	1.3355	2.4912	1.5307	1.2365
Zone III	Sample 3	0.8759	1.8505	2.1809	2.5399

Table 3. shows the values of the calculated bioconcentration factor (BCF), translocation factor (TF), and biological absorption coefficient (BAC) for juniper, Sastavci (Badanj). It can be concluded that copper does not meet the criterion BCF>1 and TF>1 in any zone or sample. Regarding copper, it can be concluded that juniper is not suitable for phytoextraction or phytostabilization of the investigated element under the given conditions of the investigated surface mine Sastavci (Badanj) and its immediate vicinity.

Table 3. Bioconcentration factor (BCF), translocation factor (TF), and biological absorption coefficients (BAC) for Juniperus communis

Factor	Sampling site/Elements	Cu
BCF	Sample 1	0.3390
	Sample 2	0.2967
	Sample 3	0.3282
TF	Sample 1	0.6449
	Sample 2	0.8669
	Sample 3	**1.8833**
BAC	Sample 1	0.3893
	Sample 2	0.2572
	Sample 3	0.7599

CONCLUSION

The results indicate that there were no exceedances of the maximum permissible or remediation values for copper. Based on the obtained enrichment factor values, there was no enrichment, i.e., minimal enrichment in sample 1. The values of the bioconcentration factor (BCF) for copper were <1, indicating that the uptake of elements from the soil through juniper roots is very low. Based on the bioaccumulation and translocation factors, we can conclude that juniper is not suitable for phytoremediation of the Sastavci (Badanj) surface mine, except for sample 3, where it appears to be suitable for the translocation of elements from roots to above-ground parts, especially leaves.

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AS^{+3} ASSESSMENT IN THE SOIL AND PARTS OF JUNIPERAT THE SASTAVCI (BADANJ) SURFACE MINE AND ITS VICINITY

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Abstract: The research was conducted to determine the concentration of As^{+3} in the soil and parts of juniper at the surface mine Sastavci (Badanj) and its surroundings. Various natural and anthropogenic (industrial) activities lead to rapid increases in the accumulation of toxic and potentially toxic metal cations in the soil. Abandoned mining areas represent significant environmental problems. Heavy metals, being non-biodegradable, can persist in the environment for extended periods. They have the potential to enter the food chain, starting from plants to animals, and then accumulate in the human body through the consumption of contaminated food. The accumulation of heavy metals in the human body can pose health risks, including various health problems, and contamination with heavy metals also poses a serious threat to ecosystems. Therefore, the remediation of contaminated areas is of great importance. Phytoremediation is a technique that has been used for the remediation of this mining area due to its innovation, efficiency, and environmental sustainability. This research was conducted to determine the concentration of As^{+3} at the surface mine itself and its surroundings, as well as to monitor the distribution of As^{+3} cations in the juniper system, including roots, branches, needles, and fruits.

Keywords: *Surface Mine Sastavci (Badanj); As^{+3}; ICP-MS; Phytoremediation; Juniperus communis.*

INTRODUCTION

Urbanization and industrialization processes have contributed significantly to the increased presence of heavy metals in the environment over the past few decades, causing great concern worldwide (Suman, 2018; Ashraf, 2019). Over the last 100 years, the world has experienced rapid and intensive industrialization, resulting in a growing demand for the exploitation of natural resources, leading to a global environmental pollution problem (Briffa, 2020; Gautam, 2016). Heavy metals are extremely persistent in soil and cannot be degraded by either biological or physical processes, making them a long-term threat to the environment (Suman, 2018). For the removal of heavy metals from contaminated areas, various mechanical or physico-chemical techniques are used, such as incineration, washing, excavation and landfilling, and the application of electric fields (Sheoran, 2011; Wuana, 2011; Dal Corso, 2019). Limitations for the application of physico-chemical techniques include high cost, inefficiency when pollutants are present in low concentrations, changes in the physico-chemical and biological properties of the soil, etc., (Ali, 2013; Dal Corso, 2019). Phytoremediation has not only proven its ability to remove heavy metals from contaminated soil but also provides an environmentally acceptable alternative. By harnessing the natural processes offered by plants, this technique is effective and sustainable, without the need for expensive technological devices or chemical agents. Phytoremediation is an ecological method that relies on the abilities of certain plant species to remove or reduce the contamination of heavy metals from soil. These plants use processes such as phytoextraction or phytostabilization to accumulate heavy metals and thus reduce their presence in the environment (Adiloğlu, 2018). Some plant species have developed the ability to tolerate high concentrations of heavy metals in the soil and accumulate them in their tissues, while on the other hand, there is a larger number of plant species that are highly sensitive to high concentrations of heavy metals (Wang, 2020; O'Connor, 2019; Liu, 2013). Juniper, belonging to the group of evergreen plant species, is prominent in research due to its characteristic needle-like leaves that function throughout the year. Previous studies indicate that juniper is an excellent candidate for phytoremediation. Juniper has an extremely deep root system, which is very suitable for the phytostabilization process, and it has the ability to grow on nutrient-poor soils (Li, 2017; Baltrenaite, 2015).

MATERIALS AND METHODS

Research Area: The Raska mining field is an area in the southwestern part of Serbia covering an area of approximately 500 km^2. It is located between the villages of Lipovice to the south and Plane to the north. Here lies the deposit of lead-zinc ore Sastavci, situated at the source of the Radisic river, on the slopes of Karachko hill (916 m) and Shanac (1098 m), at an elevation of 720-905 meters above sea level. Estimates suggest that this deposit contains around 364,000 tons of ore with an average content of 2.05 % lead (Pb) and 5.59 % zinc (Zn). High gold content (Au) has also been noted at the mine, but the high arsenic (As) content posed a problem, leading to the cessation of exploitation due to inadequate processing technology. The research included soil and plant material samples from three different zones with varying levels of contamination. Sampling locations were chosen based on the assumption that the concentration of certain metal cations would decrease with increasing distance from the surface mine. Soil samples were collected using a stainless steel probe at a depth of 20 cm. After composite samples were formed, leaves, stones, twigs, and other visible impurities were removed. This was done to ensure the cleanliness of the samples and to enable precise analysis of soil and plant material regarding contamination. Plant material and soil were sampled to investigate primary, secondary, and tertiary pollution caused by the exploitation of Pb-Zn ore. Samples were collected from three zones: Zone I: Sample 1 was taken directly from the surface mine, the primary source of pollution. Zone II: Sample 2 was collected from the immediate vicinity of the surface mine, a secondary source of pollution. Zone III: Sample 3 was taken at a distance of 1700 m from the surface mine, a tertiary source of pollution. The control zone, located at coordinates (43.328406, 20.656260) and 5 km away from the Pb-Zn surface mine near the village of Kneževići, represents an uncontaminated area. This zone serves as a reference point for assessing the degree of pollution compared to samples from zones exposed to the influence of the surface mine. The content of trace elements was determined by inductively coupled plasma mass spectrometry (ICP-MS). To assess the level of soil and plant material contamination in the given area, the Enrichment Factor (EF) is used for comparison with uncontaminated reference areas (Berghof Products, 2023; Oliva, 2007; Enuneku, 2017). The Bioconcentration Factor (BCF) is the ratio of the concentration of metal cations in plant roots to their concentration in the soil. BCF > 1 indicates the accumulation of soil elements in plant roots (Christou, 2017; Hasnaoui, 2020; Radojevic, 2017; Li, 2023). The Biological Absorption Coefficient (BAC) is the ratio of the concentration of elements in plant leaves to the concentration of elements in the soil (Favas, 2013). The Translocation Factor (TF) is the ratio of the total concentration in the root to the concentration in the aboveground parts of the plant (Nouri, 2011; Mendoza, 2015).

RESULTS AND DISCUSSION

Getting concentrations of arsenic compared with maximum permissible values and remediation values (RV) proposed by the regulations of the Republic of Serbia. The maximum permissible value (LV) prescribed by the Regulation of the Republic of Serbia (Regulation no. 30/2018-50) for arsenic is 29 mg/kg, and the remediation value (RV) is 55 mg/kg. In Figure 1, concentrations of arsenic in the root zone of juniper soil are shown. Remediation exceedances are observed in Zone I, where it can be noted that the exceedance was multiple. Exceedance of the remediation values is also observed in Zone II. Based on the enrichment factor values of soil with arsenic, Table 1, in Zone I, the soil was extremely highly enriched, EF=242.3383. Based on the defined enrichment factor values, it can be concluded that all samples are contaminated with this element.

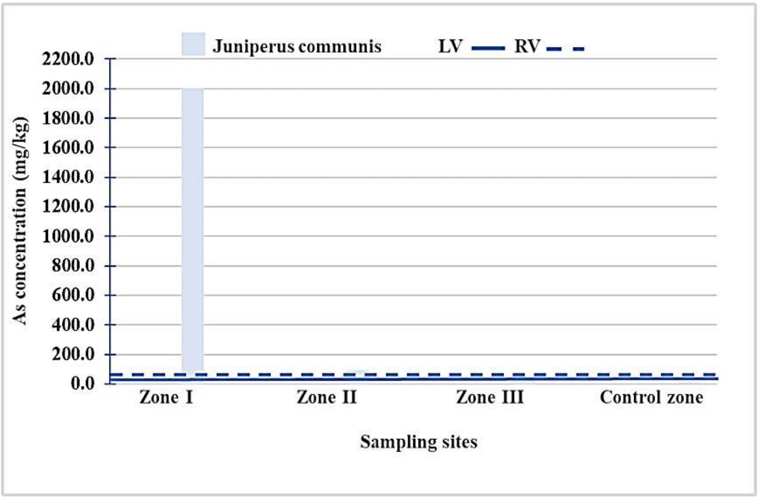

Figure 1. Concentrations of metal cations As in the root zone of juniper at 3 sampled locations (solid line represents the threshold value according to the Regulation of Serbia (Regulation No. 30/2018-50, 2018))

Table 1. Enrichment factor for soil in the Juniper Zone Sastavci (Badanj)

Elements / Sampling site	Zone I	Zone II	Zone III
	Sample 1	Sample 2	Sample 3
As	242.3383	11.1174	4.1904

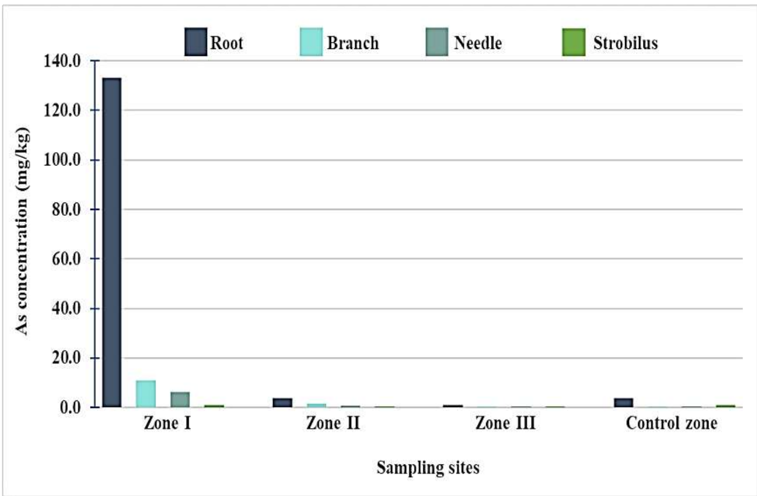

Figure 2. Concentration (mg/kg) for As in the root zone and above-ground parts of the Juniperus communis

At the Sastavci (Badanj) surface mine, an analysis of As concentration (Figure 2) was conducted in various parts of juniper, including roots, branches, needles, and fruits. The highest detected concentration was observed in the juniper roots in the first zone (133.2877 mg/kg), while the lowest concentration was detected in the juniper fruit in the third zone. The enrichment factor value for arsenic indicates significant enrichment for needles to extremely high enrichment for juniper roots and branches. It can be considered that the origin of arsenic in plant material is predominantly anthropogenic. Table 2 shows the values of the calculated Bioconcentration Factor (BCF), Translocation Factor (TF), and Biological Absorption Coefficient (BAC) for juniper, Sastavci (Badanj). It can be concluded that arsenic does not meet the criterion of BCF > 1 and TF > 1 in any zone and sample. Regarding arsenic, it can be concluded that juniper is not suitable for phytoextraction or phytostabilization of the investigated element under the given conditions of the Sastavci (Badanj) surface mine and its immediate vicinity.

Table 2. Bioconcentration factor (BCF), translocation factor (TF), and biological absorption coefficients (BAC) for Juniperus communis

Factor	Sampling site/Elements	As
BCF	Sample 1	0.0666
	Sample 2	0.0426
	Sample 3	0.0261
TF	Sample 1	0.0473
	Sample 2	0.1609
	Sample 3	0.2801
BAC	Sample 1	0.0508
	Sample 2	0.0120
	Sample 3	0.0153

CONCLUSION

The results indicate that there were exceedances of the arsenic limit values in zones I and II. The enrichment factor ranged from moderate to significant enrichment, except in zone I, where the soil was extremely highly enriched. It can be concluded that arsenic in the soil from the juniper root zone originates from the process of Pb-Zn ore exploitation. The values of the Bioconcentration Factor (BCF) for arsenic were <1, based on which we conclude that the uptake of elements from the soil through juniper roots is very low. Based on the bioaccumulation and translocation factors, we can conclude that juniper is not suitable for phytoremediation of the Sastavci (Badanj) surface mine.

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WIRELESS SENSOR NETWORK FOR SURFACE WATER-QUALITY MONITORING IN PROTECTED AREAS IN SERBIA AND CROATIA

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Abstract: This study aims to examine the application of low-cost wireless sensors for analysis of surface water quality. A wireless sensor network (WSN) was installed to monitor the contamination of surface water of two wetland eco-systems in cross-border protected areas, Zobnatica Lake in Serbia and the Wetlands of Tompojevci in Croatia. An independent sample t-test was used for the comparison of the results obtained by the WSN with results measured by the multiparameter device using standard laboratory methods. The use of the WSN overcomes the problem of sampling at remote locations and contamination of samples, which enables real-time data and more comprehensive conclusions in comparison to standard laboratory methods.

Keywords: *wetlands; cross-border monitoring; sensor devices.*

INTRODUCTION

Wetlands are invaluable ecosystems, with important roles in the environment, including water storage and purification, but also as providers of habitat for diverse species (Zedler & Kercher 2005; Ghermandi et al. 2010). Lakes and wetlands are important natural water resources, but they're also delicate ecosystems vulnerable to urbanization and exploitation, and especially the expansion of agricultural activities that can lead to contamination (McLaughlin and Cohen, 2013; Chen et al., 2019). Preserving these ecosystems is crucial, as they play significant roles in maintaining biodiversity. The deterioration in water quality emerges as a prominent factor contributing to the loss of biodiversity in these ecosystems. Therefore, monitoring of water quality in protected areas such as lakes and wetlands is vital for early detection and response to contamination risks.

Water quality monitoring in protected areas is usually performed by standard laboratory methods. However, optical sensor methods offer a promising alternative for remote water quality assessment. These methods analyze light spectra to detect contaminants accurately using small, robust instruments (Utkin et al, 2011). Water quality monitoring systems utilizing WSN are pivotal for real-time analysis, enabling rapid actions to maintain water quality (Tubio et al, 2023; Miller et al, 2023).

This research focuses on monitoring key physico-chemical parameters in surface water over two years to compare results obtained by the WSN with standard laboratory methods. The WSN-based measurement system was installed to evaluate water quality parameters such as water level, water temperature, pH, conductivity, and dissolved oxygen. Research conducted in cross-border protected areas, Wetlands of Tompojevci (Croatia) and Lake Zobnatica (Serbia), demonstrates the reliability of the WSN in water quality analyses by comparing the WSN monitoring data with standard laboratory results.

MATERIAL AND METHODS

Sampling locations

Lake Zobnatica with an area of 250 ha is located in the North Bačka District near the municipality of Bačka Topola. Zobnatica was declared as the national Nature Park in 1976. Around Lake Zobnatica there is agricultural land irrigated with water from the lake. Agriculture is the main human activity, and there are also industrial facilities for meat processing a few kilometers from the lake.

Wetlands of Tompojevci are spread over 5700 ha of cultivable land located in the eastern part of Vukovar-Srijem District, Tompojevci municipality. Agriculture is one of the main activities in the Tompojevci region, with almost no industrial activity.

Analytical and sensor methods

Measurement of pH, dissolved oxygen, and electrical conductivity was performed directly in the field using the multiparameter device. On three locations at Lake Zobnatica and two locations at Wetlands of Tompojevci sensor nodes were installed. Individual sensors are placed on each device to measure: pH, dissolved oxygen, electrical conductivity, water level, and water temperature. The sensor device consists of two parts, the surface part of the device with hardware that collects and sends measurement data, while electronics and individual sensors for measuring 5 parameters in surface water are placed on the floating plastic enclosure (Figure 1). These two parts are connected by cable, which is used for sending data and power.

Figure 1. Sensor device

The surface part hardware consists of:

- Microprocessor unit that controls the whole system- receives data from sensors, saves it in a memory circuit, sends it in predefined periods, and turns on and off the system power.
- GSM/GPRS unit (Global Systems for Mobile/General Packet Radio Service) with antenna, for sending data over the GSM network to the Internet.
- Power control unit for controlling which part of the system is powered.
- Battery which provides power for the whole system. The non-rechargeable LSH20 - Lithium Thionyl Chloride battery is used here.
- Communication channel for hardware on the lower part of the system.

The power control unit powers off the whole system when no measurement is made, and approximately once a day delivers power from the battery, and for 2-3 minutes the system makes measurements, sends them via the GSM network, or saves them if the GSM signal is too weak. Ultra-low power consumption is enabled in such a manner, so battery can last for 2-3 years without replacement.

Hardware in the floating part of the device consisted of:

- Sensor probes for measuring water parameters,
- Electronics for processing signals from sensors,

- Microcontroller unit for collecting signals from all sensors,
- Communication channel for hardware on the upper part of the system,
- Internal sensor for temperature and humidity inside the enclosure, to ensure no moisture is inside hardware.

A closed air pocket inside the plastic enclosure enables the device to float on the water surface (inside a plastic pipe fixed to the pier). Signals from every probe are processed with specialized electronics and gathered via the microcontroller. Data is sent to the surface part via cable, which is also used to send power to the surface part.

Statistical data analysis

The IBM SPSS (Statistical Package of Social Science) software package version 25 was used for statistical data processing. Descriptive statistics and independent sample t-tests were performed for the data analysis. Descriptive statistics were applied to determine the basic features (mean, minimum, and maximum) of the observed physico-chemical parameters. An independent sample t-test was applied to compare the cumulative surface water pollution between the two observed cross-border protected areas in Serbia and Croatia.

RESULTS

During the two-year monitoring period with the WSN, five parameters were observed in selected cross-border protected areas, Lake Zobnatica in Serbia and the Wetlands of Tompojevci in Croatia. Descriptive statistics were applied to determine the mean, minimum, and maximum values (Table 1) which were used for water classification according to regulations in two cross-border areas (Official Gazette of the RS 50/2012 for Serbia and Official Gazette no. 77/98 and 137/08 for Croatia) (Table 2). Based on the results shown in Table 2, it can be concluded that the amount of dissolved oxygen is extremely low in Lake Zobnatica (Class V), while the conductivity is elevated in the Wetlands of Tompojevci (Class II).

Table 1. Descriptive statistics for analyzed physico-chemical parameters in surface water

Parameters	Unit	Zobnatica lake			Wetlands Tompojevaci		
		Mean	Min.	Max.	Mean	Min.	Max.
pH	-	8.49 ± 3.02	2.01	14.00	6.55 ± 1.89	2.9	8.78
Electrical conductivity (EC)	μScm^{-1}	867.72 ± 285.75	299.5	1499	1115.28 ± 85.25	888	1232

Dissolved oxygen (DO)	*mgL*$^{-1}$	3.43 ± 2.51	0.4	33.77	8.01	2.13	21.72
Water level	*m*	1.01 ± 0.36	0.02	1.54	0.069 ± 0.05	0.02	0.28
Water temperature	*°C*	13.33 ± 8.64	2.36	35.33	14.74 ± 7.99	2.98	35.86

The study examined whether there was a significant difference in pH value, dissolved oxygen, electrical conductivity, water level, and water temperature in relation to the cross-border areas. Based on the results of the t-test of independent samples (Table 3), it can be concluded that a significant difference exists for all observed parameters, where the pH value and water level are significantly higher in Zobnatica, while dissolved oxygen concentration, conductivity, and water temperature are higher in the Wetlands of Tompojevci.

Table 2. Classification of surface water

	Zobnatica lake	Wetlands Tompojevaci
pH	Class I	Class I
EC	Class I	Class II
DO	Class V	Class I
Total	Class V	Class II

Table 3. Differences in the values of measured parameters for cross-border protected areas

	Tompojevci	Zobnatica	t	p
	Mean			
pH [-]	8.49 ± 3.02	6.55 ± 1.89	11.840	<0.0005*
DO [*mgL*$^{-1}$]	3.43 ± 2.51	8.10 ±5.09	-14.040	<0.0005*
EC [*μScm*$^{-1}$]	867.72 ± 285.75	1115.28 ± 85.25	-15.296	<0.0005*
Water level [*m*]	1.01 ± 0.36	0.069 ± 0.05	37.024	<0.0005*
Water temperature [*°C*]	13.33 ± 8.64	14.74 ± 7.99	-2.038	0.042*

* Statistical significance (p) at the level of 0.05

The results obtained by the WSN were compared with results measured by the multiparameter device (MPD) using standard laboratory methods (Table 4). In Lake Zobnatica the lowest standard deviation for pH was observed, while the largest was obtained for dissolved oxygen. For Wetlands of Tompojevci, the lowest deviation was observed for dissolved oxygen and relatively similar to pH and electrical conductivity.

Table 4. Differences in the results of the multiparameter device and the WSN

	Range MPD	Range WSN	Mean MPD	Mean WSN	Deviation [%]
			Zobnatica		
pH [-]	6.96-12.80	4.6-12.80	8.37	8.49	1.42
DO [mgL^{-1}]	0.10-24.48	0.1 – 9.00	4.64	3.43	35.27
EC [μScm^{-1}]	248-1442	298-2882.99	1013.80	867.72	16.83
			Tompojevci		
pH [-]	6.96-12.80	6.30-11.11	7.71	6.55	17.7
DO [mgL^{-1}]	0.1-24.48	0.80-8.29	8.37	8.10	3.33
EC [μScm^{-1}]	248-1442	207-2273.5	913.75	1115.28	18.07

CONCLUSION

The wireless sensor system for surface water quality monitoring was installed in three locations at Lake Zobnatica and two locations at Wetlands of Tompojevci. The use of the WSN enables the obtaining of real-time data and overcomes the problem of traveling to the sampling site as well as contamination of the sample during collection and transport to the laboratory for standard laboratory analyses. The WSN also enables a much higher frequency of data collection in comparison to standard laboratory methods, which is especially important if the sampling locations are a quite far from the laboratory. Therefore, results obtained by the WSN provide a more relevant and extensive database and more comprehensive conclusions drawn from the collected data compared to data obtained by standard laboratory methods.

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ANALYSIS OF DIFFERENT BATTERY TECHNOLOGIES FOR ELECTRIC VEHICLES

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Abstract: This paper presents an analysis of different battery technologies that have been improved together with the development of electric vehicles. The PROMETHEE method (Preference Ranking Organization METHod for Enrichment of Evaluations) is used for ranking of battery technologies as one of the multicriteria decision making (MCDM) methods. The ranking criteria are the characteristics of batteries: the working temperatures range, the self-discharge rate, the specific energy, the lifetime, the number of cycles, the cost per energy unit, and the charge/discharge efficiency, with the chosen weighting coefficients. The best ranked are lithium-ion (Li-Ion) batteries, the second ranked are lead-acid (Pb) batteries, then nickel-cadmium (Ni-Cd), and the worst ranked are the nickel-metal hydride (Ni-MH) batteries, as for the chosen criteria and their weights.

Keywords: *Battery technology; Multicriteria decision making methods; Electric vehicles.*

INTRODUCTION

Different battery technologies have been improved in order to satisfy the worldwide increasing demand for electric vehicles. After the development of lead-acid batteries, the nickel-cadmium technology was developed, followed by the nickel-metal-hydride technology because of the high toxicity of cadmium. Batteries based on lithium had many advantages over other technologies except for the cost, but this has changed significantly in the last decade. There are also new technologies in order to reduce the risk of fire and the toxicity for the environment, as well as to increase the safety and the battery performance. The most used battery technologies are ranked in this paper based on the working temperatures range, the self-discharge rate, the specific energy, the lifetime, the number of cycles, the cost per energy unit, and the charge/discharge efficiency. For the chosen weighting coefficients, the ranking is done by using the PROMETHEE II method for the complete ranking (Brans, 1982), (Brans, 1984). Other methods for multicriteria decision making can be used as well. The ranking depends not only on the chosen criteria, but also on the chosen weights. The subjective weighting methods such as Analytic hierarchy process – AHP (Saaty, 1986) and the Best–worst method – BWM (Rezaei, 2015) can be used for determining the weighting coefficients based on the preferences of decision maker.

TYPES OF BATTERIES FOR ELECTRIC VEHICLES

The first electric cars that appeared at the beginning of the twentieth century used lead batteries whose technology was already sufficiently developed. The main disadvantages of these batteries are the high weight ($25 \div 50$ % of the total weight of the electric vehicle) and the low specific energy of the battery. The efficiency of such batteries is from 70 to 75 %, but it decreases up to 40 % with a decrease in external temperature. They charge more slowly than other types of batteries, and the lifetime of lead-acid (Pb) batteries decreases if they are discharged with high currents in the mode of use, as well as in the case of low temperatures.

A nickel-cadmium (Ni-Cd) battery has a longer lifetime than a lead-acid battery, a higher specific energy density, enables high discharge currents and is resistant to extreme temperatures. Its disadvantage is that cadmium is a very toxic metal and dangerous for the environment. From environmental reasons, cadmium has been replaced by metal hydrides that contain less toxic metals.

Nickel-metal hydride (Ni-MH) batteries have a higher specific energy than Ni-Cd batteries and a shorter lifetime, but longer than Pb batteries. Cell voltage of nickel-based batteries is 1.2 V, whereas cell voltage of Pb batteries is 2.1 V. Ni-MH batteries can be recycled and are less hazardous to the environment. At high temperatures, faster self-discharge and heat release occur. Since some of the shortcomings of batteries were more pronounced at low temperatures, batteries called Zebra appeared, for which it was necessary to heat the electrolyte to 270 °C at the start of operation. They are non-toxic and have a specific energy of up to 120 Wh/kg.

Lithium-ion (Li-Ion) batteries appeared in 1979. They have less weight, higher energy density, longer lifetime and higher capacity than other types of batteries, but they were much more expensive. Due to the improvement of production technology, the price of batteries decreased from 7500 $/kWh in 1991 and 750 $/kWh in 2010 to 130 $/kWh in 2021, with a tendency to further decrease. Disadvantages of Li-Ion batteries that first appeared were: temperature sensitivity, deformation at high temperature, poor performance at low temperature, and early battery degradation. If they are completely discharged, they cannot be recharged, unlike Ni-Cd batteries which can. Newer generations of Li-Ion batteries have a longer lifetime, faster charging speeds, less risk of fire and less impact on the environment. Cell voltage is about 3.7V.

Besides Li-Ion batteries, there are other types of lithium-based batteries: lithium-iron-phosphate (LFP), lithium-titanium-oxide (LTO), lithium-nickel-manganese-cobalt (LNMC), lithium-manganese-oxide (LMO) and lithium-nickel-cobalt-aluminium-oxide (LNCAO).

New systems for energy storage in electric vehicles are being developed with the aim of increasing the specific energy density and lifetime, as well as reducing the risk of fire (Sun, 2020). There is a risk of fire due to microscopic changes in the structure of lithium during the continuous flow of energy, as well as due to voltage interruptions, and there is also a chemical reaction that causes corrosion in a thin layer on the surface of the electrodes. Battery producers have replaced the anode alloy of the Li-Ion battery with a niobium-titanium oxide alloy that has superconducting properties at very low temperatures, which reduces charging time. Technologies for replacing graphite with silicon in lithium batteries are also being developed in order to increase the specific energy density.

The development of solid battery technologies that do not use an electrolyte is also promising, which enables greater stability and energy density, faster charging, greater safety and longer duration. Suitable materials to replace electrolytes are still being sought, and besides, the process of manufacturing solid batteries is more complex.

Electric vehicle batteries consist of cells, modules and packs, as shown in Fig. 1 a), b) and c).

Battery cells can be connected in series, parallel or in a mixed connection. Multiple cells form a battery module. For protection against external impacts, heat and vibrations, it is necessary to place the cells in a frame. A battery pack includes multiple modules, structural components, wiring, cooling loops, and power electronics (Garcia-Valle, 2013), (Samsung, 2016), (Influit Energy, 2023).

Based on the shape, three types of battery cells are distinguished: cylindrical, prismatic and pouch cells, shown in Fig. 2 a), b) and c).

The characteristics of some types of battery cells are shown in Table 1.

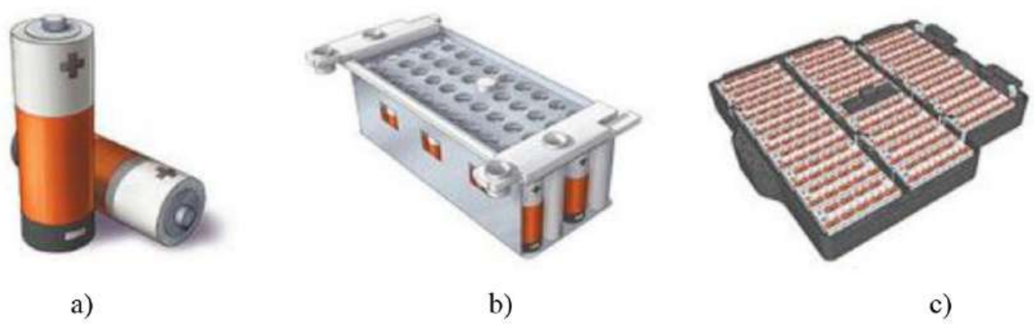

Figure 1. a) Battery cell; b) battery module; c) battery pack.

a) b) c)

Figure 2. a) Cylindrical cell; b) prismatic cell; c) pouch cell.

Table 1. Characteristics of some types of battery cells.

	Working temp.	Self-discharge	Specific energy	Lifetime	Number of cycles	Cost	Charge/ discharge efficiency
	(°C)	(% per month)	(Wh/kg)	(years)		($/kWh)	(%)
Pb	-40 ÷ 55	4 ÷ 6	30 ÷ 50	6	500 ÷ 1000	250	50 ÷ 95
Ni-Cd	-40 ÷ 50	10 ÷ 20	45 ÷ 80	10	500 ÷ 2000	800	70 ÷ 90
Ni-MH	-20 ÷ 50	15 ÷ 25	60 ÷ 120	2 ÷ 5	300 ÷ 600	500	66 ÷ 92
Li-Ion	-20 ÷ 50	2	90 ÷ 250	10	3000 ÷ 5000	130	80 ÷ 90

Table 2 shows the capacity and range of some of the most commonly sold electric vehicles (Offer, 2015), (Houx, 2017), (Berjoza, 2017). The ranges of electric vehicles are most often taken from the data of the United States Environmental Protection Agency (EPA, 2021), the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) and the New European Driving Cycle (NEDC). Their data differs from each other because each of them has its own specific testing procedures (Idaho National Laboratory, 2016). The manufacturer's data also differs from the real ranges of electric vehicles, which depend on many factors. The maximum range of the latest models of electric vehicles is up to 750 km. The Battery Management System (BMS) manages the power, charge/discharge and temperature of the battery (The Boston Consulting Group, 2010).

Table 2. Battery capacity, specific energy density, cell shape and range of some models of electric vehicles.

	Battery capacity	Specific energy density	Cell shape	Range (Data source)
	(kWh)	(Wh/kg)		(km)
Nissan Leaf S (2017)	40	229	Pouch	243 (EPA)
Renault Zoe 40 (2017)	41	228	Pouch	400 (NEDC)
BMW i3 (2016)	42.2	230	Prismatic	246 (EPA)
Tesla Model S (2017)	90	248	Cylindrical	509 (NEDC)

Figure 3 a) shows a battery module for the Tesla Model S (2012) with cylindrical battery cells 65.3 mm long and Ø 18.5 mm in diameter. The battery pack with a capacity of 85 kWh contains 7104 cells. The Tesla Model S (2017) has a range of about 500 km, and its 90 kWh battery pack contains 18650 cylindrical battery cells. Figure 3 b) shows a battery pack for a Nissan Leaf (2011) with prismatic cells of dimensions 290 mm x 216 mm x 7.1 mm, containing 192 cells in a pack with a capacity of 24 kWh. Figure 3 c) shows a battery pack for the Chevrolet Volt (2011) with pouch cells of dimensions 177 mm x 127 mm x 6.3 mm, containing 288 cells in a pack with a capacity of 60 kWh.

a) b) c)

Figure 3. a) Tesla Model S (2012) battery module; b) Nissan Leaf (2011) battery pack;

c) Chevrolet Volt (2011) battery pack.

Each electric car manufacturer uses a specific type of battery cell. Tesla uses cylindrical cells, BMW and Volkswagen use prismatic cells, while Nissan, Renault and Chevrolet use pouch cells. The capacity of Li-Ion batteries (Kolly, 2014), depending on the type and manufacturer, varies from 3 to 300 Ah. For example, Tesla uses LNCAO cylindrical cells with 3.4 Ah per cell.

RANKING OF DIFFERENT TYPES OF BATTERIES

Different types of batteries: Pb, Ni-Cd, Ni-MH and Li-Ion are ranked in this paper by using PROMETHEE II method (Brans, 2005), (Mareschal, 2011-2023) as given in Fig. 4 a) and b), for the chosen weighting coefficients and the chosen criteria.

The criteria for ranking are: working temperatures range (WTR), self-discharge (SD), specific energy (SE), lifetime (LT), number of cycles (NC), cost (Cost) and charge/discharge efficiency (Eff) as denoted in Fig. 4 b). The chosen weighting coefficients are: 20 % for the WTR, 10 % for the SD, 20 % for the SE, 10 % for the LT, 10 % for the NC, 20 % for the cost and 10 % for the charge/discharge efficiency. The best ranked technology is the Li-Ion battery, followed by Pb, Ni-Cd and Ni-MH. The values of the flow Phi+, Phi-, and Phi = (Phi+) – (Phi-) are given in Table 3.

Figure 4 b) shows the PROMETHEE rainbow. For each alternative above the rectangle that denotes the alternative is the list of criteria for which it is preferable over other alternatives. Under the rectangle is the list of criteria for which the alternative is less preferable over other.

Table 3. Flow table for the battery technologies ranking.

Rank	Alternative	Phi	Phi+	Phi-
1	Li-Ion	0.6333	0.7667	0.1333
2	Pb	-0.0667	0.4667	0.5333
3	Ni-Cd	-0.1000	0.4333	0.5333
4	Ni-MH	-0.4667	0.2333	0.7000

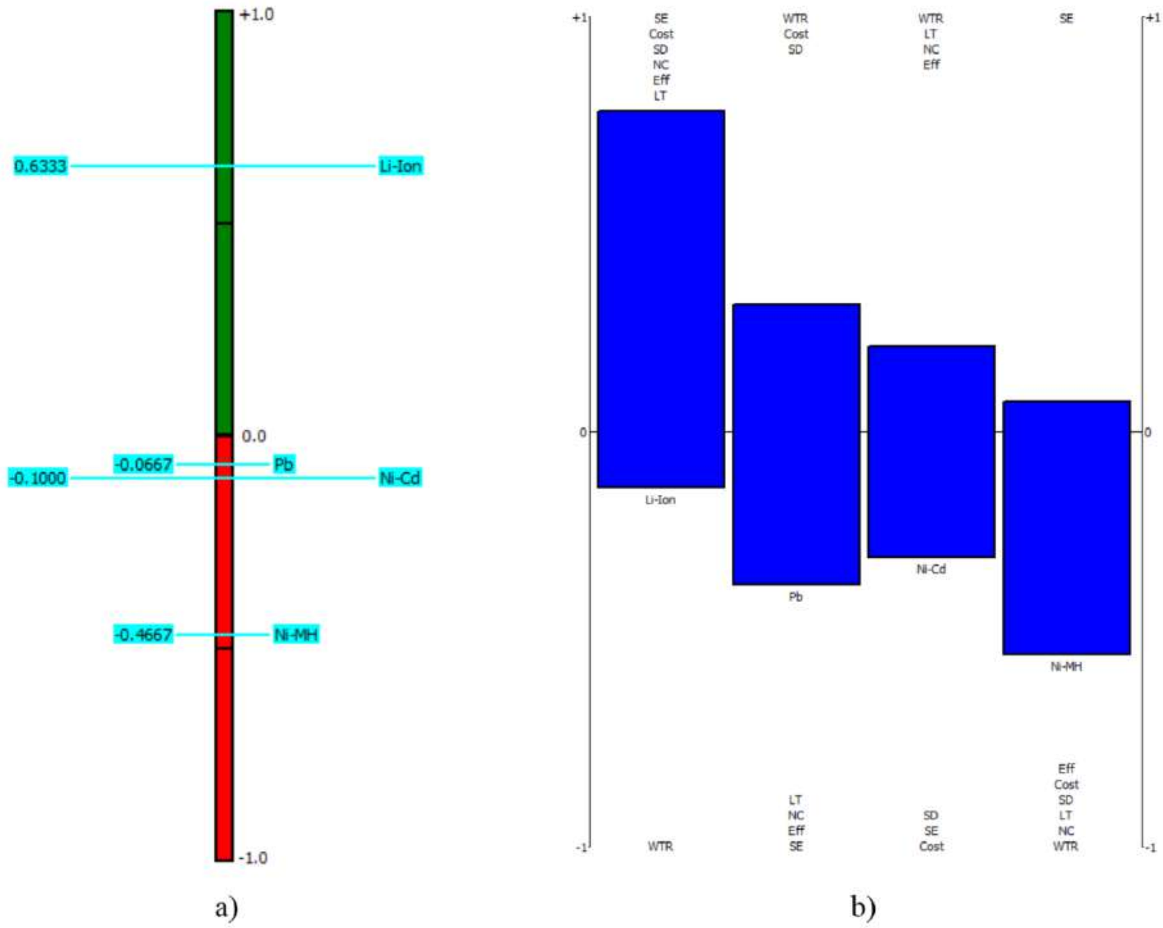

Figure 4. a) Ranking of different battery technologies by using PROMETHEE II method; b) PROMETHEE rainbow.

CONCLUSIONS

The most important characteristics of the recent battery technologies for electric vehicles are analysed in this paper such as the working temperatures range, the self-discharge rate, the specific energy, the lifetime, the number of cycles, the cost per energy unit, and the charge/discharge efficiency. There are also characteristics that are not analysed in this work, but may be important, such as the risk of fire, toxicity, recyclability, risk of environment pollution, and other. For the chosen weighting coefficients of the selected criteria, the ranking of battery technologies is done by using the PROMETHEE II method.

The best ranked among four alternatives of battery technologies are lithium-ion (Li-Ion) batteries, followed by lead-acid (Pb) and nickel-cadmium (Ni-Cd) batteries, and the worst ranked are the nickel-metal hydride (Ni-MH) batteries, as for the chosen criteria and their weights.

The presented procedure can be used in further research for a greater number of various criteria and for the weighting coefficients determined by some of the subjective weighting methods.

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ARSENIC SEPARATION STRATEGY USING NATURE-BASED SOLUTIONS: COMBINED AND HYBRID SYSTEMS

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Abstract: Arsenic (As) contamination of water is a ubiquitous problem affecting more than 1.3 % of current world population. Different water purification technologies were applied to mitigate the problem, however, each of them has certain limitations. To overcome limitations of single technology, integrated systems of two or more technologies were investigated for arsenic removal. The study explained utilisation of two novel *eco-friendly* materials (coagulant and adsorbent) within single and integrated technology, for the arsenic reduction from water. The results showed that removal efficiency was affected by the type of system (single or integrated) and the type of two system integration and showed the best results when combined system was applied. Slightly less efficiency had hybrid system where there was a successive addition of coagulant and biochar to treated water, respectively. Although the results showed a potential of combined and hybrid systems to remove arsenic from aquatic matrix, it should be noted that the present study serves as an indication for further study with real aquatic matrixes and directions for technology optimisation and reaching its full potential.

Keywords: *integrated systems; coagulation; adsorption; green technology; sustainable solutions.*

INTRODUCTION

Arsenic (As) contamination is a global phenomenon as it is reported that more than 100 million people (more than 1,3% of current world population) are exposed to As concentration higher than 10 µg/L (Kobya et al., 2020; Shakoor et al., 2018). 10 µg/L is recommended by The World Health Organization (WHO) as an upper safe (permissible) limit in drinking water (Edition, 2011). However, in less developed countries and countries where there is a constant excessive level of As, that limit is higher and amounts to 50 µg/L (Camacho et al., 2011; Chakraborti et al., 2010). It is noted that some of the most As contaminated waters are located in Bangladesh, India, China, Taiwan, Philippines, North and South America, Croatia, Hungary, Romania, as well as in Serbia, with the highest concentration of 48,000 µg/L reported in the Western USA (Habuda-Stanić et al., 2007). In Vojvodina municipality, the north part of Serbia, groundwater contains up to 750 µg/L of As (Kristoforović-Ilić et al., 2009). Arsenic originates dominantly from natural sources like soil, rocks, and sediments but also from several anthropogenic sources. Due to its carcinogenic effects on living beings, arsenic is concerned as a group-I human carcinogen (Asere et al., 2019)., however it should be noted that As exists in organic and inorganic form, and that some of them are more toxic than others. In water As is usually present in form of inorganic oxyanions arsenite - As (III) and arsenate - As (V) (Ozola et al., 2019). In comparison to arsenate, arsenite is far more toxic (around 60 times) (Tsiepe et al., 2018). In which form As will occur highly depends on pH value and redox potential (Eh) of the medium (Figure 1).

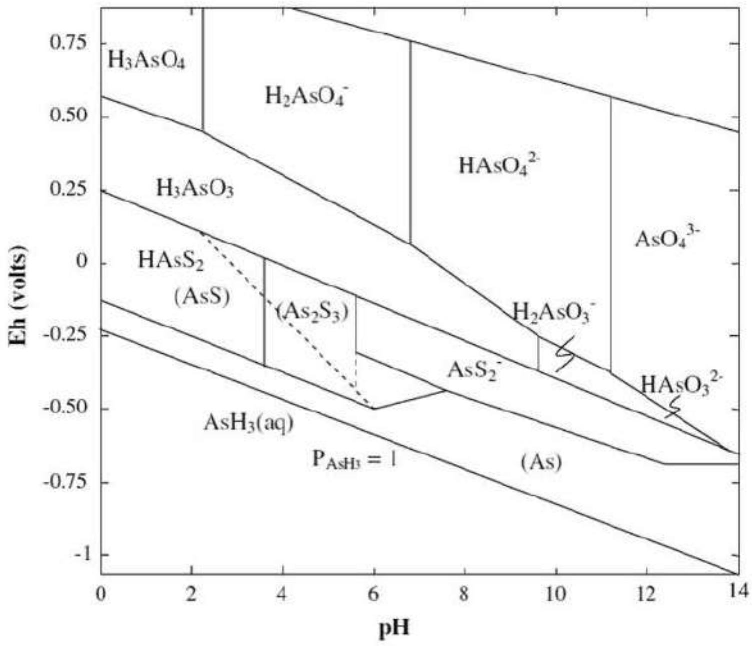

Figure 1. Diagram of different As ionic species occurring on different pH and redox potential (Eh) (Asere et al., 2019)

Different technologies were applied in order to reduce arsenic from aquatic matrixes, including adsorption, ion exchange, electrocoagulation, chemical precipitation, phytoremediation and membrane processes (each of them having their advantages and limitations) (Alka et al., 2021). An integrated systems were less investigated, usually including expensive membrane systems (Pessoa Lopes et al., 2020; Wang et al., 2024). Hence, there is still a lot of space for research in this area. Integrated (hybrid or combined) systems represent systems composed of two or more conventional/advanced/low-cost technologies which complement each other in such a way that advantages of one technology are used for overcoming lacks/limitations of another to achieve complete eradication of target pollutants and/or reduce cost of applied treatment processes (Radovic et al., 2023). Although different authors have different interpretations of hybrid and combined systems, herein, one-stage integrated processes will be denoted as hybrid processes, whereas successive processes will be characterised as combined processes. For instance, it has been noted that adsorption technology is highly effective but can have limitations such as adsorbent bed saturation and need for their replacement. The idea of prolonging self-life of adsorbent is to apply another technology, such as coagulation as a pre-treatment or part of hybrid system and reduce materials that can cause clogging or occupation of adsorption active sites, needed for the adsorption of targeted pollutants. Along with tendency to achieve the highest removal of targeted pollutants, there is a constant need for more *eco-friendly* and cost-benefit approach in water management systems. Hence, investigation of alternative materials, which will be used in water purification technology is another important strategy in this sector.

Present work gives an overview of two novel *eco-friendly* materials production and their utilisation for arsenate (As (V)) reduction from model water. Removal efficiency of those materials is emphasised in both, single and integrated systems (coagulation and adsorption). The comparison of the results will give an important insight into technology performances and the potential and need for system integrations in this sector.

MATERIALS AND METHODS

Eco-friendly coagulant and low-cost biochar preparation

Novel *low-cost* biochar was prepared from abundant waste biomass from oil industry - sunflower seed hulls (SSH). First, the SSH were cleaned from eventual impurities and washed with tap water. Washed hulls were oven-dried at 100 °C, milled and sieved (particles size between 800 µm and 2 mm in diameter were used in further experiments). The sieved SSH were functionalised with $FeSO_4$. Biomass was immersed in previously prepared 9.5 % $FeSO_4$ solution (9.562 g of $FeSO_4$ in 100 mL Milli-Q water) at 35 % wt mass ratio of Fe to biomass and stirred for 2 h. Suspensions were than left in the oven at 105 °C overnight, after which they were thermally treated in muffle furnace (Carbolite CWF 1200) at 650 °C for 15 min. Obtained biochar (FeSUN) was washed with Milli-Q water until pH near neutral, dried in the oven at 105 °C, grounded in mortar and kept in air-tight bags before usage.

Novel eco-friendly coagulant was produced from common bean seeds (*Phaseolus vulgaris*). Production process considered three steps: grinding and screening, extraction and drying (Radovic et al., 2022). First, bean seeds were ground in a mechanical mill and sieved to <0.4

mm. Smaller powder fraction was used for an ultrasound extraction with distilled water as extraction agent. Prior to extraction, bean suspensions were prepared by suspending at a ratio of 1/20 powder/extraction agent. The ultrasound frequency used within ultrasound extraction was 40 kHz for 45 min at 42 °C. The optimal extraction conditions were determined experimentally (unpublished data). After extraction, suspensions were filtered through a filter paper (Macherey-Nagel, MN 651/120) to obtain crude extracts of active components. Crude extracts were poured in glass beakers and left in the freezer, overnight. Finally, frozen extracts were freeze dried in a freeze dryer (Alpha 1-2 LDplus, Martin Christ Gefriertrocknungsanlagen GmbH, Germany) under vacuum at 0.07 mbar and at -45°C for 48h.

Model water

Experiments were conducted on model water, kaolin suspension (200 nephelometric turbidity units (NTU)) spiked with arsenate solution (initial As (V) concentration was set to be 20 mg/L). Detailed preparation of kaolin suspension was previously explained in the work of Antov et al. (2012). Initial pH 6 was adjusted by HCL addition.

Jar test experiments

Before conducting jar-test experiments, powdered coagulants were returned from their powdered into liquid form (suspension of 0.1716 g of UVO coagulant into 10 mL of distilled water). Suspension was moderately stirred for 10 min on a magnetic stirrer, and it was ready for use.

1 mL/L of UVO coagulant (dosage was determined based on the previously conducted experiments – unpublished data) was added during fast mixing to 600 mL beakers containing 200 mL of model water. Model water mixed without a coagulant created a blank sample. Samples were first mixed fast (200 rpm) for 1 min, then slowly (60 rpm) for the next 30 min and finally left to settle for 1 h. After 1 h of sedimentation, the upper clarified liquid was collected, and pollutant concentration was measured.

Coagulation activity (CA) was expressed as arsenate removal, and it was calculated using the following equation:

$$Coagulation\ activity = \frac{(C_b - C_s)}{C_b} \times 100\ (\%) \qquad (1)$$

where C_b and C_s represent arsenate concentration (mg/L) of the blank and the samples, respectively.

Adsorption experiments

Adsorption experiments were conducted in batch mode. Adsorbent dosage was 2 g/L, while an initial arsenate concentration was 20 mg/L. Suspensions were stirred for 2 h (mixing speed (60 and 200 rpm)). Following the experiments, the treated suspension was filtered through 0.45 μm nylon filters (Fisherbrand nylon syringe filters, UK) and analysed for residual arsenate concentration.

The experiments were conducted in duplicates and the results were presented as average values with corresponding standard deviations. To calculate removal efficiency (R (%)) the following equation was used:

$$R = \frac{C_o - C_e}{C_o} x\ 100 \qquad (2)$$

Where C_o (mg/L) is initial arsenate concentration and C_e (mg/L) is residual arsenate concentration.

Combined and hybrid system experiments

Within combined system (denoted as C+A), coagulation was first conducted in previously explained regime. After sedimentation, supernatant was collected and used in further adsorption treatment. Adsorption treatment was conducted under previously denoted conditions. Removal efficiency was calculated using arsenate concentrations prior coagulation and after adsorption (Equation 2).

Hybrid systems were conducted in jar-tester in three regimes:

1) Simultaneous addition of coagulant and adsorbent (C&A). 1 min of fast mixing (200 rpm) followed by 2 h of slow mixing (60 rpm) and 1 h of sedimentation.
2) Successive addition of coagulant and adsorbent (1C2A). Firstly, coagulant was added to model water followed by 1 min of fast mixing (200 rpm) followed by 30 min of slow mixing (60 rpm). Secondly, adsorbent was added, and the slow mixing was continued for another 2 h. Finally, suspensions were left to settle for 1 h.
3) Successive addition of adsorbent and coagulant (1A2C). Firstly, adsorbent was added to model water and mixed under fast regime (200 rpm) for 15 min. Afterwards, coagulant was added, and the fast mixing continued for another 1 min followed by slow mixing (60 rpm) for another 30 min and 1 h of sedimentation.

Coagulant and adsorbent dosages were 1 mL/L and 2 g/L, respectively. Initial arsenate concentration was 20 mg/L and the pH of model water was 6. All the experiments were conducted in duplicates and presented with corresponding standard deviations.

RESULTS AND DISCUSSION

The results of single and integrated systems show that there was a significant difference in arsenate removal efficiency (R (%)) achieved by single coagulation technology and other types of treatment, under tested conditions (Figure 2). Coagulation showed almost no activity (R < 5 %), whereas adsorption and integrated systems achieved over 25 % of arsenate removal. However, herein coagulation was applied with different primary purpose, to reduce turbidity and make arsenate adsorption easier (optimisation of turbidity removal was previously studied, unpublished data). Influence of coagulation on adsorption effectiveness could be seen by the comparison of adsorption and combined and integrated system activity. Single adsorption has comparable results to those of integrated systems, having even higher efficiency in comparison to hybrid systems (in C&A and 1A2C regimes of coagulant and biochar addition). However, combined system (C+A) showed the highest effectiveness for arsenate removal, while slightly less effectiveness was achieved by hybrid system where coagulant was added first to model water, and which has relatively similar working regime to combined system. This might be attributed to the fact that coagulation succeeded to decrease turbidity removal (caused by kaolin in model water) and positively affected adsorption of targeted anions. This is yet to be investigated in more complex aquatic matrixes saturated with different compounds which could interfere adsorption of targeted pollutants. Moreover, experiments were conducted in batch mode and there is an assumption that coagulation influence on adsorption performance would be much obvious and much higher in fixed-bed working regime, where there is a constant inflow of new untreated water. It is expected that coagulation as a pre-treatment will prolong adsorption bed self-life and lead to higher and prolonged targeted pollutants removal (arsenic in this case). This is considered as an important task for future study.

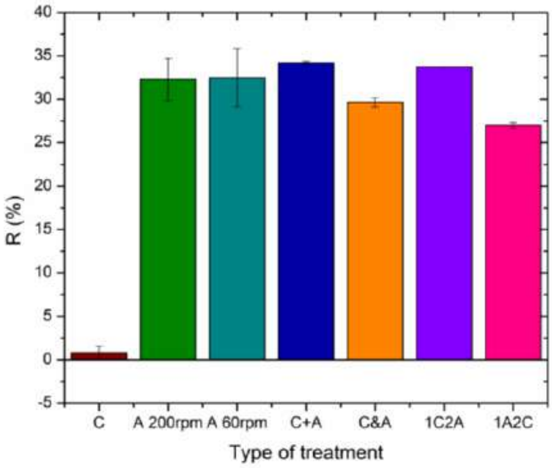

Figure 2. Comparison of different single and integrated technology effectiveness for arsenate removal from water (C-coagulation, A 200 rpm – adsorption conducted in fast mixing regime of 200 rpm, A 60 rpm – adsorption conducted in slow mixing regime of 60 rpm, C+A – coagulation followed by adsorption, C&A – simultaneous coagulant and adsorbent addition, 1C2A –hybrid system, coagulant addition followed by adsorbent addition, 1A2C –hybrid system, adsorbent addition followed by coagulant addition)

CONCLUSION

Combined and hybrid systems which use alternative *eco-friendly* materials have a good potential to remove As (V) from water. They could enhance performance of single technologies, however, should be thoroughly investigated in more environmentally relevant conditions. Future studies should include more complex aquatic matrixes, containing different organic and inorganic matter, which could interfere removal of selected pollutants. Furthermore, considering influence of coagulation on adsorption technology should be investigated in fixed-bed regime and later pilot and real scale, to reveal their full potential.

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ORGANIC SOLVENTS AS HAZARDOUS MATERIALS IN THE CHEMICAL INDUSTRY

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Abstract: Human activities during the work process can lead to specific hazards that negatively affect people, the abiotic environment, and property. The level of negative impact on people, flora and fauna, the abiotic environment, and property will depend on the characteristics of generated stressors, which, in chemical industry, are usually viewed in terms of hazardous materials and exposure to them. This paper reviews the most frequently used organic solvents as hazardous materials in the chemical industry. The paper presents a methodology according to which the fire/explosion and toxic properties of hazardous materials are classified and lists different categories of organic solvent hazards in terms of flammability, toxicity, and environmental impact.

Key words: *hazardous materials; organic solvents; toxicity; fire and explosion properties*.

INTRODUCTION

Hazardous materials used in industry, which have immediate practical value, may possess varying degrees of toxicity and pose a threat to human health upon exposure. Additionally, hazardous materials may exhibit properties such as flammability, explosiveness, corrosiveness, reactivity, etc., thereby potentially having a destructive impact on the environment. Therefore, it is necessary to study and analyze the properties of hazardous materials with the aim of establishing preventive and protective measures against their unwanted harmful effects. Due to the significant and ever-increasing risks associated with the application and use of hazardous materials, adherence to the International Program on Chemical Safety (IPCS) is essential. The primary objective of IPCS is to define procedures ensuring the safety of the work and natural environment, whereby safeguarding the health of individuals exposed to hazardous materials is the priority.

Due to their potential to endanger human health and property and degrade the environment, hazardous materials are considered within the chemical industry in the context of continuous adverse effects on environmental media such as air, water, and soil in case of uncontrolled emissions, accident events, and handling of waste with hazardous material properties.

PROPERTIES OF HAZARDOUS MATERIALS

The hazardous materials used in modern technological processes undergo changes and may have harmful effects on humans and the environment. The transformation of hazardous materials into harmful ones can occur even under normal conditions of technological process application, as well as during specific accident events, such as fires, damage, explosions, uncontrolled discharges, etc. The properties of some harmful substances under specific conditions have yet to be determined with a high degree of relevance. To eliminate or minimize unwanted effects during the use and handling of hazardous materials, as well as during hazardous events, it is imperative to know the basic properties of hazardous materials to which individuals are exposed. The essential information required for the use and handling of hazardous materials includes the following: chemical name and trade name, general properties (chemical, physicochemical, physical), molecular formula and structural formula, molar mass (M-g/mol), CAS number, ADR number, UN number, fire and explosion properties, toxic properties, corrosive properties, and radioactive properties. Knowledge of the basic physicochemical properties of hazardous materials enables the understanding of their phase transformations and solubility, which is important for analyzing the impact of hazardous materials on the work and natural environment. For example, if the boiling point is lower, the material's volatility is higher, and the retention time of materials in a specific environmental medium, as well as in the technological process, is shorter. Substances with a lower boiling point evaporate more rapidly, allowing for an increase in their concentration in the work and natural environment atmosphere.

Fire and explosion properties of hazardous materials

The basic properties of fire-and-explosion-prone hazardous materials are examined through the following properties: ignition, combustion, self-ignition, spontaneous heating, smouldering, and explosion temperatures, flammability group, minimum oxygen concentration for explosive hazards, minimum ignition energy, and minimum extinguishing concentration, flammability limits of vapour in air, combustion rates, burning, and pressure rise during explosion, heat of explosion, explosion pressure, parameters for detonation waves, flaring duration, heat doses, and mass fraction of released explosive material. The fire and explosion properties of substances used in the chemical industry are particularly considered when making decisions on storage methods and conditions as well as during handling. In the management of risks associated with the use of volatile solvents, special attention is paid to conditions that can lead to explosions due to static discharge and other sources of ignition. Parameters considered for the analysis of flammability and explosiveness of substances include: boiling point, flash point, autoignition temperature, electrical conductivity, and vapour pressure.

For example, solvents with a low boiling point and high volatility form flammable mixtures in the air at pressures present during evaporation, and if their electrical conductivity is low, they pose a much greater risk of ignition by electrostatic discharge compared to other solvents.

There are various methodologies for selecting solvents that are safer for the environment and human health. One applicable methodology is the one proposed by the National Fire Protection Association (NFPA).

Toxic properties of hazardous materials

In the narrower sense, the toxic effect is a process involving two components: a toxic substance (toxicant), as the active factor, and a living organism (parts of a cell, a cell, a tissue, an organism), as the reacting structure of a biosystem (Figure 1).

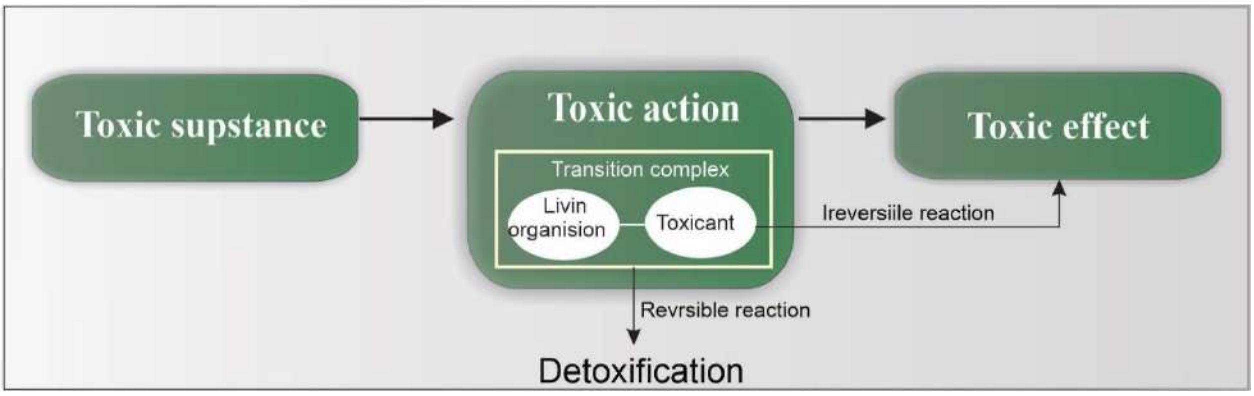

Figure 1. Cause-and-effect relationship between a toxicant and a biosystem

Slightly toxic substances cause irritation to certain organs, as a reversible and transient toxic effect. Moderately toxic substances cause not only reversible but also irreversible changes to certain organs. Highly toxic substances, during short-term or consecutive prolonged action, induce only irreversible, life-threatening, changes. Extremely toxic substances result in irreversible consequences for humans, including fatal outcomes. Super toxic substances lead to fatal outcomes for one or more individuals even after a brief contact. The intensity of the toxic effect is proportional to the concentration of the toxic substance and ranges from mild inflammatory reactions to tissue necrosis (chemical burns). Substances of unknown toxicity are a group of substances whose toxicity has not yet been studied, or for which there is no data in the literature, or, if data exist, they are insufficiently reliable. There are several different methodologies used to determine the degree of substance toxicity. One possible methodology is based on knowing the class of substance toxicity and the class of substance volatility as given by the REHRA methodology. The class of substance toxicity is determined based on experimentally determined values of the median lethal dose (LC_{50}) after a four-hour exposure, while the class of volatility is determined based on the knowledge of physicochemical parameters such as vapour pressure (Pp) at a temperature of 20°C and normal boiling temperature (Tk), and based on working pressure (P) (Table 1) (Đorđević, A., Stevanović, V. (2020)).

The European Chemicals Agency (ECHA) has also categorized the degree of substance toxicity. When evaluating the quality of the work environment, in terms of safety during work with toxic substances, legally prescribed maximum allowable concentrations (MACs) are also utilized.

Table 1. Degree of toxicity as a function of LC_{50} and volatility class

Degree of toxicity in relation to LC_{50}		Volatility classes for liquids and gases			Toxicity	
$LC_{50rat - (4h)}$ (ppm)	Class (tox)	Phase	Pressure Temperature	Class (vl)	tox+vl	Degree
0.01 - 0.1	8		Pp ≤ 0.05 bar	1	< 6	Low
			0.05 bar < Pp ≤ 0.3 bar	2		
		Liquid	Pp > 0.3 bar	3		
0.1 - 1	7				7	Moderate
		Gases converted to liquid under pressure	Tk > 265 °K	3		
1 - 10	6		Tk ≤ 265 °K	4	8	High
10 - 100	5					
		Gases converted to liquid by freezing	Tk > 245 °K	3	9	Very high
100 - 1000	4		Tk ≤ 245 °K	4		
1000 - 10000	3	Gases under pressure	P < 3 bar	2		Extreme
			3 bar ≤ P < 25 bar	3	10-12	
10000 - 100000	2		P ≥ 25 bar	4		

CLASSIFICATION OF FIRE/EXPLOSION AND TOXIC PROPERTIES OF ORGANIC SOLVENTS

Substances are classified into ten categories based on their fire and explosion properties and toxic properties according to the NFPA and ECHA methodology. Flammability and explosiveness are considered from the aspect of electrostatic charge, and electrical resistance is observed depending on the source and purity of the applied solvents as well as other substances dissolved in the solvent. The basic criterion for such a classification of solvents, as toxic substances, is human exposure to saturated concentrations at 20°C compared to the maximum allowable concentrations in the workplace. According to this classification of solvents, solvents classified as category 1 have a lower risk of flammability, explosiveness, and toxicity, while solvents in category 10 pose the highest risk. The classification is further simplified through the use of colours to code the groups, ranging from 1 to 3 in green, 4 to 7 in yellow, and 8 to 10 in red. The American Chemical Society (ACS) also applies this classification (Table 2) (Henderson, K. R., Jimenez-Gonzalez, C., Constable, J. C. D., Alston, R. S. (2011); Technical EIA guidance manual for the integrated paint industry, IL&FS, Ecosmart Limited Hyderabad, 2010).

Table 2. Hazard categories of commonly used organic solvents in the chemical industry

Substance (CAS no.)	Hazard		
	Flammability and explosiveness	Toxicity	Environmental impact
Benzene C6H6 (71-43-2)	3	1	3
Toluene C_7H_8 (108-88-3)	4	4	3
Xylene C_8H_{10} (1330-20-7)	7	2	7
Naphthalene $C_{10}H_8$ (91-20-3*)	-	-	-
Methanol CH_4O (67-56-1)	5	5	9
Ethanol C_2H_6O (64-17-5)	6	8	8
Propanol C_3H_8O (71-23-8)	7	5	7
n-Butanol $C_4H_{10}O$ (71-36-3)	8	5	7
Amyl alcohol $C_5H_{12}O$ (123-51-3)	9	7	6
Cyclohexanol $C_6H_{12}O$ (108-93-0)	9	7	6
Ethylene glycol $C_2H_6O_2$ (107-21-1)	10	7	8
Benzyl alcohol C_7H_6O (100-51-76*)	-	-	-
Ethyl ether $C_4H_{10}O$ (60-29-7)	2	5	4
n-Propyl ether $C_6H_{14}O$ (108-20-3)	1	8	3

Dioxane $C_4H_8O_2$ (123-91-1)	4	4	4
Acetaldehyde C_2H_4O (75-07-0*)	-	-	-
Acrolein C_3H_4O (107-02-8*)	-	-	-
Furfural $C_5H_4O_2$ (98-01-1*)	-	-	-
Aceton C_3H_6O (67-64-19	4	8	9
Acetic acid $C_2H_4O_2$ (64-19-7)	8	6	8
Formic acid HCOOH (64-18-6)	3	10	4
Methyl formate $C_2H_4O_2$ (107-31-3*)	-	-	-
Ethyl formate $C_3H_6O_2$ (109-94-4)	4	5	6
Methyl acetate $C_3H_6O_2$ (79-20-9)	4	7	9
Ethyl acetate $C_4H_8O_2$ (141-78-6)	4	8	8
Chloroform $CHCl_3$ (67-66-3)	6	3	6
Carbon tetrachloride CCl_4 (56-23-5)	4	3	5
Ethyl chloride C_2H_5Cl (75-09-2)	6	4	6
Dichloroethylene $C_2H_4Cl_2$ (107-06-2)	6	2	4
Trichloroethylene C_2HCl_3 (79-01-6*)	-	-	-
Tetrachloroethylene C_2HCl_3 (127-18-4*)	-	-	-
Chlorobenzene C_6H_5Cl (108-90-7)	8	4	6
Aniline C_6H_7N (62-53-3*)	-	-	-
Pyridine C_5H_5N (110-86-1)	7	4	4
Acetonitrile C_2H_3N (75-05-8)	6	6	6
Nitrobenzene $C_6H_5O_2N$ (98-95-3*)	-	-	-
Carbon disulfide CS_2 (75-15-0)	1	2	6
Methyl glycol $C_3N_8O_2$ (109-86-4)	7	2	8
Ethylene glycol $C_4N_{10}O_2$ (107-21-1)	10	7	8
Diethylene glycol $C_4N_{10}O_3$ (111-46-6)	9	7	8
o-Chloroaniline C_6N_6ClN (95-51-2*)	-	-	-

*****No classification data was found in the literature*

Classes of organic solvents are determined based on the correlation of cause-and-effect vulnerability of the exposed object and/or exposed subject and resistance - the ability of the system, community, or society to adapt or return to the previous level of functioning.

Classification of hazardous materials, based on the knowledge of their chemical and physicochemical properties, enables the proper selection of precautionary and preventive measures when handling and working with hazardous materials.

Table 2 provides an overview of the most prevalent organic solvents used in technological processes within the chemical industry, their impact on human health and the environment, and their danger in terms of flammability and explosiveness, which is particularly considered when assessing accidental events.

As one of the general precautionary measures when working with toxic and flammable materials, examining the possibility of replacing some materials with others that are less hazardous is recommended. In many cases, such attempts at substitution have not yielded satisfactory results; nevertheless, efforts to replace hazardous materials with others have also produced certain positive results. Table 3 provides a list of substances that can be replaced with substances that have less destructive effects on humans and the environment and that are also used in the paint and varnish industry.

The substitution of materials with less hazardous ones is possible but in a limited number of cases. In technological processes involving the use of volatile organic solvents, it is often the case that no substitution is possible, so that even those substances classified as highly hazardous materials are used.

Table 3. Substances that can be substituted by less destructive substances

Organic solvents	Most common substitutes
Toluene	Water-based product, xylene (mixed isomers), acetone, powder, ethyl acetate
Xylene	Water-based product, toluene, o-xylene, acetone, powder
Methanol	Isopropanol, water-based product, ethanol
Trichloroethylene	1-Bromopropane, water-based product
Tetrachloroethylene	p-Chlorobenzotrifluoride

As a precautionary measure in calculations of ventilation, recuperation, and maximum allowable concentrations of flammable substances in the air, data on flammability limits are used to avoid the possibility of ignition and explosions in devices or in workspaces.

For the purpose of approximate calculation of flammability concentration limits, an approximation formula is applied:

$$\varphi_{zapr}\% = \frac{100}{a_M \beta + b_M}, \tag{1}$$

where: $\varphi_{zapr}\%$ – lower/upper flammability limit in volume percent; a_M and b_M - constants.

Parameter β u formula 1 depends on the elemental composition of the compound being investigated and is calculated according to the formula

$$\beta = m_C + m_S + \frac{m_H - m_X}{4} - \frac{m_O}{2} + 2.5 m_P, \tag{2}$$

where m_C, m_S, m_H, m_O, m_P are numbers of carbon, sulfur, hydrogen, oxygen, and phosphorus atoms, respectively, while m_X represents the number of halogen atoms in the molecule of the compound being investigated, which oxidize hydrogen to halogenated hydrogens and carbon to halogenated carbons of the CH_4 type.

Considering that pollutants are emitted in the workplace in the form of dust, smoke, gases, or mist, thereby polluting the air the exposed workers breathe, an organized system of workplace ventilation should be applied. The amount of fresh air that needs to be introduced into the room to reduce the concentration of hazardous substances below the maximum allowable concentration in the workplace (MAC_{gr}) can be calculated using the expression (Stojadinović J. Danijela (2023))

$$L = \frac{1000\,G}{MAC_{gr} - C_{HM}}, \tag{3}$$

where: L (m^3/h) - fresh air rate required to dilute the air polluted with hazardous materials to a concentration below the value of MAC_{gr}; G (g/h) - mass of hazardous materials in the air of the workplace per hour; MAC_{gr} (mg/m^3) - maximum allowable concentration of hazardous materials in the air of the workplace; C_{HM} (mg/m^3) - current concentration of hazardous materials present in the fresh air used to dilute the polluted air.

It is crucial that the concentration of hazardous materials in the fresh air used for diluting polluted air be lower, not exceeding 30% of the MAC value. The values of emission concentrations of organic solvents are usually determined based on the consumption of the amount of solvent used, rather than on current or continuous measurements. Generally, there is little information available on emissions of volatile organic solvents occurring under regular work conditions. Since emissions are not quantified, there are no available data on emission factors that can be used to assess technological and environmental risks. Emissions occurring during accidental events can have a significant impact on environmental degradation and the health of exposed surrounding populations. The risk associated with such emissions depends on the basic properties of the solvent and the quantity involved in the accidental event.

CONCLUSION

Various technological processes used in the chemical industry utilize a large number of substances, which differ in their properties and characteristics. These substances include those that can be classified as hazardous. Upon comparison of the substances classified as hazardous materials used in the chemical industry, it can be concluded that the most significant risks to the work and natural environment and human health are associated with the use of volatile organic solvents. In order to prevent adverse effects on the environment and on exposed workers, precautionary measures are implemented during regular operations and during handling of volatile organic solvents. The proper selection of precautionary measures requires the knowledge of chemical and physicochemical properties of substances, specifically their flammability, explosiveness, and toxicity. Modern trends in the chemical industry are focused on substituting hazardous substances with less hazardous ones to be used in given technological processes. However, in some cases, such substitution is still not possible, and some processes even involve substances classified as highly hazardous materials, whose use is justified in terms of meeting the visual and functional requirements of the final product.

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ASSESSMENT OF THE QUALITY OF THE RIVER IBAR USING SWQI

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Abstract: The paper deals with the importance of preserving the natural environment by improving the quality of watercourses using a new approach to surface water quality analysis through Serbian Water Quality Index (SWQI). Data from the Serbian Environmental Protection Agency for the year 2022 were used, focusing on the hydrological measurement stations at Batrage, Raška, and Kraljevo along the course of the Ibar River. The research results indicate that the water quality of the river Ibar, based on the SWQI values ranging from 80 to 92, is classified as "good". This suggests a relatively favourable water quality in accordance with EU water protection standards and other relevant directives, but also implies the need for further efforts in preserving and improving the quality of watercourses for the purpose of long-term protection of this valuable resource. This paper contributes to the understanding of the conditions of water resources, emphasising the importance of their protection for environmental sustainability and community well-being.

Keywords: *SWQI index; the Ibar River; water pollution; water quality*

INTRODUCTION

The Serbian Water Quality Index (SWQI), developed by the Serbian Environmental Protection Agency (SEPA), was used in a series of studies to assess water quality at various locations and during different time periods across the country. In the period from 2001 to 2006, SWQI was applied to assess water quality in the main watersheds in Serbia, such as the Sava River, the Velika Morava River, Vojvodina Province, tributaries of Lake Đerdap and the Danube (Veljković et al. 2008). Afterwards, from 2004 to 2011, the SWQI was used to assess the water quality of the Sava River in Vojvodina Province (Bjelajac et al. 2013), while from 2003 to 2012, the water quality of the Tisa River was analysed (Leščešen et al. 2014). In addition, SWQI was a key tool for evaluating the water quality in the Gruža reservoir from 2003 to 2010 (Stefanović et al. 2012), as well as for analysing the water quality in the Barje reservoir from 2005 to 2009 (Takić et al. 2011). Furthermore, SWQI was used to analyse the water quality index of the Ibar

River from 2007 to 2013 (Elezović et al. 2018). These studies provide valuable insight into the state of water quality at various locations in Serbia over the past decades, while also highlighting the importance of applying SWQI in monitoring and preserving water resources (Jakovljević, 2012).

The analysis of water quality in the Republic of Serbia represents a key initiative for preserving the environment and ensuring adequate protection of water resources. The Environmental Protection Agency is responsible for implementing the water quality monitoring program, which involves systematic collection, processing, and analysis of data. Access to water quality analysis requires a thorough analysis of data available in the database of the SEPA. This process comprises a detailed examination of various parameters of water quality, including chemical, physical, and biological characteristics. Through the systematic analysis of these data, potential sources of pollution can be identified, and the effectiveness of existing protection measures can be assessed. The factors that can affect water quality are diverse, including industrial and municipal wastewater, agricultural activities, as well as natural phenomena such as erosion and changes in the hydrological cycle. Based on the results of the analysis, appropriate measures are taken to reduce pollution and improve water quality (Elezović et al., 2018).

The paper focuses on assessing the water quality of the Ibar River in Serbia for the year 2022, using the SWQI. This methodology has been chosen for a detailed analysis and evaluation of effectiveness in assessing water quality in the specific case of the Ibar River. This research aims to provide a deeper understanding of the state of water resources in Serbia and to identify potential challenges and opportunities for improving water resource management in the future.

MATERIALS AND METHODS

Sampling area

The Ibar River represents a key hydrological entity within the Black Sea Basin, specifically within the West Morava Basin, as the largest and most significant tributary of the West Morava River. Its course extends over a length of 276 km, with a basin area of 8060 km² (Elezović et al., 2018).

The river Ibar springs from beneath Mountain Hajla (at an altitude of 1360 meters) in Montenegro, a few kilometres upstream from Rožaje town. The river flows eastward, entering the territory of the Republic of Serbia slightly south of Rožaje. It continues its course eastward all the way to Kosovska Mitrovica, where it accepts the tributary Sitnica and then turns northward, culminating its course in Kraljevo, where it flows into the West Morava. The basin of the Ibar River in the territory of Kosovo covers an area of 3966 km², which constitutes a significant portion of the total area of the Ibar basin and the length of its course. Significant tributaries of the Ibar River include the rivers Raška and Studenica on the left side, while notable tributaries on the right side include the rivers Sitnica and Jošanica (Elezović et al., 2018). These hydrological attributes make the Ibar River a vital water resource in this area, which preservation and protection require continuous monitoring and management. Water quality analysis, pollution control, and the implementation of adequate protection measures are key activities that need to be carried out to ensure sustainable use of this important natural resource (Elezović et al., 2015).

Various anthropogenic factors have a significant impact on the water quality of the Ibar River (Elezović et al., 2015). Uncontrolled discharge of wastewater as a result of anthropogenic, industrial, and economic activities has a significant negative impact on the water system, as untreated wastewater is discharged directly into the recipients without adequate treatment (Sremački et al., 2018).

The lack of a system for treating and channelling wastewater and protective buffer zones between agricultural land and aquatic systems has a negative impact on water quality (Sremački et al., 2018). The runoff of pollutants from roads, such as oil, gasoline, and other chemicals, during rainfall, additionally contaminates the Ibar River (Elezović et al., 2015). Inadequate maintenance of septic tanks in larger settlements can result in direct discharge of faeces matter into watercourses. Landfill leachate from municipal waste landfills may contain various toxic substances and chemicals that are discharged into the Ibar River. The use of chemical agents in agriculture, such as pesticides, can lead to the leaching of these substances from fields and into the Ibar River. Disposal of waste from livestock farms, both liquid and solid waste, can result in the release of pollutants into the watercourses of the Ibar River.

All these factors contribute to significant pollution of the Ibar River, with the discharge of untreated wastewater from settlements and industries standing out as the primary cause. Therefore, it is necessary to take comprehensive measures to reduce the impact of these sources of pollution and improve the water quality of the Ibar River.

DATA AND METHODS

Within the SEPA, an indicator has been developed for monitoring water quality, contemplated for both the professional community and the general public. This indicator is based on the Water Quality Index method (Development of a Water Quality Index, Scottish Development Department, Engineering division, Edinburgh 1976) (SRDD, 1976), which reduces ten key water quality parameters, such as biochemical oxygen demand (BOD_5), pH value, oxygen saturation, coliform bacteria, suspended solids, ammonium ions, nitrogen oxides, phosphates, temperature, and conductivity, to a single index number, thus reflecting the overall water quality.

Each of the mentioned parameters has a specific impact on water quality and is assessed accordingly, receiving an appropriate number of points in accordance with its significance.

Calculation of the index involves summing the products of parameters (q_i x w_i), where the goal is to achieve an index value of 100, which indicates ideal water quality. The results are interpreted on a scale from 0 to 100 using the SWQI classification system. This approach enables a comprehensive assessment of surface water quality, providing experts and the public with a clear picture of the state of water resources based on the analysis of key parameters.

Surface water quality indicators obtained using the SWQI method were analysed by comparison with the original Water Quality Index (WQI) indicators (SRDD, 1976; Elezović, 2013). Table 1. shows the adopted classification criteria for descriptive surface water quality indicators based on the calculated value of the SWQI index number.

Table 1. Indicators of surface water quality using the SWQI method presented with colors

	Numerical indicator	**Descriptive indicator**	**Color**
Serbian Water Quality Index	100-90	Excellent	
	84-89	Very good	
	72-83	Good	
	39-71	Bad	
	0-38	Very bad	
	/	No data	

*Source: *www.sepa.gov.rs*

The mean quantitative values of selected measured parameters of the river Ibar are calculated based on data collected by SEPA, which are available in the Water Quality Hydrological Yearbook for the year 2022 (SEPA, 2022). The numerical value of the water quality index is obtained using the software package developed by the SEPA.

RESULTS AND DISCUSSION

The results of the SWQI water quality index for the river Ibar, as well as the mean annual values of water quality indicator parameters at the measurement points Batrage, Raška, and Kraljevo, are given in Table 2.

Table 2. SWQI water quality index for the river Ibar for the year 2022.

Parameters	**Batrage**	**Raška**	**Kraljevo**
Temperature (°C)	9,99	12,15	12,92
pH value	8,21	8,02	7,58
Electrical conductivity (µS/cm)	306,33	498,16	441,50
Oxygen saturaton (%)	99,16	92,33	104,75
BOD_5 (mg/l)	1,67	2,76	2,61
Suspended matter (mg/l)	14,18	18,58	18,08
Total nitrogen oxides (mg/l)	0,12	1,75	1,39
Orthophosphates (mg/l)	0,04	0,11	0,33
Ammonium (mg/l)	0,08	0,16	0,12
Coliform bacteria (u 100ml)	/	/	/
SWQI	**92**	**80**	**80**

The results of the calculated values of the Serbian Water Quality Index (SWQI) for selected measurement points along the course of the river Ibar in 2022 indicate water quality ranging from 80 to 92, corresponding to the descriptive indicators "good" and "excellent”.

Specifically, at the inlet profile Batrage, the SWQI index was 92, while at the measurement stations Raška and Kraljevo it was 80. The overall quality of the river Ibar, calculated through the median of the ordered series of mean index values, is SWQI=84 for the monitored one-year period, which falls under the descriptive indicator "very good".

Analysis of data presented in Table 2, shows that the water at the measurement point Batrage is of the highest quality, while the water quality at the measurement stations Raška and Kraljevo gradually decreases.

A higher concentration of ammonium ions and total nitrogen oxides is observed at the measurement station Raška, compared to the other two measurement points, while oxygen saturation is the lowest in comparison to the other two measurement points. The BOD_5 parameter has the highest value at the measurement station Raška and the highest concentrations of electrical conductivity and suspended solids are also found at the measurement station Raška. These specified parameters indicate the presence of organic pollution and point to the need for more efficient treatment of municipal wastewater before it is discharged into the recipients, thus preserving the quality of the river Ibar.

The comparison of SWQI values with the results of previous research shows the significant improvement of water quality of the river Ibar in the year 2022. The reduction in the concentrations of ammonium ions and total nitrogen oxides indicates that the quality of the river Ibar is better than it was in 2011. However, an increase in the value of BOD_5 has been observed, indicating the presence of biological pollution. Therefore, future research should be devoted to identifying the causes of biological pollution.

CONCLUSION

The Serbian Water Quality Index (SWQI) methodology plays a crucial role in assessing the quality of the river Ibar. The analysis of the SWQI index has provided a deeper understanding of the environmental conditions along the course of the river Ibar during 2022. The results show that the water quality at the measurement station Batrage (SWQI = 92) is rated as excellent, while lower scores were assigned to the measurement stations Raška and Kraljevo (SWQI = 80), indicating the potential sources of pollution.

Identification of sources of municipal waste and the implementation of efficient technological solutions for purification represent crucial steps towards preventing further deterioration of the water quality of the river Ibar. Preservation of this valuable water resource requires continuous monitoring and implementation of appropriate environmental protection measures. Through a comprehensive approach to protection of water resources, it can be ensured that the river Ibar remains a clean and safe source of water for the environment and the local community in the forthcoming period.

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IMPACT OF MAGNETIC FIELDS ON PLANT SPECIES AND THE ENVIRONMENT

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Abstract: Plants and plant species can be found in environments with enhanced magnetic fields compared to Earth's natural magnetic fields. It has been observed that magnetic fields have effects on the metabolic activities of living organisms, including plants. Effects on germination, growth, and substance accumulation in plants have been noted, and the action can be both positive and negative. Plant species, as one of the fundamental elements of the environment, influence all environmental elements. Positive effects can be utilized to increase yields in agricultural production, while negative effects can impact individual species, ecosystems, and the overall environment. This paper provides a broader analysis of observed effects, proposes a methodology for study, presents conclusions from various research available in the literature, and suggests possible research directions and questions that need to be illuminated in this area.

Key words: *magnetic field, plant germination and growth, effects of magnetic fields on plants, environment and magnetic field*.

INTRODUCTION

Enhanced magnetic fields can occur in various places in the environment and can be natural or artificially generated. Under enhanced magnetic fields, we consider all magnetic fields that have values 50% higher or several times greater than natural magnetic fields. Fields of these intensities are generated by humans within electric distribution networks and infrastructure of various industrial processes accompanied by enhanced current strengths, as well as electronic devices that are sources of magnetic fields in households and medicine.

Electrical networks, transformers, and other electrical infrastructure generate magnetic fields as a byproduct of electric energy. High-voltage lines, in particular, can generate significant magnetic fields nearby. Various industrial processes such as steel production, oil refineries, electrolysis plants, power plants, and other industrial facilities can produce enhanced magnetic fields as part of their operations. Electronic devices that use magnets or electromagnetic components, such as electric motors, computer devices, televisions, and other devices, can be sources of magnetic fields in their immediate vicinity. Medical devices such as magnetic resonance imaging (MRI) and devices for diagnostics or medical therapy can produce strong magnetic fields for medical procedures.

Natural sources can also generate enhanced magnetic fields as natural geological phenomena; anomalies in Earth's magnetic fields and volcanic activities can generate increased magnetic fields, although usually, their intensity is not as high as artificial sources.

Humans generate magnetic fields primarily through the use of electric energy and technology that employs magnets or electromagnets. These fields can have various intensities and frequencies, which can affect their potential impact on the environment and human health.

The effects of magnetic fields on the living world can be demonstrated through their impact on plant life. The effects of magnetic fields on plants vary depending on the plant species, the intensity of the field, and the duration of exposure to the magnetic field. Positive effects have been observed, defined as effects of improved development, growth, and stimulation of certain plant expressions, mass of fruit, or enhanced production of a substance, but there are also negative effects that can endanger the survival and development of the plant or make it less resistant to external environmental agents. These positive effects, potentially improving growth rates and resistance to stresses, can be beneficial in agricultural production.

The negative effects are observed through various stressful impacts on plants, such as changes in normal development and metabolism, which can have harmful consequences over the long term. If this is linked to the ecocenoses and interdependencies with other plants and animals in the environment, the effects can be significant on both the environment and human health.

Magnetic fields are increasingly attracting attention in agricultural research due to their potential to transform traditional methods of cultivating plants. As an aspect of physics applied in biology, magnetic fields offer innovative approaches to controlling and enhancing plant growth, seed germination efficiency, and plant resistance to various abiotic stresses such as drought, salinity, and extreme temperatures. These impacts of magnetic fields can significantly increase yield, thereby directly contributing to food security, especially in regions susceptible to frequent climatic changes and extreme conditions.

Using magnetic fields in agriculture is not just a technological novelty; it is an opportunity to fundamentally change the way we understand and apply agricultural measures to improve production. For example, magnetic fields can be used for seed treatment before planting, which can result in faster germination and more robust plant growth in the early stages of their development. This is particularly important for crops that are sensitive to initial growth conditions and can have a significantly increased yield through a better start. Additionally, the application of magnetic fields can help reduce the use of chemical agents such as pesticides and fungicides by strengthening the natural defensive mechanisms of plants and making them more resistant to diseases and pests.

Furthermore, magnetic fields have the potential to improve the uptake of water and nutrients from the soil, which is crucial in conditions of limited resources or during drought periods. Optimizing these parameters can lead to a reduction in the need for irrigation, which is particularly relevant for arid and semi-arid zones where water is a precious resource. Managing magnetic fields allows for precise targeting and modification of biological processes within plants in a way that traditional methods cannot achieve.

This technology also opens doors for further research in the field of plant genetics, as the interaction of magnetic fields with plant tissues can provide insights into the mechanisms that regulate growth and development at the molecular level. Understanding these processes can contribute to the development of new varieties that are tailored for growth in specific, often challenging conditions, potentially pushing the boundaries of agricultural production.

METHODOLOGICAL APPROACH TO RESEARCHING THE IMPACT OF MAGNETIC FIELDS

Previous research has gone in several directions, and here the most significant procedures of research, some results, and potentials for further research that can determine the directions of likely future investigations will be stated.

Researching the impact of magnetic fields on plants requires a complex approach that combines various techniques and methodologies to obtain valid and reliable results. The methodology includes planning the experiment, selecting and preparing plant material, defining magnetic field parameters, monitoring plant growth and development, analyzing data, and interpreting the results. These steps are essential for understanding how magnetic fields affect plants in various ways.

Setting Up Experiments

The first step in the methodology is designing the experiment. This includes determining the type and strength of the magnetic field as well as the duration of exposure. A typical experiment for studying the effects of magnetic fields on plants includes exposing plants to magnetic fields of various intensities and durations. Magnetic fields can be applied using permanent magnets or electromagnets that allow precise control of intensity and orientation of the field. The experimental setup usually requires the development of special chambers or spaces where plants are exposed to the magnetic field under controlled conditions. Plants can be exposed to magnetic fields continuously or periodically depending on the specific research goals. To define the parameters of the experiment, various calculations and modeling are used to ensure that exposures are uniform and can be reliably replicated. These parameters include frequency, intensity, and duration of exposure to the magnetic field, which must be precisely controlled to minimize any unwanted side effects.

Selection and Preparation of Plant Material

The choice of plant material depends on the research goals. Fast-growing species such as wheat, peas, or lettuce are commonly used to quickly and efficiently monitor the effects of magnetic fields. Plants are grown under standardized conditions before the start of treatment to minimize variations not related to the magnetic field.

For experimental purposes, it is important to select plants that are in a similar stage of development and have similar physiological characteristics. This ensures that any changes in growth or development of the plants are due to the magnetic field and not genetic or environmental differences between individual plants.

Monitoring Growth and Development

Monitoring plants during the experiment includes detailed measurement of various aspects of their growth and physiology. This involves measuring the height of the plants, the number and size of leaves, the mass of roots and above-ground parts. Physiological responses of plants to magnetic fields, such as changes in chlorophyll content, photosynthesis activity, respiration, and antioxidant enzyme activity, are also tracked. A range of methods is used for detailed growth analysis, including digital photography of plants, 3D scanning, and traditional measurement methods. These techniques allow researchers to quantitatively assess how exposure to magnetic fields affects the growth and development of plants over time.

Biochemical and Molecular Analyses

Biochemical and molecular analyses are essential for understanding how magnetic fields affect internal processes in plants. These analyses include measuring levels of various growth hormones, enzymes, antioxidants, and other important molecules. Techniques such as spectrophotometry, gas chromatography, mass spectrometry, and various types of electrophoresis are used for detailed analysis of biochemical changes within plants.

Monitoring gene expression using quantitative PCR (qPCR) technology also provides insight into how plants respond at the molecular level to exposure to magnetic fields. This technique allows researchers to identify which genes are activated or inhibited by magnetic fields, which may indicate possible pathways through which plants adapt or respond to these conditions.

Drawing Conclusions from Conducted Experiments

Measurements and monitoring of plant elements are conducted to assess: stress and resilience, changes in biological and physiological mechanisms in plants, and growth outcomes, as well as to assess the ecological aspects of plant growth.

It is important to assess the ability of plants to tolerate abiotic stress under the influence of magnetic fields. In these studies, plants are exposed to stressful conditions such as drought, high or low temperatures, or salinity while simultaneously exposed to magnetic fields. Monitoring plant responses to stress, including levels of stress hormones, content of osmoprotectants, and activity of stress-responsive genes, helps to understand how magnetic fields can modify the response of plants to undesirable conditions. Ecological and long-term studies can provide conclusions about the impact of magnetic fields on ecosystem interactions and biocenoses. These studies may include analyzing how magnetic fields affect interactions between plants and pollinators, pests, and the soil microbiome.

Researchers in this field should particularly consider significant studies that describe research methodologies, highlighting several of the following. The study by Florez et al. (2007) describes in detail how controlled use of magnetic fields can affect water parameters, further influencing plant growth conditions. The study by Teixeira da Silva and Dobránszki (2013) used Arabidopsis thaliana to study the effects of magnetic fields on growth and development, showing how the choice of model organism can provide insight into specific physiological responses. The study by Maffei (2014) uses a range of techniques to monitor these parameters to evaluate how exposure to magnetic fields affects the evolution of plants at the physiological level. The study by Johnson et al. (2008) provides a detailed analysis of how magnetic fields affect the accumulation of specific metabolites, using techniques such as gas chromatography and mass spectrometry to identify changes in secondary metabolites. These findings are essential for understanding how plants can modify their biochemical pathways in response to physical stimuli.

DISCUSSION OF CURRENT KNOWLEDGE IN THE FIELD OF THE IMPACT OF MAGNETIC FIELDS ON PLANTS

Analyzing the extensive literature, some research areas that have been particularly investigated are structurally presented.

Impact on germination and early growth

Understanding and optimizing the germination of seeds and early growth of plants are crucial for success in modern agriculture. Seed germination is the first and one of the most important stages in the life cycle of a plant. The efficiency of this process directly affects the growth rate, health of plants, and overall yields. Magnetic fields offer significant opportunities to improve these aspects by acting at the molecular level within plant cells. Studies show that exposing seeds to magnetic fields before planting can stimulate biological processes necessary for faster germination.

The study by Radhakrishnan et al. (2019) documents how treatments with magnetic fields increase antioxidant activity in plants, which can be crucial in combating oxidative stress in the early stages of plant growth. This directly contributes to faster and healthier development of young plants, which can result in better yields and resistance to diseases. On the other hand, Florez et al. (2007) recorded improvements not only in root and shoot length but also in photosynthesis efficiency in plants exposed to magnetic fields. This shows that magnetic fields can help plants better use light and nutrients from the environment, increasing their ability to grow and develop rapidly.

Additionally, exposure to magnetic fields can reduce the negative effects of stressful conditions such as drought or low temperatures on seed germination. This is especially important in regions where climatic conditions are unpredictable or extreme. For example, studies have shown that seeds treated with magnetic fields show better resistance to abiotic stress, increasing the likelihood of successful germination and growth even in suboptimal conditions. This ability of magnetic fields to modify the physiological response of plants to stress opens new possibilities for their use in global agriculture, especially in the context of climate change that increases the frequency and intensity of stressful events.

Magnetic fields, in addition to increasing resistance to abiotic stressors, also show promising results in improving the metabolic efficiency of plants during key early stages of their development. Research has shown that magnetic fields affect the concentration of certain important growth hormones in plants, such as gibberellins and auxins, which play a vital role in regulating growth and development in plants. For example, a study conducted by De Souza et al. (2006) shows that treatments with magnetic fields can improve gas exchange and increase chlorophyll content in leaves, directly affecting photosynthetic activity and overall plant health.

These findings are confirmed in the work of Bhattacharya et al. (2012), which documented how low-intensity magnetic fields affect faster opening of stomata on leaves, allowing more efficient transpiration and better gas exchange. Additionally, this effect can contribute to better adaptation of plants to variations in external temperature and humidity, improving their ability to survive and develop in variable environmental conditions.

In conclusion, the use of magnetic fields in the early stages of plant growth can have significant positive effects on germination, growth, and overall vitality of plants. An increasing number of studies indicate that magnetic fields could play a key role in developing new sustainable agricultural technologies that could help overcome the challenges posed by global climate change. As research in this area continues, it is expected that even more innovative techniques for applying magnetic fields in agriculture will emerge, opening new opportunities for increasing the efficiency of food production on a global scale.

Impact on Vegetative Growth

Vegetative growth of plants, which includes the development of stems, leaves, and other non-reproductive tissues, is crucial for the overall health and productivity of plants. Studies have shown that exposure of plants to magnetic fields can lead to significant improvements in these processes. Specifically, Teixeira da Silva and Dobránszki (2013) documented that magnetic fields increase photosynthetic activity, leading to increased biomass production. This increase in biomass can be vital for production plants as it directly affects their ability to generate higher yields. Additionally, research shows that magnetic fields can affect cell differentiation and proliferation, which is a fundamental process for plant growth. A study conducted by Maffei (2014) indicates that exposure of plants to magnetic fields can induce an increase in enzyme activity involved in cell wall synthesis, resulting in stronger and more lush plants. Additionally, magnetic fields can help optimize the use of nutrients from the soil, which is essential for supporting healthy vegetative growth. One of the interesting aspects of research on magnetic fields is their impact on microbial activity in the rhizosphere of plants. Studies have shown that magnetic fields can modify the activity of microorganisms in the soil, improving the availability of nutrients for plants. This is particularly relevant for nitrogen-fixing bacteria, whose activity is enhanced in the presence of magnetic fields, which can lead to better plant growth due to increased availability of nitrogen.

Additionally, exposure to magnetic fields can improve plant resistance to abiotic stresses such as extreme temperatures and variations in humidity. This is significant because stressful conditions often limit vegetative growth and can lead to reduced yields. For example, research conducted by Bhattacharya et al. (2012) reveals that magnetic fields can help plants maintain optimal transpiration even under stress, ensuring continuous growth and development.

Overall, the application of magnetic fields in agriculture can significantly contribute to enhancing vegetative growth in plants, which is essential for maintaining high yields and economic viability of agricultural production. Further research is needed to better understand the mechanisms of action and to optimize these techniques for widespread use in different agricultural conditions.

Impact on Reproductive Development

Reproductive development of plants, which includes processes of flowering and fruit formation, is crucial for successful agricultural production. Research shows that magnetic fields can have a significant impact on these processes, potentially increasing the number and quality of fruits, which directly affects commercial value and productivity. For example, research conducted by Matsuda et al. (1993) showed that exposure of strawberry plants to magnetic fields can significantly increase the number of flowers and fruits. These effects are not only superficial; they are the result of deep changes in physiological and biochemical processes within plants that lead to improved reproductive function.

Magnetic fields can induce changes in signaling exchange within plants that are crucial for initiating and maintaining reproductive development. For instance, research by Gubbels (1982) showed that magnetic fields can affect levels of phytohormones such as auxins and gibberellins, which regulate flowering and fruit development. An increase in the concentration of these hormones can lead to early initiation of flowering, a greater number of flowers, and enhanced fruit formation. Additionally, exposure to magnetic fields can increase plant resistance to biotic and abiotic stressors that can negatively affect reproductive development. For example, research by Vasilevski (2003) showed that magnetic fields can reduce the impact of pathogens and pests on plants, allowing healthier and more lush flowering. Also, exposure of plants to magnetic fields can improve their ability to cope with stressful temperatures and water conditions, which is often a key factor in successful reproductive development. One of the most promising aspects of using magnetic fields in agriculture is their ability to improve the quality of fruits. Research has shown that magnetic fields can increase the content of sugars, vitamins, and other nutrients in fruits, which can significantly increase their nutritional value and market attractiveness. This is especially important in the production of fruits and vegetables, where the quality of fruits directly affects the price and demand in the market.

Overall, the application of magnetic fields in agricultural practices offers great opportunities for improving reproductive development in plants, which can lead to increased yields, improved product quality, and increased overall productivity. Further research is needed to more thoroughly investigate the mechanisms of action of magnetic fields and to optimize techniques for their application for specific crops and growing conditions.

Impact on Resistance to Stressful Conditions

Increasing plant resistance to stressful conditions such as drought, soil salinity, and extreme temperatures is crucial for maintaining stability and productivity in agricultural production. Magnetic fields offer a promising opportunity to improve the ability of plants to cope with these challenges. Studies show that exposure of plants to magnetic fields can modify their physiological and biochemical responses in a way that increases their resistance to abiotic stress.

For example, research by Radhakrishnan et al. (2019) indicates that treatment with magnetic fields can improve osmotic regulation in plants, which is extremely important for maintaining cell functions under stressful conditions such as drought or high salinity. These treatments increase the activity of antioxidant enzymes, which play a key role in neutralizing oxidative stress caused by unfavorable conditions. Additionally, magnetic fields can stimulate the expression of certain stress-responsive genes, further strengthening plant resistance. In addition to direct effects on plants, magnetic fields can affect microbiological activity in the soil, which indirectly contributes to plant resistance. Studies have shown that exposure of soil to magnetic fields can change the composition of the microbiome, promoting the growth of beneficial microorganisms that can help plants better access nutrients and be more resistant to pathogens. These effects can be particularly useful in conditions where the soil is depleted or contaminated.

Additionally, research such as that conducted by Hiscock and Worley (2012) shows that magnetic fields can help plants maintain better water balance even under limited water availability. This is achieved by increasing the efficiency of water channels in plant cell membranes, improving the ability of plants to absorb and retain water, which is crucial for their survival and growth in dry periods. Increasing plant resistance to stressful conditions such as drought, soil salinity, and extreme temperatures is crucial for maintaining stability and productivity in agricultural production. Research shows that exposure of plants to magnetic fields can significantly improve their ability to withstand these conditions, providing a vital adaptive advantage in an increasingly challenging global climate context.

The study by Radhakrishnan et al. (2019) demonstrates how treatments with magnetic fields increase the activity of antioxidant enzymes in plants, which is essential for combating oxidative stress often accompanying abiotic stressors. This increased activity helps plants maintain healthy metabolic processes even under stress, leading to better survival and growth. Additionally, Hiscock and Worley (2012) showed that magnetic fields can improve the efficiency of water channels in plant cell membranes, helping plants use available water more efficiently and maintain hydration even when water resources are limited. Exposure to magnetic fields can also affect the composition of the microbiome in the soil, as researched by a group of researchers including Smith et al. (2015), who discovered that magnetic fields can favor the growth of beneficial microorganisms that support plant growth and help them better access nutrients. This can be of critical importance in conditions of poorly fertile soils or soils with high levels of salinity where plants often suffer due to a lack of key nutrients.

Additionally, magnetic fields have shown the ability to modify physiological responses of plants to temperature extremes. Research conducted by Perez et al. (2018) suggests that magnetic fields can induce the production of heat shock proteins that help plants tolerate high temperatures, which is especially useful in regions facing frequent heat waves.

All these advantages make magnetic fields an extremely useful tool in modern agriculture, especially in the context of global climate changes that bring more frequent and intense periods of drought, increased soil salinity, and extreme temperatures. Further research is necessary to fully understand the mechanisms of action of magnetic fields and to adapt these technologies to different agricultural conditions worldwide.

All these studies indicate that the application of magnetic fields can provide farmers with a powerful tool to increase plant resistance to a range of abiotic stressors, which can significantly contribute to the sustainability and efficiency of agricultural production. Continuous research and experiments in this area will be key to developing optimized protocols and technologies that will enable the widespread application of this knowledge in practice.

Observed Harmful Effects of Magnetic Fields on Plants

Although the application of magnetic fields can bring numerous benefits in agricultural practices, it is important to highlight the potential harmful effects that this exposure may have on plants. Studies have shown that high intensities of magnetic fields or inadequate application can cause stressful reactions in plants, including changes in growth and development, which can negatively affect their physiology and metabolism.

Growth Inhibition: Research has shown that extremely strong magnetic fields can inhibit plant growth, affecting processes such as photosynthesis, respiration, and transpiration. For example, a study conducted by Carpentier et al. (2011) shows that exposure of plants to excessive magnetic fields can lead to a reduction in the activity of photosynthetic enzymes, leading to reduced biomass production.

Changes in Metabolism: Magnetic fields can affect the metabolism of secondary metabolites in plants, which can have both beneficial and harmful effects. According to the study by Johnson et al. (2008), intense exposure to magnetic fields can increase the production of certain alkaloids, which can be toxic to plants in higher concentrations.

Stress and Cell Damage: The study by Shabrangi et al. (2015) investigates how prolonged exposure to strong magnetic fields can induce oxidative stress in plants, which can lead to cell and tissue damage, worsening their overall health and vitality.

Possible Effects on Plant Biocenoses and the Environment

Magnetic fields can have broader ecological effects that extend beyond the plants themselves, affecting plant biocenoses and the overall environment. These effects can be both direct and indirect and depend on numerous factors, including intensity and duration of exposure.

Changes in Plant-Pollinator Interactions: Studies have shown that magnetic fields can affect the behavior and efficiency of pollinators such as bees and butterflies, which can have long-term consequences on pollination and reproductive success of plants. The study by White et al.

(2016) describes in detail how local magnetic fields can disorient pollinators, reducing their ability to effectively locate flowers.

Impact on Soil Microbial Communities: Magnetic fields can also change the composition and activity of microbial communities in the soil, which can have both beneficial and harmful effects on the availability of nutrients and the health of plants. The study by Smith et al. (2015) shows how altered microbial communities can affect decomposition processes and mineralization, further affecting the nutrient cycle in the ecosystem.

CONCLUSION

The existing literature highlights the positive effects of magnetic fields on plants but also emphasizes the need for a deeper understanding of ecological and long-term effects.

All positive effects of magnetic fields on plants can be summarized in key directions:

1. Improvement of Germination and Early Growth: Magnetic fields increase the activity of antioxidants and improve metabolic processes in plants, leading to faster and healthier growth in the early stages of development. This is crucial for achieving better yields and reducing the time needed to grow plants.
2. Enhancement of Vegetative Growth: Exposure of plants to magnetic fields improves photosynthetic efficiency and increases biomass production, resulting in lusher and healthier plants capable of greater production.
3. Increase in Reproductive Development: Magnetic fields can increase the number of flowers and fruits as well as improve the quality of the same, which is especially useful in commercial production of fruits and vegetables.
4. Resistance to Stressful Conditions: Exposure to magnetic fields helps plants develop better resistance to abiotic stressors such as drought, soil salinity, and extreme temperatures, which is increasingly important in the light of global climate changes.

All negative effects of magnetic fields on plants can be summarized in key directions:

1. Exposure of plants to magnetic fields can have harmful effects, especially when the fields are of high intensity or inadequately applied. These effects include growth inhibition due to reduced photosynthetic activity, changes in metabolism that can lead to the production of toxic metabolites, and induction of oxidative stress that can damage cells and plant tissues.
2. Excessive exposure can negatively affect the reproductive functions of plants and disrupt interactions with pollinators, which have further ecological consequences.

3. Magnetic fields can affect plant biocenoses and the wider environment in various ways. Exposure to magnetic fields can disrupt the behavior of pollinators, potentially reducing the efficiency of pollination and negatively affecting plant reproduction. Additionally,
4. Magnetic fields can alter microbial communities in the soil, affecting decomposition processes and nutrient availability, which can have far-reaching consequences for plant health and ecosystem functions.

The integration of magnetic fields into agricultural practices represents a revolutionary approach that can significantly impact the enhancement of productivity, efficiency, and sustainability in agriculture. Through a series of studies and experiments, it has been demonstrated that magnetic fields can positively affect germination and early growth, vegetative growth, reproductive development, and plant resistance to various stressful conditions. These advantages are essential in the context of global challenges such as climate change, biodiversity loss, and the need for sustainable food production.

In the necessary further research, more detailed investigation at the molecular level is needed to clarify how magnetic fields affect signaling pathways in plants. Research should be expanded to long-term effects of magnetic fields on ecosystems, including biodiversity and interactions between species.

The future application of magnetic fields in agricultural production must lead to the development of technologies that will revolutionize agricultural practices and enable precise and controlled exposure of plants to magnetic fields, which, especially in the context of global changes, could enable increased production of healthy food without the use of chemical agents.

All in all, the field of research on the impact of magnetic fields on plants is still relatively unexplored, with many possibilities for future development and breakthroughs in science that can contribute to both the improvement of agricultural production and environmental protection.

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FLUE GAS DESULFURIZATION SYSTEM (FGD) IN THERMAL POWER PLANT UGJEVIK

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Abstract: Here we analyze the harmful impact of thermal energy plants on the environment and human health. Primarily, the aspect is focused on the harmful influence of sulfur as the biggest and most dangerous pollutant in the operation of thermal power plants. The principles and methods of flue gas desulfurization at thermal power plants were analyzed. The coal used in the operation of the Ugljevik thermal power plant has a high sulfur content, so this plant is the biggest polluter in this area and beyond due to the high height of the chimney. That's why a flue gas desulphurization plant was built first in these areas and wider. The effect of the operation of the plant and the improvements that have been achieved in terms of reducing environmental pollution are presented.The financial effect was not analyzed, because it is a relative matter and belongs to a different context.

Keywords: *Environment, sulfur dioxide, thermal power plant, flue gases, absorber, limestone, water, coal and thermal power plant*.

INTRODUCTION

It is hard to imagine your daily life without electricity, but the negative impact that electricity production from fossil fuels has on the environment and people's health cannot be ignored. Electricity production is still based on the use of fossil fuels, among which coal is the most common. In 2021, 36% of the total electricity at the world level was produced by burning coal. During the burning of fossil fuels, thermal power plants emit dust particles and oxides of: sulfur, nitrogen and carbon into the atmosphere. High concentrations of sulfur dioxide threaten flora and fauna by causing acid rain, while increasing the risk of cancer, respiratory and cardiovascular diseases in humans. Thermal power plants in our areas have been exceeding the permitted levels of sulfur dioxide SO_2 emissions for years, and we are among the first in Europe in terms of the level of sulfur dioxide emissions into the atmosphere. The thermal power plant Ugljevik consists of one boiler unit with a power of 300 MW and is considered the biggest polluter in this area. Due to the height of the chimney, the pollution is transmitted to the wider environment, so neighboring countries are also at risk: Serbia, Croatia, Hungary, Romania and Slovakia. This was the key reason to initiate the construction of the flue gas desulphurization plant at the Ugljevik thermal power plant. This plant was the first to be put into operation on the territory of Bosnia and Herzegovina.

FLUE GASES AS POLLUTION SOURCES

About pollution in general

Sulfur oxides SO_2 and SO_3 as well as nitrogen oxides NO and NO_2 have long been recognized as the most common and most dangerous gases of anthropogenic origin with a serious negative impact on human health, plant and animal life as well as on construction facilities. Considering the harmful impact of these gases, it is of particular importance that their emission limit values (GVE) be reduced to an acceptable level that will not be harmful to the environment and human health. The limit values are calculated at a temperature of 273.15 K, a pressure of 101.3 kPa and after correction for the content of water vapor in waste gases at an oxygen content of 6% for solid fuels. The only way to reduce the emission of harmful gases, primarily SO_2 and SO_2, is to build a flue gas desulfurization plant. In the 1990s, the construction of these plants began in Europe, while newer thermal power plants were equipped with these systems from the beginning.

Procedures for reducing SO_2 emissions

All procedures for reducing sulfur dioxide emissions after burning coal are based on physical or chemical reactions of the active substance and sulfur oxides.

Procedures for reducing sulfur dioxide emiss:

- dry procedure
- wet procedure
- Spraying procedure

In thermal power plants, flue gas desulfurization systems are based on wet processes, i.e. wet processes with limestone, which uses lime suspension as a sorbent and produces gypsum as a byproduct.

Basic principles of wet process technology

Desulphurization of flue gases is performed after purification in an electrofilter plant, and dusty flue gases are directed to flue gas filters. In old power plants, the flue gas fan is not designed to overcome pressure losses in the subsequently built FGD plant, so a booster fan is added to overcome these losses. After the booster fan, the flue gases are passed through the absorber, where they are purified. The purified flue gases are then released into the atmosphere through the chimney. Figure 1 shows the process of flue gas desulfurization at the Ugljevik thermal power plant.

Flue gas purification is carried out in contact with the limestone suspension that takes place in the absorber of the desulphurization system. The flue gas and suspension flow is opposite: the gas is introduced into the absorber in the lower part and flows upwards coming into contact with the dispersed limestone suspension, which falls downwards from several spray levels. The number of spray levels depends on the required efficiency and concentration of SO_2 input and output gases. The preparation of limestone suspension is carried out in the grinding plant in which wet grinding of limestone in ball mills with control of quality and fineness of grinding takes place. A suspension is formed to the ground limestone by adding water, where the solid matter content does not exceed 30%, which is then driven into the limestone suspension tank.

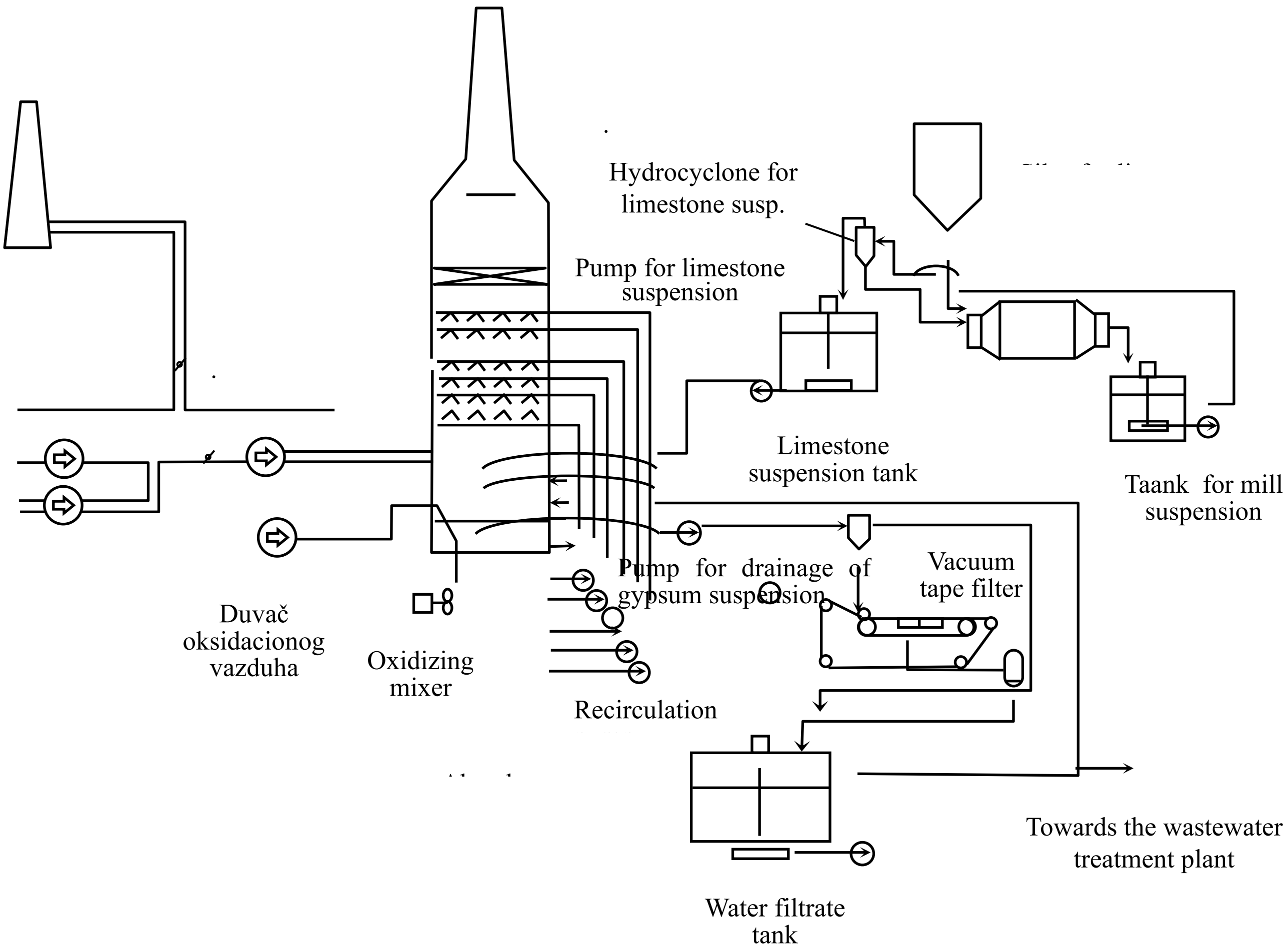

Figure 1. Flow diagram of flue gas desulphurization for the thermal power plant Ugljevik

The suspension is driven from this tank by pumps to the absorber and its quantity is regulated by controlling the process parameters, i.e. the input and output concentration of SO_2. The suspension circulating in the absorber is passed through the spray nozzles through the spray nozzles to fine coils and thus brought into uniform contact with the flue gas.

The droplets of the suspension absorb SO_2 from the flue gas, which then passes through the drop eliminator to remove water droplets from it before entering the chimney. As the gas is warm and the droplets of suspension-water cold, water evaporates so that a larger amount of water vapor comes out through the chimney. As a result of the flue gas reaction and lime suspension, a single calitium sulfite and calcium sulfate are formed, which fall heavier to the bottom of the reaction pool. To prevent the deposition of the suspension at the bottom of the tank it is constantly stirred using a mixer. Chemical reaction in the wet process and the formation of gypsum.

CHEMICAL REACTION IN WET PROCESS AND FORMATION OF GYPSUM

(1) hydrolysis of sulfur dioxide: $SO_2 + H_2O \rightarrow H_2SO_3$

(2) decomposition of hydrolysis products: $H_2SO_3 \rightarrow H(+) + HSO_3(-)$

(3) limestone dissolution: $CaCO_3 + H_2O \rightarrow HCO_3(-) + Ca(++) + OH(-)$

(4) re-establishment reaction: $Ca(++) + SO_3(-) \rightarrow Ca\ SO_3$(sulphite)

(5) oxidation reaction: $2CaSO_3 + O_2 \rightarrow \boxed{2\ Ca\ SO_4} \rightarrow$ gypsum

oxygen from flue gas + additional oxygenated air

($CaSO_4$ x $2H_2O$) calcium sulfate solution

The calcium sulfate solution, which settles together with the lime suspension at the bottom of the absorber tank, is de-silted, i.e. constantly removed, and introduced into special hydrocyclone and vacuum dryer facilities, where gypsum is obtained as a building material. The maximum degree of desulfurization that is currently guaranteed is up to 97% and even in some cases it is possible to achieve an efficiency of up to 98%.

FGD PLANT IN UGLJEVIK

Overviewof the needs for the construction of the FGD plant

TPP Ugljevik with a rated projected power of 300 MW represents an integral part of the company "Rudnik i Termo elektrana Ugljevik", within MH – ERS "Elektroprivreda of

Republika Srpska". It was put into operation in 1985 and produces 1/3 of the total electricity in The Republic of Srpska. It burns brown coal from the Bogutovo selo surface mine, about 4 km away from the thermal power plant with a projected annual consumption of 1,800,000 tons. Coal contains a high concentration of sulfur (3-6%) and has a lower heat output (DTV) of 10.000–13.000 kJ/kg. TPP Ugljevik emits a significant amount of sulfur compounds into the atmosphere. The SO_2 emission from the Ugljevik Chimney is about 90.000 to 100.000 tons per year and makes this TPP one of the biggest polluters in Republika Srpska as well as in Bosnia and Herzegovina. In view of this, and in connection with the tightened international conventions for the operation of such facilities as large pollutants from the point of view of environmental protection, the need for the construction of flue gas desulphurization plants (FGD) was imposed. MH ERS was obliged to do so by accepting the "National Emission Reduction Plan" (NERP). The FGD plant at TPP Ugljevik is the first such plant in Bosnia and Herzegovina.

Goal of construction of FGD plant

The main goal of the construction of the FGD plant is to reduce the concentration of SO_2 and solid particles in flue gases to the permissible level. In Table 1, the limit values of emissions into the air of solid fuel combustion plants are given.

These values represent basic functional guarantees that TPP Ugljevik could function smoothly from the aspect of environmental pollution. The limit allowable value of SO_2 emissions is 200 mg/Nm^3 6% O_2 dry and 20 mg/Nm^3 6% O_2 dry for solid particles. During the test run in 2020, the output concentration of SO_2 on the wet chimney was about 130 mg/Nm^3 and solid particles about 2 mg/Nm^3, which is significantly below the permissible values. In Figure 2 is the FGD plant at TPP Ugljevik.

Table 1. Air emission limit values of combustion plants

Pollutant	***Emission limit value***		
	Ordinance Republike Srpske br 39/05	Directive 2001/80/EC	**Directive2010/75/EU**
SO_2(mg/m^3)	400	200	**200**
NO_x(mg/m^3)	650	200	**150**
Particles(mg/m^3)	50	20	**10**
Minimum degreeof desulfurization %	94		**97**

Figure 2. FGD plant of TPP Ugljevik

Technical concept of FGD plant

The basic parameters for the construction of the FGD plant and the calculation of the necessary components for the operation of the same are given in Table 2. Parameters are taken for 100% boiler load i.e. power 283 MW (so much power the boiler can achieve with available coal). SO_2 emissions are 21 t/h, if we take that TPP operates about 6800 h per year, about 143.000 tons of SO_2 would go into the atmosphere. However, TE operates on average with a power of less than 250 MW so this amount is up to 100.000 t/yr. SO_2.

Table 2. Project case. Mode 100%, boiler load 283 MWE (SO_2 = 21 t/h)

FGD input flow	1.943.176 Nm^3/h (wet)
	1.651.700 Nm^3/h (dry)
Absorber input H_2O koncentr.	15,0 vol% wet
Absorber input O_2 koncentr.	9,25 vol% dry
Absorber input SO_2 koncentr.	12.983 mg/Nm^3_{dry} kod 6vol% O_{2dry} cca 14500
Absorber input SO_3 koncentr.	250 mg/Nm^3_{dry} kod 6vol% O_{2dry}
Absorber input HCl koncentr.	20 mg/Nm^3_{dry} kod 6vol% O_{2dry}

Absorber input HF koncentr.	10 mg/Nm^3_{dry} kod 6vol% O_{2dry}
Absorber input of solid particles	50 mg/Nm^3_{dry} kod 6vol% O_{2dry}
Absorber output SO_2 koncentr.	200 mg/Nm^3_{dry} kod 6vol% O_{2dry}
Absorber output of solid particles	20 mg/Nm^3_{dry} kod 6vol% O_{2dry}
SO_2 effect of cleaning	98,44 %
The purity of limestone	94,0% $CaCO_3$
By-product gypsum	humidity < 12 %
Degree of water flow	< 348 m^3/ 48 h
Content of solid particles in wastewater	< 2 gr/lit
Plant operating time	< 7000 h/year

Plant operation parameters

Figures 3 and 4 show the effects of the FGD TPP Ugljevik. We see that the concentration of SO2 after exiting the FGD plant has decreased manifold. The height of the chimney in the FGD plant is 100 m and is built of carbon steel inside lining with rubber. The capacity of limestone mills is 2 x 29,3 t/h and gypsum drying plants are 2 x 52 t/h.

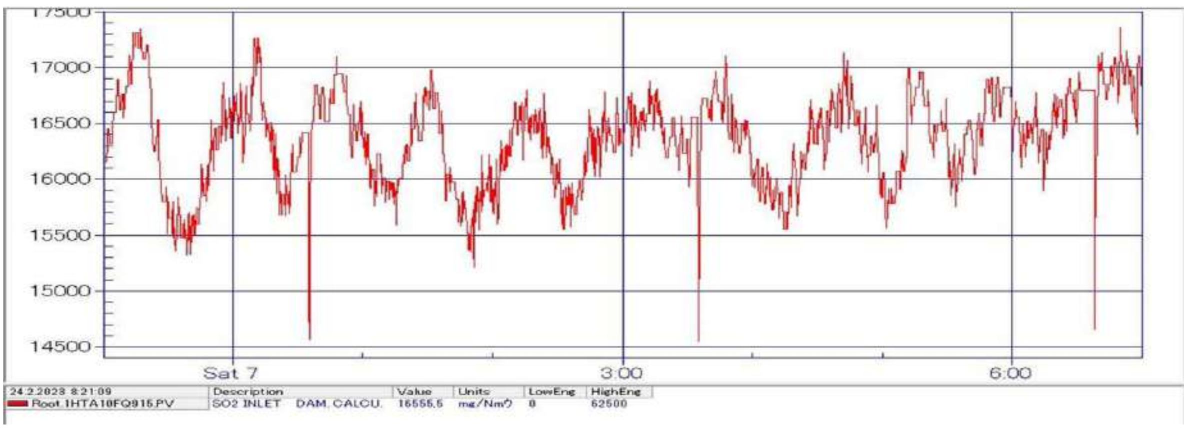

Figure 3. Input of SO_2 to the FGD TPP Ugljevik

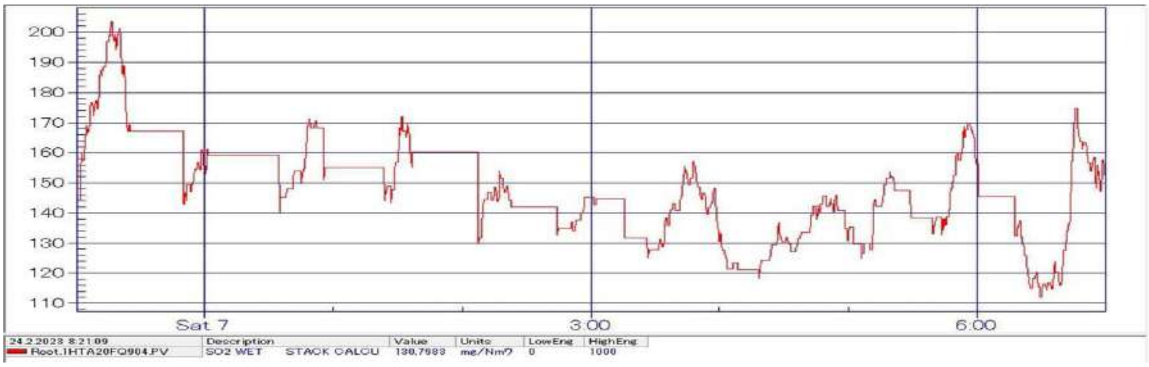

Figure 4. Output of SO_2 to the FGD TPP Ugljevik

ECONOMIC EFFECTS OF THE CONSTRUCTION OF FGD TPP UGLJEVIK

The construction of the FGD plant, in addition to the initial investments for the construction of the plant itself, has significant costs in operation. The cost of operating the system is:

- electricity consumption
- absorbent consumption
- consumption of process water
- production of additional CO_2, from the reaction of limestone with SO_2 (it is likely that in the future we will pay taxes for the release of CO_2 into the atmosphere due to the greenhouse effect).

Electricity consumption

The maximum power of FGD plants with process and non-process equipment is about 15 MW, which is a significant percentage compared to the power of the block (about 5%). In the trial run, electricity consumption ranged from 10.485 kW/h to 11.600 kW/h. This greatly increases the operating costs of TPP Ugljevik and at the same time reduces its efficiency, which requires higher coal consumption and higher CO_2 emissions into the atmosphere.

Absorbent consumption

According to the project, limestone consumption is 26,3 t/h, although it was up to 28 t/h in the test run. If we take that TPP works on average about 6800 h per year, that is the annual consumption of limestone about 190.000 t, or about 600-650 t / day. It is a crushed limestone with a maximum granulation of 20 mm at the entrance to the FDG plant, where it is further micronized in the mill plant.

Consumption of process water

The projected water consumption is 10.600 t/48 h, i.e. reduced to hourly consumption of 220,83 t/h. The test run showed that this consumption is about 200 t/h. Taking the total annual operating time of TPP consumption is about 1.360.000 – 1.500.000 t/year.

Production of additional CO_2 from reaction with SO_2

This data is optional at the moment, due to the very likely obligations of thermal power and industrial plants in terms of limiting greenhouse gas emissions in the near future. The expected maximum CO_2 emissions from this plant is about 11,226 t/h.

Gypsum from FDG plant

During the operation of FDG plant as a by-product, gypsum is obtained as a building material. The projected amount of gypsum generated per year is about 350.000 tons based on work 6800 h/year. at a maximum power of 283 MW. Realistic predictions are 300.000 tons per year, i.e. to produce 1.000-1.200 tons per day. For the purpose of storing gypsum, a silo with a capacity of 7.000 m^3 was built.

CONCLUSION

With the construction of the flue gas desulphurisation system (FGD), the Ugljevik thermal power plant has been removed from the black list of the biggest polluters in the Republic of Srpska and Bosnia and Herzegovina and beyond. The amount of SO_2 emitted into the atmosphere has been reduced approximately 100 times while the emission of solid particles is well below the permissible limit. The construction of this plant from foreign loans has significantly burdened this company, which is already over-indebted due to some disputes from the past. Also with the construction of the FGD plant, which consumes about 5% of the total electricity produced, the efficiency of TPP Ugljevik has significantly deteriorated.

If we add to this the costs: maintenance, absorbents, water, labor, as well as the announcement of taxes on the emitted amount of CO_2 generated in the plant, the question of the survival of this company arises. Environmental protection and human health is certainly in the foreground and with the construction of this plant TPP Ugljevik becomes an environmentally healthy company. Not wanting to diminish the positive effects of this FGD plant on the environment and human health, as well as RiTE Ugljevik's desire to operate as a socially responsible company according to its environment and beyond, however, for the survival of this collective, we must note that a successful story threatens to become a negative ballast for the company, especially in the light of the present market way of doing energy companies.

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VIRTUAL REALITY AS A TOOL FOR OCCUPATIONAL SAFETY TRAINING: PUBLIC PERCEPTION AND ATTITUDES

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Abstract: While traditional training methods have their merits, there's growing interest in innovative approaches such as Virtual Reality (VR) technology. This research delves into public perceptions regarding the adoption of VR for occupational safety training. Through an online survey conducted in April 2024, insights were gathered from 107 respondents representing diverse professions. Results indicate a significant interest in VR-based training, with a majority expressing support for its implementation and recognizing its potential to enhance safety comprehension and responses in the workplace. Results reveal that 86% responders underwent occupational safety training, with 75.5% responders supporting VR adoption over traditional methods. Construction (88%), industry (72.9%), and healthcare (33.6%) emerged as sectors prioritizing VR training. These results underscore the promising role of VR in enhancing workplace safety comprehension and mitigating accidents.

Keywords: *safety at work; preventive measures; safety awareness; health at work; training*

INTRODUCTION

The principles of the United Nations, the World Health Organization (WHO) and the International Labor Organization (ILO) emphasize the importance of protecting health and safety at work as a basic human right. This means that every individual, regardless of geographical location, has the right to a working environment that guarantees healthy and safe work, providing the foundations for social and economic progress. According to the WHO, workers make up a significant part of the world's population and play a key role in economic and social development (Nedic & Belkić, 2018).

In order to prevent industrial accidents and improve the effectiveness of safety management within the organization, more and more emphasis is placed on engagement in the field of safety. This includes raising security awareness among organization members and establishing a security management system that fits the organization's specific situation. This can include training employees on safety procedures, establishing clear guidelines and procedures for responding to emergencies, and constantly monitoring and improving systems to ensure optimal safety in the work environment. (Seo et al., 2021).

According to the Ministry of Labour, Employment, Veterans and Social Affairs of the Republic of Serbia, Table 1 shows the number of work-related injuries by employer's activity for the previous three years. The highest number of work-related injuries in 2021 was in processing industries 388 (29.82 %). In 2022, the number of injuries in the processing industry is also dominant with 289 injuries (25.64%), and during 2023 it increased with 413 injuries at work, i.e. 31.24%. During the year 2023, the highest number of injuries at work was 1322. (Work Report, 2022; Work Report, 2023; Work Report, 2024).

Occupational health and safety training provides the necessary education and knowledge for work tasks, workplace hazards and personal safety in order to protect workers and companies. Such training is an essential tool in all industries and a key criterion for regulatory compliance. Incidents can occur due to unsafe working conditions, but the importance of identifying inadequate or non-existent training is often overlooked in this case (National Safety Council, 2021). There are a variety of approaches to safety training, including reading, listening to lectures, watching video clips, and online courses like the 10-hour online OSHA course. Some researchers are already considering alternative methods to increase student interest and improve the quality of safety training. Using Virtual Reality (VR) as a training tool is one of the new methods being explored (Xie et al., 2006).

Virtual reality is the use of computers and specialized hardware and software equipment to create a "virtual environment" in real time, which provides users with an experience of reality. This term describes an interactive, three-dimensional space that is generated by computers and that users can experience through technological aids, such as sensory interfaces (Okuka, 2022).

VR technology, due to its ability to create virtual environments that are almost identical to real situations, has become a key solution for training in industry. Previous research has revealed that active participation during training in a virtual environment brings greater benefits than passive acceptance of information from classical theoretical classes (Seo et al., 2021). Through virtual simulations, workers can face potential hazards and learn how to respond in those situations (Zhao, 2014). Thanks to the flexibility provided by VR, safety training programs can be tailored to the needs of almost any industry and simulate different environments and situations (Norris et al., 2019). Training based on VR technology has been used with varying success in many industries such as firefighter training, mine safety training, safe surgical procedures training, refinery safety, safe equipment handling, and construction education (Zhao, 2014).

The aim of this research is to gain insight into the attitudes and knowledge of the public about the use of virtual reality in training in the field of occupational safety and health.

METHOD AND MATERIAL

The survey was conducted online in April 2024 and included respondents from the city of Zrenjanin. The survey was shared online through social networks and was divided into three groups of questions:

- **Group 1:** General questions: This set of questions aimed to help us better understand the respondents, including their gender, age group, and profession/industry.
- **Group 2:** A group of questions related to individual experiences with occupational safety and health training: this group of questions is designed to gain a deeper understanding of the profile of the respondents. With this group of questions, we wanted to determine the levels of safety at work among the respondents. The answers to the questions presented ranged from the simplest (yes or no) to more complex questions where specific answers were offered. Also, one of the answers is shown through the value scale of the respondent's opinion (Table 1).

Table 1. Questions and offered answers from group 2

Group 2 - questions	***Offered answers***
What profession or industry do you belong to?	Health care, Industry, Construction, Education, Economy, Administration, IT, Driver, Other (please specify)
Have you had occupational safety training at your workplace?	Yes, No
How often is occupational safety training organized at your workplace?	Regular (every 6 months), Occasional (every year or less), One time, only when signing the employment contract, Never
Rate the difficulty of the work you do at your workplace:	Light physical work, More difficult physical jobs, Heavy physical work
Do you spend the most time at your job:	In direct contact with patients, When working on a computer, On the production line, In the maintenance of machines and equipment, On construction/demolition of buildings, In supervision of construction sites and worker safety, When working with manual vibration and impact tools, When working at height, Other (please specify)

What type of occupational safety training is available at your workplace?	Traditional lectures, Tests Interactive workshops, Online courses, Other (please specify)
Do you think that the occupational safety training you received was effective enough?	Yes, No, I am not sure
On a scale of 1 to 5, how effective do you consider the occupational safety training you received?	1 - Very ineffective 2 - Ineffective 3-Neither effective nor ineffective 4 - Effective 5 - Very effective
During the training, were you presented with all potential dangers and protection measures at your workplace?	Yes, No
Have you ever felt unsafe at your workplace?	Yes, No
If your answer to the previous question is YES, what are those situations?	
Have you ever had a work-related injury at your workplace that could have been prevented by more detailed occupational safety and health training?	Yes, No

- **Group 3:** A group of questions related to respondents' attitudes and opinions when it comes to the use of virtual reality in occupational safety and health training: this group of questions was designed to define the opinions of respondents about new technologies in training, as well as comparing traditional training methods with previously mentioned (Table 2).

Table 2. Questions and offered answers from group 3

Group 3 - questions	*Offered answers*
Have you ever heard of this type of training (VR)?	Yes, No, Yes, I have undergone this type of training
Would you support the implementation of virtual reality (VR) for occupational safety training in your workplace?	Yes, I think it would be a better option than traditional methods No, I think traditional teaching methods are more effective I'm not sure
On a scale of 1 to 5, how much do you support the use of virtual reality (VR) for occupational safety training in your workplace?	1 - Very little support 2 - I support a little 3 - Neutral 4 - I support 5 - Very supportive
Do you think there would be fewer accidents at work if this training were implemented in Serbia?	Yes, No, Maybe
Would you be interested in participating in occupational safety training through virtual reality (VR)?	Yes, No, Maybe
How useful would you rate VR technology in occupational safety training?	1 - Completely useless 2 - Less useful 3 - Partially useful 4 - Useful 5 - Very useful
Do you think that training through VR technology would improve your understanding and reactions to safety situations in the workplace?	Yes, No, Maybe
In your opinion, for which profession is this training the most important (possibility of choosing more than one profession)	Health care, Industry, Construction, Education Economy, Administration, IT, Other (please specify)

In order to gain a deeper understanding of the views of the respondents, the survey is structured to include different types of questions. In addition to the classic questions with the options "yes", "no" and "maybe", more complex questions are included that use a scaling response, allowing respondents to express their views numerically.

RESULTS AND DISCUSSION

A survey was conducted to gauge the opinions and views of Zrenjanin residents regarding the utilization of virtual reality for occupational safety training, where 107 respondents from different fields participate.

Regarding general data on respondents, 68.2% were female, i.e. 73 respondents and 31.8% were male, i.e. 34 respondents, age structure were as 33.6% (ages from 26 to 35 years) and the ages between 36 and 45 (31.8%) predominate. Considerably fewer respondents belong to the age category of 46 to 55 years (17.8%), while there are only 8% of respondents aged 18 to 25, and also 8% of respondents aged 56. Participants age structure is given in Figure 1.

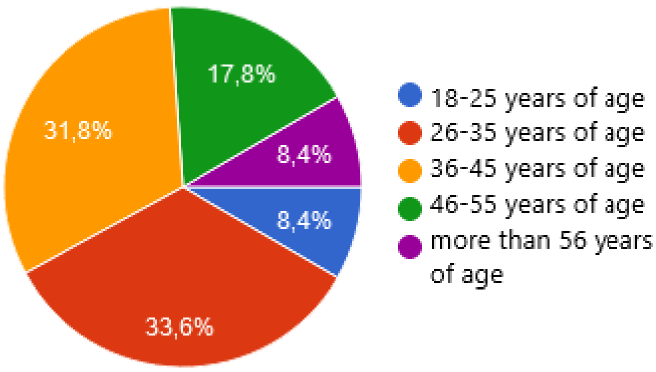

Figure 1. Participants age structure

The basic professions that were assigned in the survey are: health, industry, construction, education, economy, administration, IT, driver, trade (Table 3). Respondents who do not belong to any of the offered professions could write which profession they belong to.

Table 3. Basic professions of responents

Basic professions of respondent in percentage	
Education	18%
Industry	17.8%
Construction	15%
Trade	12.1%
Healthcare	7.5%
Administration	4.7%
Economy	3.7%
IT	2.8%
Driver	0.9%
Other	17.5%

Regarding occupational health and safety training, as many as 86% of respondents successfully passed this training, which was organized: occasionally (every year or less) for 49.5% of respondents, once, only when signing an employment contract in 24.3% of respondents, regularly (every 6 months) in 14% of respondents and never in 12.1% of respondents.

Most respondents, 31.8%, spend most of their time at the computer at work, 14% of respondents in direct contact with patients and 10.3% of respondents on the production line. 7.5% of the respondents spend the most time supervising the construction site and checking the safety of workers, 5.6% of the respondents spend the most time working at height, while the same percentage of respondents (5.6%) spend the most time in the construction or demolition of buildings. 3.7% of respondents spend the most time working with manual vibration and impact tools, while 2.7% of respondents spend most of their time working with machines and equipment. The answers of the other respondents, 18.8%, are individual and different.

Training in the field of occupational safety was conducted in the form of tests for 43.9% of respondents, and in the form of traditional lectures for 40.2% of respondents. 3.7% of respondents passed the online occupational safety course, while only 1.9% of respondents passed the interactive workshop. The rest of the respondents either did not undergo the above training or the training was of a combined type. 45.8% of the respondents believe that the training that the respondents have undergone is effective enough, 33.6% of them think that it is not effective, and the remaining respondents (20.6%) are not sure about its effectiveness.

Regarding the training issues, 21.5% of the respondents believe that the training is very effective, and 24.3% of the respondents believe that it is effective. Training is neither effective nor ineffective, according to 22.4% of respondents, and 15% of respondents believe that it is ineffective. 17.8% of respondents believe that the training is very ineffective. To the question "During the training, were you presented with all the potential dangers and protection measures at your workplace?" 70.1% of the respondents answered yes, while the rest of the respondents, 29.9%, believe that they were not presented with all the potential dangers and measures protection at the workplace.

When it comes to the perception of personal safety at the workplace, 69.2% of respondents have never felt unsafe at the workplace, while 30.8% of respondents feel unsafe at least once during working hours. Respondents had the opportunity to state which situations in which they did not feel safe. Situations in which they did not feel safe, are ignorance of the machine they are working on, construction work without protective fence next to my workplace, work at height without a platform, assembly of elements with improvised tools and mechanization

However, most often answers were related to work at height that is not properly secured or are related to some other situations at the workplace.

Since work-related injuries are a frequent occurrence in any type of activity, of the total number of respondents, 79.4% had no work-related injuries that could have been prevented by more detailed training in the field of occupational safety, while 20.6% of respondents experienced an injury.

Training based on VR technology is unknown to 69.2% of respondents, while 29.9% of respondents have heard of this type of training. Only one respondent underwent this type of training. When asked "Would you support the application of virtual reality (VR) for occupational safety training at your workplace?", as many as 75.5% of respondents believe that it is a better option than traditional training methods, and 17.8% of respondents are unsure. Only 6.5% of respondents would not support this type of training, because they believe that traditional methods in the form of lectures are more effective (Figure 2).

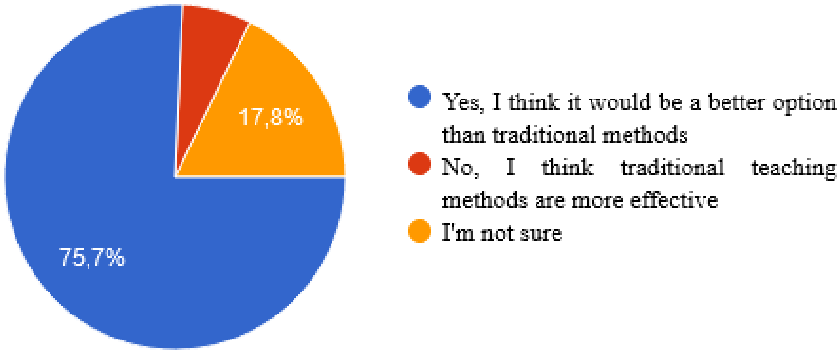

Figure 2. Would you support the application of virtual reality (VR) for occupational safety training at your workplace?

Regarding the use of VR technology, majority of respondents (58.9%) strongly support the application of VR technology at their workplace, while 12.1% of respondents support this type of training in the field of occupational safety and health. 18.7% of respondents are neutral, while 3.7% of respondents support this type of training a little or 6.5% support it very little (Figure 3).

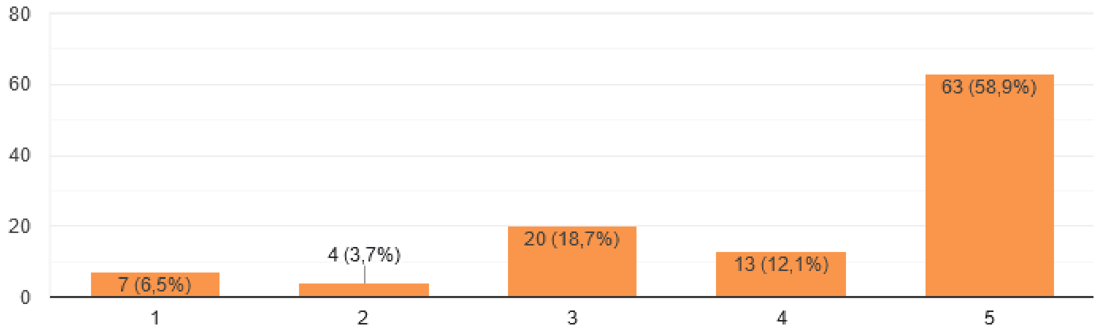

Figure 3. How supportive are you of implementing virtual reality (VR) for occupational safety training in your workplace.

Regarding the perception and willingness to take a VR training as many as 52.3% of the respondents gave an affirmative answer, and the answer maybe, was given by 39.3% of the respondents. Only 8.4% of respondents do not believe that the application of VR technology contributed to the reduction of the number of accidents at work. Respondents expressed interest in participating in this type of training, namely 65.4% of respondents, while 26.2% of respondents would perhaps participate in this type of training, and only 8.4% of respondents are not interested in this type of training.

When it comes to the usefulness of this type of training, 51.4% of respondents think that this type of training is very useful, and 23.4% of respondents think that it is useful. 19.6% of respondents believe that this type of training is partially useful, and 5.6% of respondents think it is less useful (figure 4).

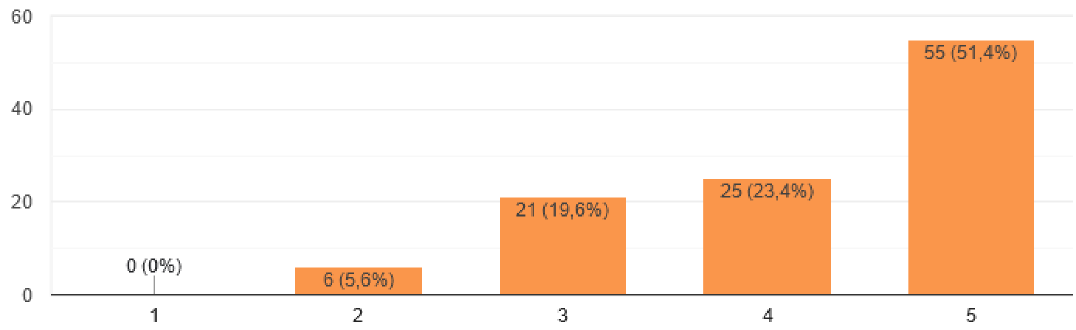

Figure 4. Respondents' perception of usefulness of VR technology in occupational safety training

In participants opinion training through VR technology would improve your understanding and reactions to safety situations at the workplace as many as 57.9% of respondents has positive answer, while 38.3% of respondents thought that this training might improve understanding and reactions to security situations. Only 3.7% of respondents gave a negative answer.

Respondents were given the opportunity to choose the profession (or several) for which they consider this training to be the most important. Construction was chosen by 88% of respondents, industry by 72.9% of respondents, and healthcare by 33.6% of respondents, while fewer respondents chose other professions.

CONCLUSION

Comprehensive training programs are essential to educate employees about safety protocols, procedures, and best practices. VR training offers a unique opportunity to simulate real-world scenarios in a controlled environment, allowing employees to practice safety procedures without being exposed to actual risks. Findings from a survey reveal positive insights into the perspectives and attitudes of Zrenjanin's populace regarding the adoption of virtual reality technology for enhancing occupational safety training. However, prioritizing safety and implementing proactive measures to prevent injuries, employers can create a safer and healthier work environment for their employees while minimizing the potential impact of workplace accidents.

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RISK ASSESSSMENT USING THE AUVA METHOD FOR THE WORKPLACE „OPERATOR OF CONSTRUCTION MACHINERY“

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Abstract: The purpose of the professional risk assessment procedure is quality management, which implies the achievement of the required system quality. The required quality of the system refers to ensuring the protection, safety, and health of employees, as well as minimizing the possibility that employees or the environment will be endangered during the work process. This research contains an overview of the conducted risk assessment for the workplace of operator of construction machines in civil engineering and road construction. A modified AUVA method was used for the occupational risk assessment procedure at the mentioned workplace. The elements on which the AUVA method is based are the probability of occurrence of danger and/or harm and the severity of possible consequences. The purpose of this research is to determine the level of risk for the workplace of operator of construction machines in civil engineering and road construction. Based on the estimated level of risk, the measures are defined to eliminate and/or reduce the level of risk, which aim to reduce the risk to an acceptable level.

Keywords: *professional risk management; risk assessment; the AUVA method; the operator of construction machinery.*

INTRODUCTION

Risk assessment describes and determines the phases and functions of the state of the working environment system process, in order to eliminate, control and minimize the causes of risk and the potential effects of risk events. Based on the analysis of the state of the working environment, the assessment determines the type and level of risk in relation to the possibility of endangering the health of workers and the severity of possible consequences.

The modernization of society leads to the modification and introduction of new technologies into work processes, which result in the emergence of new risks. Technical-technological changes, on the one hand, led to the creation of new risks, and on the other hand, enabled more efficient management of professional risk.

The process of managing professional risk involves the identification and quantification of risk, which is achieved by applying different methods for risk assessment. The main goal of occupational risk assessment is the identification of hazards and harm in the workplace and in the work environment, as well as the definition of various activities and measures for their elimination or reduction to an acceptable level. Achieving safe and healthy conditions at the workplace and in the working environment is a priority and is implemented through the application of preventive measures that affect the prevention and elimination of risks of a different nature. With the development and progress of society, there is also an increase in awareness of the importance of human resources and their participation in the development of the organization itself, which is reflected in the increase in awareness of the need to manage safety and health at work.

How much importance is given to the field of safety and health at work can be seen through the state's efforts to legislate that organizations must identify hazards and harms, assess the risk of their occurrence, and implement appropriate measures to reduce their impact. The Republic of Serbia regulates the professional risk assessment procedure in the workplace with the Rulebook on the method and procedure of risk assessment in the workplace and in the working environment, while the Law on Safety and Health at Work requires that all employers must have an Act on risk assessment in the workplace and in the working environment.

In accordance with the above, professional risk management is a prerequisite for achieving healthy physical, psychological, and moral integrity of people, but also a prerequisite for the stable and efficient functioning of socially responsible organizations.

MATERIALS AND METHODS

The risk assessment was carried out based on systematic recording and assessment of all factors in the technological process of the company engaged in construction works in civil engineering and road construction. The risk assessment is based on the identification of hazards and harm in the workplace and in the working environment, which can cause injury at work, damage to health or illness of the employee. The workplace for which the risk assessment was carried out is the operator of construction machines on a construction site in civil engineering and road construction.

A modified AUVA method was used to carry out the risk assessment procedure. The elements that are applied within the mentioned method, for risk assessment and evaluation, are: the probability of occurrence of danger and/or damage (RP - probability rank) and the severity of possible consequences (RP-consequences rank), (Anđelković et al. 2013).

The probability of occurrence of hazard and/or harm is determined depending on the exposure of workers to hazards and/or harm (RE-exposure rank) and the state of the working environment, i.e. the fulfillment of safety and health requirements at work. Exposure of employees to hazards and harms during working time is expressed in percentages and can be divided into qualitative (very rarely; occasionally; often; most of the working time; all working time) and quantitative (1-5) ranking of exposure to hazards and harms (Anđelković et al. 2013). The fulfillment of safety and health requirements at work, i.e. the state of the working environment, implies insight and assessment of the following elements: the state of the work space and work surfaces; state of means and equipment for work; state of protection against electric shock; state of heating and ventilation; microclimate condition; lighting condition; state of electromagnetic radiation; condition of noise and vibration; atmospheric and climatic influences, i.e. performing work outdoors; state of fire and explosion protection; condition of roads for passage, approach and evacuation; state of raw materials, basic, auxiliary and waste materials; the state of organizational safety and health measures at work; condition of means and equipment for personal protection; state of competence for safe work; state of awareness in the field of safety and health at work; giving first aid; protection of non-smokers, consumption of alcohol and other addictive substances; state of maintenance of work rooms and rooms for personal hygiene; inspection findings on the performed finding; injuries at work,occupational diseases and illnesses related to work (Anđelković et al. 2013). The fulfillment ofsafety and health requirements at work is expressed in percentages, based on which a qualitative (satisfactory; medium-term necessary measures; short-term necessary measures; currently necessary measures; measures for the immediate interruption of the work process) and quantitative (1-5) ranking of the working conditions is carried out the environment (Anđelković et al. 2013). The ranking of the state of the working environment (RE-environment rank), for the analyzed workplace, was rated 1 based on the insight and evaluation of the mentioned elements.

Risk assessment includes the analysis of possible consequences of hazards and harm, which are manifested as work injuries, occupational diseases and work-related diseases, which participate in determining the probability of occurrence of hazards and/or harm. The rank of the probability of occurrence of hazard and/or harm is defined as the product of the rank of exposure and the rank of environmental conditions. The ranking of the probability of danger and harm can be qualitative (negligible; small; medium; large) and quantitative (1-4), (Anđelković et al. 2013).

Based on the description of the consequence (only first aid is sufficient; medical treatment with sick leave for up to 3 days; treatment including hospitalization; permanently altered work ability; collective injury and/or permanent endangerment of vital functions and/or injuries with a fatal outcome) and a qualitative description of the severity consequences (very light, light, medium light, severe; fatal and/or collective) the rank of severity of possible consequences is determined (1-5), (Anđelković et al. 2013).

The level of risk (RL-risk level) is defined as the product of the rank of probability of hazard and/or harm and the rank of severity of possible consequences. Risk ranking can be qualitative (insignificant; small; medium; high; extreme) and quantitative (I-V) (Anđelković et al. 2013). The quantitative level of risk is determined for each hazard and/or harm that is likely to occur at the workplace and in the work environment. Workplaces with risk rank 1 and 2 areworkplaces with acceptable risk, while workplaces with ranks 3, 4 and 5 are workplaces with an increased risk (Anđelković et al. 2013).

RESULTS AND DISCUSSION

The analysis of the construction machine operator position found that the employee in this position performs earthworks on the construction site in civil engineering and road construction. He spends most of his working time in a sitting position, operating the machine. Also, the operator of the construction machines performs the tasks of inspection and basic maintenance of the machine.

The risk assessment procedure was carried out using the modified AUVA method, analyzing and identifying hazards and harms at the workplace of the operator of construction machinery. Based on the conducted work organization recording procedure, applied safety and health measures at work, determination of hazards and harm in the workplace and in the working environment, and risk ranking, it was estimated that the workplace with increased risk was analyzed.

The hazards and harms that classify the analyzed workplace as a workplace with increased risk are shown in the following table.

Table 1. Identification of hazards and harm in the workplace and in the working environment for the analyzed workplace

Code	Hazards and/or Harms	Possible consequences	REx	REn	RP	RC	RL	Rank Risk
Mechanical hazards arising from the use of work equipment								
03	Internal transport, the movement of work machines and themovement of certain work equipment (danger of being hit by construction machinery; danger of being hit by a truck; during all work carried out on the construction site, work site and near traffic roads, it is possible to bump into employees working in a narrow space without the possibility to take cover);	Injuries to certain parts of the body and injuries to certain parts of the body with a fatal outcome.	2	1	2	5	10	III
Hazards that arise in connection with the characteristics of the workplace								
08	Work at height, in terms of safety and health at work (danger when climbing and dismounting from the work machine, etc.);	Multiple fractures, polytrauma with a possible fatal outcome.	2	1	2	5	10	III

	Other harms							
39	Psychomotor and psychosensory loads (operators of construction machines during work simultaneously monitor a large number of objects, sound and light signals, evaluate the speed of the vehicle, the position of the worker, the quality of the performed work operation);	The loss of psychosensory abilities can cause occupational illness, but also serious injuries at work when the employee does not notice the approaching self-propelled equipment or machine in time.	4	1	4	3	12	III

In accordance with the estimated risk for the construction machinery operator job, measures were defined to eliminate and reduce the level of risk, i.e. reduce the risk to an acceptable level. Defined measures of safety and health at work for hazards and harms that determine the analyzed workplace as a workplace with increased risk are shown in the following table.

Table 2. Occupational safety and health measures for the analyzed workplace

Code	The type of hazard or harm	Safety and health measures at work
	Mechanical hazards arising from the use of work equipment	
03	Internal transport, the movement of work machines and the movement of certain work equipment (danger of being hit by construction machinery; danger of being hit by a truck; during all work carried out on the constructionsite, work site and near traffic roads, it is possible to bump into employees working in a narrow space without the possibility to take cover);	It is forbidden to keep people in the places where loading and shaping of materials is carried out using a combination machine, a loading shovel, and an excavator. It is forbidden to stay in front of the asphalt cutting machine. The cutting board must be adequately cooled, and its repair and cleaning is carried out when it is completely stopped. The machine for cutting asphalt must have a valid professional report, the employee who uses it in the work must be professionally qualified.
	Hazards that arise in connection with the characteristics of the workplace	

08	Work at height, in terms of safety and health at work (danger when climbing and dismounting from the workmachine, etc.);	Work at heights can only be performed by employees who have experience in previous work, and those who have acquired knowledge and checked their personal abilities to perform these jobs. Workers must be trained to work at height and be examined by a doctor specializing in occupational medicine. Work at heights can only be performed under the direct supervision of a professional worker. Work at heights can only be performed using appropriate protective equipment.
Other harms		
339	Psychomotor and psychosensory loads (operators of construction machines during work simultaneously monitor a large number of objects, sound and light signals, evaluate the speed of the vehicle, the position of the worker, the quality of the performed work operation);	Regular rest. Conduct regular medical examinations. Use breaks in work to rest both physically and mentally. The consumption of alcohol and addictive substances is strictly prohibited during working hours and outside of working hours. If it is noticed that the vehicles and machinery do not have proper lighting and signaling, it is necessary to inform the immediate manager and the driver. When an employee feels tired, he should contact his immediate supervisor and take a break from work. The employee must not start work if he does not feel capable.

In addition to the defined safety and health measures at work for the position of operator of construction machines, it is necessary to carry out preliminary and periodic medical examinations, as well as controlled, targeted, and systematic examinations. As a medical measure to prevent the realization of defined dangers and harms, a continuous monitoring of the psychophysical abilities of employees at this workplace is enforced, which includes the condition of the sense of hearing and balance, good concentration, and quick and adequate reaction in every situation.

Personal protective equipment represents another measure in preventing the occurrence of danger and harm, which the employer is obliged to provide to the employees of his company. For the position of operator of construction machinery, the prescribed personal protective equipment is as follows: work suit (winter and summer version), protective shoes, helmet, high-visibility vest, safety glasses, anti-cut gloves, earplugs, and noise-cancelling headphones (if necessary, at increased intensity noise).

CONCLUSION

Risk assessment is a process of continuous and systematic recording and evaluation of all factors in the work process that can lead to injury at work or damage to the health of employees. Risk assessment is an important step in the protection of workers and in general in preserving the functioning of the working environment, and it is also a legal requirement of the employer..

Occupational risk management, in the company where a risk assessment was carried out, for the position of operator of construction machines in civil engineering and road construction, iscarried out on the basis of preventive measures of occupational safety that eliminate or reducethe risk to an acceptable level, which leads to the optimal functioning of work processes. Basedon the insight into the situation, the analysis of specific working conditions, the influence of alldangerous and harmful factors that cause the occurrence and development of unwanted events, the identification and quantification of risks was carried out. A modified AUVA method was used to carry out the risk assessment procedure for the mentioned workplace, which showed that the construction machine operator workplace is a workplace with an increased risk, basedon hazards (internal transport, work at height) and harm (psychomotor and psychosensory workload).

Based on the dangers and harms, which determined that the workplace with increased risk was analyzed, safety and health measures at work were defined in order to eliminate and reduce the risk to an acceptable level. Safety and health measures at work are defined for each hazard and harm that the specified workplace determines as a workplace with increased risk. Also, in addition to the defined safety measures, medical measures and personal protective equipment are presented, which aim to prevent the occurrence of hazards and harm in the workplace of the operator of construction machinery, and thus prevent the occurrence of occupational injuries, occupational illnesses and diseases related to work.

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STRENGTHENING CAPACITY FOR SUSTAINABLE WORKPLACE SAFETY WITH ARTIFICIAL INTELLIGENCE

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Abstract: Artificial intelligence refers to the simulation of human intelligence in machines, enabling them to perform tasks that typically require human intelligence. This encompasses a wide range of capabilities, including learning, reasoning, problem-solving, perception and language understanding. Occupational Safety and Health is a multidisciplinary field dedicated to ensuring the health, safety and well-being of workers in the workplace. It unites policies, procedures and practices aimed at preventing work-related injuries, illnesses and accidents, as well as promoting a safe and healthy work environment for all employees. The aim of this paper is to show the importance and use of artificial intelligence in the field of safety and health at work through a literature review, as well as highlighting the emerging modern challenges.

Keywords: *Artificial intelligence; Occupational Safety and Health; modern challenges*.

INTRODUCTION

Artificial intelligence (AI) represents the advancement of computer systems to execute tasks that traditionally demand human intellect. This encompasses a wide array of abilities, spanning from perception and logical reasoning to learning and resolving complex problems. AI applications, such as virtual assistants, autonomous vehicles, and sophisticated robotics, demonstrate diverse manifestations of this technology, continually expanding the possibilities of what machines can accomplish (Anastasiou et al., 2021).

The primary goals of occupational health and safety (OHS) are to prevent accidents and injuries, minimize occupational illnesses, promote health and well-being, comply with regulations and standards, and create a safety culture. The advent of new technologies has been a double-edged sword in the realm of workplace safety, introducing both new hazards and innovative solutions. In the realm of OHS, AI stands as a transformative force, heralding a new era where computer systems emulate and, in some cases, surpass human cognitive capabilities. By leveraging AI, organizations can revolutionize their approach to workplace safety, augmenting traditional methods with innovative technologies to enhance hazard identification, risk assessment, and incident prevention.

The methodology employed for reviewing scientific literature concerning the utilization of AI in addressing contemporary challenges within the OHS domain is depicted in Figure 1. *Science Direct* was used as a database of scientific papers and three search terms were used.

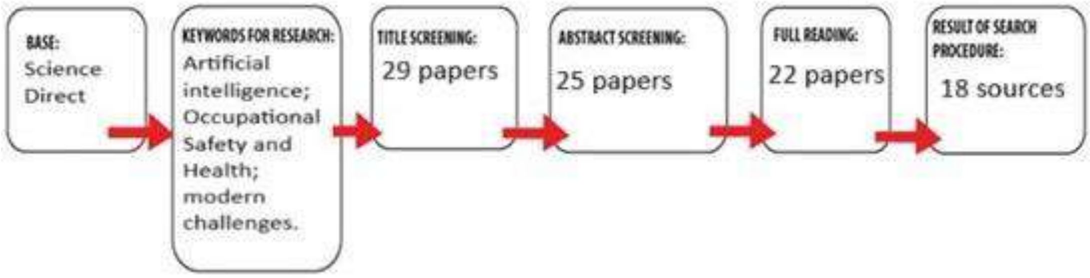

Figure 5. The literature selection process

AI systems exhibit diverse manifestations, categorized into distinct classes based on their capabilities and functionalities, as elucidated by Papi et al. (2022):

1. Narrow AI refers to AI systems designed to perform specific tasks or functions within a limited domain. In the context of OHS these AI systems could be tailored to address particular challenges or requirements related to ensuring the health and well-being of workers in various occupational settings.
2. General AI refers to AI systems that possess human-like intelligence and are capable of understanding, learning and reasoning across a wide range of domains. In theory, the concept of General AI revolutionizing OHS practices by emulating human reasoning, intuition, and adaptability has been discussed in previous studies (Miller, 2019, EU-OSHA, 2021, Russel and Norvig, 2021).
3. Machine learning (ML) focuses on developing algorithms and techniques that enable computers to learn from data and improve their performance over time without being explicitly programmed. In the context of OHS, ML algorithms can analyze vast amounts of workplace data to identify patterns, predict hazards, and optimize safety measures. Some potential applications of ML in OHS are hazard identification and risk assessment, predictive maintenance, personal protective equipment (PPE) monitoring, behavioral safety analysis, workforce health monitoring, incident prediction and prevention (Sarigiannidis et al., 2020; Bakker et al., 2020; He et al., 2020; Abbas et al., 2021).
4. Deep learning is a subset of machine learning that involves the use of artificial neural networks inspired by the structure and function of the human brain. Deep learning algorithms, also known as deep neural networks, are capable of learning from large volumes of data and extracting complex patterns and representations, making them

particularly well-suited for tasks such as image and speech recognition. Deep learning, within the realm of OHS, holds promise for revolutionizing hazard recognition, risk assessment, and safety management practices: hazard recognition, risk assessment, predictive maintenance, human activity recognition, natural language processing (NLP) (Anastasiou et al., 2021; Papi et al., 2022; Smith and Doe, 2023; Johnson and Wang, 2022).

THE USE OF ARTIFICIAL INTELLIGENCE

In the ever-evolving landscape of workplace safety, AI has emerged as a powerful ally, revolutionizing how organizations identify, reduce and prevent occupational hazards. From predictive analytics to real-time monitoring systems, the integration of AI technologies holds the promise of transforming traditional approaches to safety management, leading to a new era of proactive risk mitigation and worker protection (Karanikas et al., 2021).

At the heart of AI's impact on OSH lies its capacity for predictive analytics. By analyzing vast datasets encompassing factors such as historical incident reports, environmental conditions and employee behavior, AI algorithms can identify patterns and trends that may precede safety incidents.

In addition to predictive analytics, AI-driven real-time monitoring systems play a crucial role in enhancing situational awareness and response capabilities in the workplace. By integrating sensors and cameras, AI can continuously monitor environmental conditions, worker activities and equipment performance, providing instant insights into potential hazards.

For example, wearable sensors equipped with AI algorithms can detect signs of fatigue or fatigue in workers, alerting supervisors to prevent injuries. Similarly, AI-powered video analytics can identify unsafe behaviors or near-miss incidents in real-time, enabling immediate corrective actions to be taken to mitigate risks (Karanikas et al., 2021).

Traditional risk assessment methods often rely on manual inspections and subjective judgments, leaving room for oversight and inconsistency. However, AI streamlines the process of risk assessment through the following steps (Vallor, 2019):

1. **Collection of data** from various sources within the workplace, including historical incident reports, environmental monitoring systems, employee records and safety inspection reports (accident frequency, severity, location, time of occurrence and contributing factors).
2. Prior to analysis, the raw data collected by the risk assessment tool undergoes **preprocessing** to clean, organize and prepare it for analysis. This may involve data cleaning techniques to remove errors and inconsistencies, data normalization to

standardize units and formats and data transformation to extract relevant features or variables.

3. AI algorithms rely on **identifying relevant features or variables** within the dataset that are predictive of safety risks. Feature selection techniques may be used to identify the most important variables and discard irrelevant ones.
4. AI-powered risk assessment tools employ various machine learning algorithms, such as classification, regression, or clustering, to **build predictive models** that can identify and quantify different types of risks in the workplace.
5. The AI models are capable of **predicting the likelihood and severity of different types of risks** based on input data.
6. AI-powered risk assessment tools may **provide recommendations for reducing identified risks**. These recommendations may include implementing engineering controls, administrative controls, or personal protective equipment, as well as scheduling preventive maintenance activities or safety training programs.
7. By regularly updating and retraining the models with fresh data, these tools can **improve their accuracy and effectiveness over time**, enabling organizations to stay ahead of emerging risks and hazards.

MODERN CHALLENGES AND CONSIDERATIONS

The integration of AI into OHS initiatives brings about a host of modern challenges and considerations that intersect with broader sustainability objectives, including those outlined in the United Nations Sustainable Development Goals (SDGs).

One such challenge pertains to the ethical implications of AI deployment in OHS. As AI systems gain autonomy, questions arise regarding accountability, transparency, and fairness in decision-making processes (Bostrom and Yudkowsky, 2014). This includes concerns about potential bias and discrimination in areas such as hiring practices and worker surveillance, which could hinder progress towards SDG 8 (Decent Work and Economic Growth) by undermining fair and inclusive employment practices.

Additionally, the collection and utilization of large volumes of data in AI-driven systems raise privacy concerns, impacting employee autonomy and consent (Barocas and Selbst, 2016). Organizations must address these ethical complexities to ensure that AI algorithms adhere to ethical principles and regulatory standards, thus contributing to SDG 16 (Peace, Justice, and Strong Institutions) by promoting transparent and accountable governance practices.

Another significant challenge lies in the interpretability and transparency of AI algorithms. Many AI systems operate as "black boxes," making it difficult for stakeholders to understand and trust AI-driven decisions (Rudin, 2019). This lack of transparency can hinder progress towards SDG 9 (Industry, Innovation, and Infrastructure) by impeding the adoption of innovative technologies that could enhance workplace safety.

Biases and inaccuracies in training datasets used to develop AI algorithms can perpetuate inequalities and hinder progress towards SDG 10 (Reduced Inequalities) (Caliskan et al., 2017). Organizations must prioritize data quality assurance and diversity in data sources to ensure the inclusivity and fairness of AI-driven solutions, thus advancing the goal of equal opportunity for all.

Resource constraints and accessibility pose barriers to the widespread adoption of AI in OSH, particularly for smaller enterprises and developing economies (Carayol and Roux, 2016). The high costs associated with AI implementation may exacerbate inequalities and hinder progress towards SDG 1 (No Poverty) and SDG 9 by limiting access to technology and innovation.

CONCLUSION

Amidst the evolving landscape of workplace safety and health, there exists a growing recognition of the interconnectedness between safety initiatives and broader sustainability goals, including those outlined in the United Nations Sustainable Development Goals (SDGs). By integrating AI-driven risk assessment tools into their operational frameworks, organizations not only enhance workplace safety but also contribute to sustainable development objectives.

These advanced technologies enable organizations to optimize resource allocation, minimize environmental impact, and promote social well-being, aligning with several SDGs such as Goal 3 (Good Health and Well-being), Goal 8 (Decent Work and Economic Growth), and Goal 9 (Industry, Innovation, and Infrastructure). Moreover, by fostering a culture of proactive risk management and employee empowerment, organizations can advance SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) by promoting sustainable practices and mitigating occupational hazards. Navigating the contemporary challenges and nuances of integrating AI into OSH necessitates a cohesive collaboration among industry stakeholders, regulators, researchers, and AI developers. Establishing comprehensive regulatory frameworks is imperative to effectively oversee the evolution, implementation, and utilization of AI technologies in work environments. These frameworks should encompass guidelines ensuring ethical AI design, safeguarding data privacy, and promoting algorithmic transparency.

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SWOT ANALYSIS OF OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEMS IMPLEMENTATION

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Abstract: In today's dynamic organizational landscape, the implementation of robust Occupational Health and Safety management systems is crucial for ensuring the well-being of employees and the sustainable operation of businesses. Employers across various sectors continually strive to enhance workplace safety standards through the deployment of Occupational Health and Safety management systems. However, the effectiveness of these systems varies considerably, influenced by a multitude of internal and external factors. Applying a Strengths-Weaknesses-Opportunities-Threats analysis offers a framework to evaluate the efficacy of Occupational Health and Safety management systems in different organizations. The results of the analysis showed that Occupational Health and Safety management systems can be applied in various organizations and that, in addition to strengths and opportunities, weaknesses and threats can also be found.

Keywords: *Strengths-Weaknesses-Opportunities-Threats analysis; Occupational Health and Safety management; OHSAS 18001standard; ISO 45001 standard.*

INTRODUCTION

To address the challenges associated with workplace safety systematically, many organizations choose to implement the OHSAS (Occupational Health and Safety Assessment Series) 18001 standard. It is designed to be adaptable to various organizational contexts and industries, enabling organizations to identify and control occupational health and safety (OHS) risks systematically (Levenson and Turner, 2009).

In pursuit of fostering safer workplaces, organizations worldwide turn to ISO (International Organization for Standardization) 45001, an international standard which replaces the previous OHSAS 18001 standard and aligns with other management system standards, such as ISO 9001 (Quality Management) and ISO 14001 (Environmental Management). ISO 45001 emphasizes a proactive approach to identifying hazards, assessing risks, and implementing controls to prevent work-related injuries, illnesses, and fatalities (Melo and Almeida, 2019).

The objective of this study is to conduct a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis focusing on the implementation of safety and health standards across different sectors, including construction, medical, and fashion industries. Additionally, the paper aims to review existing literature pertaining to this subject matter. By examining these diverse organizational settings, the study seeks to offer a comprehensive perspective on both the benefits and drawbacks associated with the adoption of such standards.

METHODOLOGY

Figure 1 shows the selection process for analysed scientific research on OHSAS and ISO implementation. Science Direct was used as a database of scientific papers and seven search terms were used. After title screening, abstract screening and full reading, sixteen papers were selected as a result of the paper selection process.

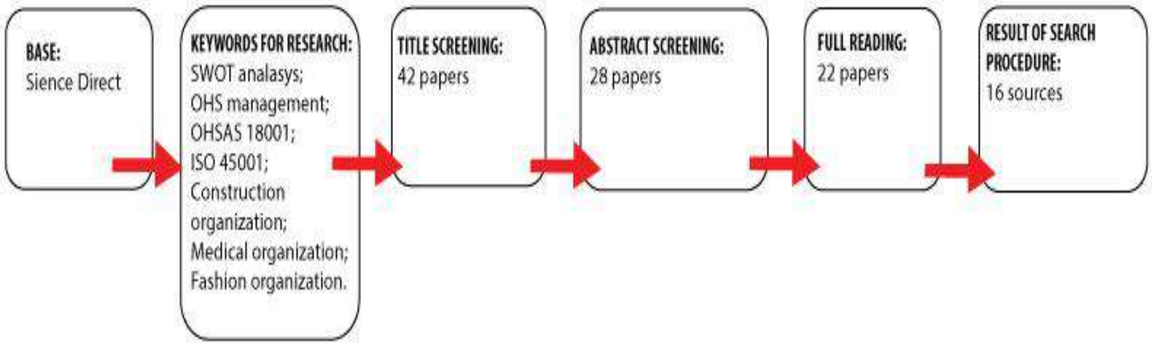

Figure 1. The paper selection process

SWOT analysis is a strategic planning methodology used to evaluate the strengths, weaknesses, opportunities and threats associated with a particular project, venture, or entity (Ntalos and Arabatzis, 2009). It provides a structured framework for assessing both internal and external factors that can impact the success or failure of a plan or decision (Ozdemir and Calisir, 2009).

RESULTS

A SWOT analysis for the application of OHSAS 18001 and ISO 45001 standards in various organizations was conducted in tabular form (Tables 1, 2, and 3). The organizations for which the analysis was conducted are contruction, medical and fashion organizations.

Table 7. SWOT (S – strengths, W – weaknesses, O – opportunities, T - threats) analysis for the application of OHSAS 18001 and ISO 45001 in construction organizations

S	**Regulatory Compliance:** Construction organizations operate in a highly regulated industry with stringent occupational health and safety (OHS) requirements. Implementing robust OHS management systems ensures compliance with regulations (Lingard and Rowlinson, 2005).
	Safety Training and Education: Construction organizations invest in safety training and education programs to equip employees with the knowledge and skills necessary to identify hazards, assess risks, and implement safety measures. Training initiatives cover topics such as fall protection, hazard communication, and equipment operation, enhancing safety awareness and competency among workers (Arain et al., 2012).

	Safety Equipment and Technology: Construction organizations provide employees with personal protective equipment, safety gear, and technological tools to mitigate occupational hazards. Utilizing safety equipment such as hard hats, safety harnesses, and respirators, coupled with advancements in construction safety technology such as drones, sensors, and building information modeling, enhances worker protection and safety outcomes (Chen and Hsiao, 2011).
	Culture of Safety: Construction organizations prioritize a culture of safety, fostering an environment where safety is valued, promoted, and practiced at all levels of the organization. Leadership commitment, employee involvement, and recognition of safety achievements contribute to a strong safety culture, reducing accidents, injuries, and fatalities on construction sites (Hinze et al., 2013).
W	**High-Risk Work Environment:** Construction work involves inherent risks, including falls from heights, electrocution, struck-by accidents, and exposure to hazardous substances. The dynamic and unpredictable nature of construction projects, coupled with tight deadlines and demanding schedules, increases the likelihood of safety incidents and injuries (Lingard and Rowlinson, 2005).
	Subcontractor Management: Construction organizations often rely on subcontractors, suppliers, and temporary workers to complete projects. Coordinating safety standards, ensuring subcontractor compliance with safety protocols, and maintaining oversight of subcontracted work pose challenges for safety management and accountability (Arain et al., 2012).
	Workforce Diversity and Language Barriers: Construction sites employ workers from diverse backgrounds, cultures, and language proficiency levels. Communication barriers, language differences, and cultural disparities may hinder effective safety communication, training delivery, and hazard recognition, increasing the risk of accidents and misunderstandings (Chen and Hsiao, 2011).
	Resistance to Change: Implementing OHS management systems requires changes in work practices, procedures, and organizational culture, which may encounter resistance from management, supervisors, and frontline workers. Overcoming resistance to change, addressing skepticism, and fostering buy-in for safety initiatives require leadership commitment and effective communication (Hinze et al., 2013).
O	**Innovations in Safety Technology:** Construction organizations can leverage technological innovations to enhance safety management systems and practices. Adopting technologies such as wearable devices, IoT sensors, augmented reality, and predictive analytics enables real-time monitoring, hazard detection, and proactive risk mitigation on construction sites (Lingard and Rowlinson, 2005).
	Collaboration and Partnerships: Construction organizations can collaborate with industry partners, trade associations, and regulatory agencies to share best practices, develop safety guidelines, and promote safety initiatives. Participating in safety-focused initiatives, alliances, and forums facilitates learning, networking, and continuous improvement in safety management (Arain et al., 2012).
	Preventive Maintenance and Equipment Safety: Implementing preventive maintenance programs and equipment safety protocols improves the reliability, performance, and safety of construction machinery and tools. Regular inspections, maintenance checks, and equipment testing ensure compliance with safety standards and reduce the risk of equipment-related accidents and breakdowns (Chen and Hsiao, 2011).
	Worker Empowerment and Participation: Empowering workers to actively participate in safety initiatives, hazard identification, and decision-making processes enhances safety ownership and commitment. Involving workers in safety committees, toolbox talks, and safety audits fosters a sense of responsibility, engagement, and accountability for safety outcomes (Hinze et al., 2013).
T	**Worksite Hazards and Accidents:** Construction organizations face threats from worksite hazards, accidents, and emergencies, which pose risks to worker safety and project continuity. Addressing hazards such as falls, electrical hazards, and trench collapses requires proactive risk management, training, and adherence to safety protocols (Lingard and Rowlinson, 2005).
	Budget Constraints and Cost Pressures: Construction projects are subject to budget constraints, cost pressures, and client demands for cost-effective solutions. Budget cuts, resource limitations, and value engineering practices may compromise safety investments, training programs, and safety equipment procurement, leading to safety risks and compromises (Arain et al., 2012).

	Workforce Shortages and Skill Gaps: Construction organizations experience workforce shortages and skill gaps due to factors such as aging workforce, labor market fluctuations, and insufficient training pipelines. Recruiting qualified workers, retaining experienced talent, and addressing skill shortages pose challenges for maintaining safety standards and project continuity (Chen and Hsiao, 2011).
	External Factors and Economic Uncertainty: External factors such as economic downturns, regulatory changes, and political instability impact the construction industry's operating environment and safety management practices. Uncertainty in market conditions, project financing, and supply chain disruptions can affect safety investments, project timelines, and resource allocation for safety initiatives (Hinze et al., 2013).

Table 2. SWOT (S – strengths, W – weaknesses, O – opportunities, T - threats) analysis for the application of OHSAS 18001 and ISO 45001 in medical organizations

S	**Regulatory Compliance:** Medical organizations are subject to stringent regulatory requirements regarding occupational health and safety. Implementing robust OHS management systems ensures compliance with regulations, reducing the risk of legal liabilities (Cox and Cox, 2018).
	Expertise in Healthcare: Medical organizations often have access to specialized expertise in healthcare, including occupational medicine, infection control, and risk management. This knowledge base enables them to develop tailored OHS management systems that address the unique risks and challenges faced in healthcare settings (El-Jardali et al., 2011).
	Access to Resources: Medical organizations typically have access to resources such as medical equipment, personal protective gear, and trained personnel, which are essential for implementing effective OHS management systems. Adequate resources facilitate hazard identification, risk assessment, and implementation of control measures to protect healthcare workers and patients (Guldenmund, 2009).
	Culture of Safety: Healthcare organizations prioritize patient safety, which often extends to a culture of safety for employees. The commitment to patient care translates into a strong emphasis on employee well-being, fostering a culture where safety is paramount and employees are empowered to report hazards and participate in safety initiatives (Pidgeon and O'Connor, 2016).
W	**High Workload and Stress:** Healthcare workers, particularly in high-pressure environments such as emergency departments and intensive care units, may experience high levels of workload and stress. This can lead to fatigue, burnout, and reduced compliance with safety protocols, undermining the effectiveness of OHS management systems (Cox and Cox, 2018).
	Complex Work Environment: Medical organizations operate in complex environments with multiple stakeholders, diverse workforce demographics, and dynamic patient care needs. Managing occupational health and safety risks amidst these complexities requires coordination, communication, and resources, which may pose challenges for implementation (El-Jardali et al., 2011).
W	**Budget Constraints:** Healthcare organizations often face budget constraints and competing priorities, limiting resources available for OHS management system implementation. Limited funding may hinder investments in training, equipment, and infrastructure necessary for maintaining a safe work environment (Guldenmund, 2009).
	High Staff Turnover: Healthcare organizations experience turnover due to factors such as career advancement, burnout, and retirement. High staff turnover can disrupt OHS management system implementation by requiring frequent training, onboarding, and reorientation of new employees to safety protocols (Pidgeon and O'Connor, 2016).
O	**Technological Innovations:** Advancements in healthcare technology, such as electronic health records, telemedicine, and wearable devices, offer opportunities for enhancing OHS management systems. Digital solutions enable real-time monitoring of workplace hazards, remote safety training, and data-driven decision-making to improve safety outcomes (Cox and Cox, 2018).

	Interdisciplinary Collaboration: Medical organizations can leverage interdisciplinary collaboration between healthcare providers, occupational health professionals, and safety experts to strengthen OHS management systems. Collaborative efforts facilitate knowledge sharing, best practice dissemination, and innovation in addressing emerging occupational health and safety challenges (El-Jardali et al., 2011).
	Preventive Health Programs: Implementing preventive health programs, such as wellness initiatives, ergonomic assessments, and mental health support, can enhance employee well-being and reduce the incidence of work-related injuries and illnesses. Proactive measures promote a culture of prevention and resilience, improving overall OHS performance (Guldenmund, 2009).
	Quality Improvement Initiatives: Healthcare organizations can integrate OHS management system implementation with quality improvement initiatives. Aligning safety objectives with quality goals enhances organizational efficiency, patient outcomes, and employee satisfaction (Pidgeon and O'Connor, 2016).
T	**Emerging Infectious Diseases:** Healthcare organizations face threats from emerging infectious diseases, such as pandemics and outbreaks, which pose significant occupational health and safety risks to healthcare workers. Managing outbreaks requires rapid response, infection control measures, and adequate personal protective equipment supply to protect frontline workers (Cox and Cox, 2018).
	Workplace Violence: Healthcare workers are at risk of workplace violence due to factors such as patient agitation, visitor conflicts, and substance abuse-related incidents. Addressing workplace violence requires comprehensive risk assessments, de-escalation training, and security measures to ensure staff safety (El-Jardali et al., 2011).
	Legal and Regulatory Changes: Changes in healthcare regulations, insurance requirements, and occupational health standards may impact OHS management system implementation. Keeping abreast of regulatory changes, updating policies and procedures, and ensuring compliance with evolving legal requirements are essential to mitigate risks (Guldenmund, 2009).
	Resource Constraints During Crises: During crises such as natural disasters or public health emergencies, healthcare organizations may face resource constraints, staffing shortages, and increased workload demands. Maintaining OHS management system effectiveness amidst crises requires contingency planning, resource allocation, and resilience-building measure (Pidgeon and O'Connor, 2016).

Table 8. SWOT (S – strengths, W – weaknesses, O – opportunities, T - threats) analysis for the application of OHSAS 18001 and ISO 45001 in fashion organizations

S	**Regulatory Compliance:** Fashion organizations are subject to occupational health and safety (OHS) regulations governing workplace safety, chemical exposure, and ergonomic standards. Implementing robust OHS management systems ensures compliance with regulations (Choi and Pai, 2020).
	Employee Training and Education: Fashion organizations invest in safety training and education programs to equip employees with the knowledge and skills necessary to identify hazards, handle chemicals safely, and use equipment properly. Training initiatives cover topics such as garment handling, ergonomics, and chemical safety, enhancing safety awareness and competency among workers (Fan et al., 2019).
	Access to Safety Equipment and Protective Gear: Fashion organizations provide employees with personal protective equipment, safety gear, and ergonomic tools to mitigate occupational hazards. Utilizing safety equipment such as gloves, safety goggles, and ergonomic workstations, coupled with ergonomic assessments and modifications, enhances worker protection and safety outcomes (Cappelli and Clark, 2018).
	Commitment to Sustainability and Corporate Social Responsibility: Fashion organizations prioritize sustainability, worker health and safety, as part of their ethical and social responsibility commitments. Integrating OHS management systems with sustainability programs, supply chain transparency, and ethical sourcing practices fosters a culture of safety and well-being throughout the organization (Calvo-Mora et al., 2018).
W	**Chemical Exposure and Toxicity:** Fashion organizations use chemicals in various stages of production, including dyeing, finishing, and garment processing, posing risks of chemical exposure and toxicity to workers. Managing chemical hazards, implementing safe handling procedures, and providing training on chemical safety are essential but may encounter challenges due to the complexity of chemical management (Choi and Pai, 2020).

	Workplace Ergonomics and Musculoskeletal Disorders: Fashion industry workers may experience musculoskeletal disorders due to repetitive tasks, awkward postures, and prolonged standing or sitting. Addressing ergonomic risks, redesigning workstations, and providing ergonomic training are necessary but may face barriers such as resistance to change and cost implications (Fan et al., 2019).
	Supply Chain Complexity and Outsourcing: Fashion organizations operate within complex global supply chains involving multiple stakeholders, subcontractors, and outsourcing partners. Coordinating safety standards, ensuring supplier compliance with safety protocols, and monitoring subcontracted work pose challenges for safety management and accountability (Cappelli and Clark, 2018).
	Fast Fashion Pressures and Production Deadlines: Fashion organizations face pressures to meet fast fashion demands, tight production schedules, and quick turnaround times. Fast-paced production environments may compromise safety protocols, worker fatigue, and quality control measures, increasing the risk of accidents, injuries, and stress-related health issues (Calvo-Mora et al., 2018).
O	**Technology Adoption for Safety Enhancement:** Fashion organizations can leverage technology to enhance safety management systems and practices. Adopting technologies such as automated machinery, robotics, wearable sensors, and digital safety platforms enables real-time monitoring, hazard detection, and proactive risk mitigation in fashion production facilities (Choi and Pai, 2020).
	Collaboration with Industry Partners: Fashion organizations can collaborate with industry partners, trade associations, and research institutions to share best practices, develop safety guidelines, and promote safety initiatives. Participating in industry forums, safety alliances, and collaborative projects facilitates learning, networking, and continuous improvement in safety management (Fan et al., 2019).
	Worker Empowerment and Participation: Empowering workers to actively participate in safety initiatives, hazard identification, and decision-making processes enhances safety ownership and commitment. Involving workers in safety committees, training programs, and safety audits fosters a culture of safety, engagement, and accountability for safety outcomes (Cappelli and Clark, 2018).
	Sustainability Integration in Safety: Integrating sustainability principles with safety management systems offers opportunities for innovation and improvement. Implementing sustainable practices, such as eco-friendly materials, energy-efficient processes, and waste reduction measures, aligns with safety objectives and enhances overall organizational sustainability (Calvo-Mora et al., 2018).
T	**Global Health Pandemics and Infectious Diseases:** Fashion organizations are vulnerable to global health pandemics, such as COVID-19, which disrupt production operations, supply chains, and worker safety. Implementing infection control measures, ensuring worker health monitoring, and managing pandemic-related risks are critical but may encounter challenges due to the unpredictability of pandemics (Choi and Pai, 2020).
	Ethical Sourcing and Worker Exploitation: Fashion organizations face risks related to ethical sourcing practices, including worker exploitation, labor rights violations, and unsafe working conditions in global supply chains. Ensuring ethical sourcing, conducting supplier audits, and addressing labor issues are essential but may face resistance from stakeholders or encounter complexities in supply chain management (Fan et al., 2019).
	Fashion Trends and Consumer Preferences: Rapid changes in fashion trends, consumer preferences, and market demands pose challenges for safety management and product safety. Balancing design creativity with safety considerations, conducting risk assessments for new materials or processes, and responding to market pressures require agility, adaptability, and risk management strategies (Cappelli and Clark, 2018).
	Environmental Hazards and Sustainability Risks: Fashion organizations are exposed to environmental hazards and sustainability risks, including pollution, waste generation, and resource depletion. Managing environmental impacts, reducing carbon footprint, and implementing sustainable practices are necessary but may face obstacles such as regulatory compliance, cost implications, and stakeholder expectations (Calvo-Mora et al., 2018).

CONCLUSION

Across construction organizations, strengths such as regulatory compliance and a culture of safety were identified, along with weaknesses including high-risk work environments and resistance to change. Opportunities such as innovations in safety technology and preventive maintenance initiatives were highlighted, while threats such as worksite hazards and budget constraints were identified.

In medical organizations, strengths such as regulatory compliance and expertise in healthcare were noted, alongside weaknesses such as high workload and staff turnover. Opportunities such as technological innovations and preventive health programs were identified, while threats such as emerging infectious diseases and legal changes were acknowledged.

Similarly, in fashion organizations, strengths such as regulatory compliance and access to safety equipment were outlined, along with weaknesses such as chemical exposure and fast fashion pressures. Opportunities such as technology adoption for safety enhancement and collaboration with industry partners were recognized, while threats such as global health pandemics and environmental hazards were highlighted.

The SWOT analysis underscores the importance of implementing robust OHS management systems tailored to the specific needs and challenges of each industry. By addressing identified weaknesses, capitalizing on opportunities, and proactively mitigating threats, organizations can enhance workplace safety, protect employee well-being, and achieve sustainable business outcomes.

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CHEMICAL HAZARD OF ACRYLAMIDE: IMPACT ON THE EXPRESSION OF CYP2E1 ENZYME IN ENDOCRINE PANCREAS

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Abstract: Acrylamide is a widely recognized industrial monomer known for its carcinogenic, mutagenic, neurotoxic, and endocrine-disrupting properties in organisms. The increased attention to acrylamide is due to its presence in numerous industrial processes as well as in a variety of food products. Our study focused on assessing the potential negative impacts of oral acrylamide administration on the expression of the CYP2E1 enzyme in the pancreatic Langerhans islets of juvenile Wistar rats. Thirty juvenile male Wistar rats were divided into three groups: one control group and two acrylamide treatment groups, receiving doses of 25 mg/kg and 50 mg/kg acrylamide for 21 days, respectively. Our results revealed a notable dose-dependent reduction in the intensity of the CYP2E1 immunopositive signal observed in immunohistochemistry (IHC)-stained islets of Langerhans. This finding suggests a reduction in CYP2E1 enzyme expression in the pancreatic Langerhans islets of juvenile Wistar rats. In the context of occupational safety, these findings underscore the importance of monitoring exposure to acrylamide and its impact on workers in the industry.

Keywords: *Acrylamide; Occupational safety; CYP2E1; Immunopositivity; Endocrine pancreas*

INTRODUCTION

Acrylamide (2-propenamide, C_3H_5NO, CAS No. 79-06-1) is a hydrophilic molecule with a molar mass of 71.08 g/mol (Fig. 1) (Wang et al., 2020). At room temperature, acrylamide is a white and odorless solid substance, soluble in water and other polar solvents.

Acrylamide is a carbonyl derivative with two functional groups: an amide group and double bonds at the α and β C-atoms, making it highly reactive and capable of participating in various chemical reactions (Wang et al., 2020). Because of its double bonds, acrylamide possesses electrophilic characteristics, allowing it to interact with nucleophilic groups. In a biological context, one notable reaction involves the oxidation of thiol groups found in the cysteine component of protein molecules (Rifai and Saleh, 2020). Reactions characteristic of the amide residue include hydrolysis, dehydration, alcoholysis, and condensation with aldehydes, while double bonds enable reactions with ammonia, aliphatic amines, chlorides, bromides, and proteins (Friedman, 2003).

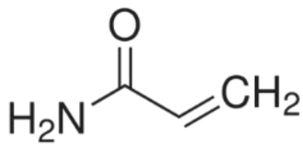

Figure 1. Acrylamide structure

Due to its vinyl double bond, acrylamide readily undergoes reactions with other acrylamide molecules, resulting in formation of polyacrylamide (ATSDR, 2012). The manufacturing of polyacrylamide for diverse applications is one of the most prominent acrylamide applications. Polyacrylamide, the derived product, is deemed non-toxic; however, its precursor, the acrylamide monomer, possesses certain toxic properties. Hence, precautions are necessary to ensure that acrylamide remains solely as a residual component within polyacrylamide, as its release into the environment during production and industrial usage can have adverse effects (ATSDR, 2012).

Polyacrylamide finds extensive use in various spheres of life. Polyacrylamide gel is employed in laboratories for genetics and molecular biology as a medium for separating molecules using gel electrophoresis. Besides its scientific research applications, one of the most common uses of polyacrylamide is in wastewater and drinking water treatment, where it enhances the efficiency of water treatment processes through sedimentation, flotation, and dewatering techniques (Wei et al., 2024). Although polyacrylamide itself is non-toxic, trace amounts of monomer residue may be found in drinking water. In the European Union, the minimal allowed presence of acrylamide in drinking water is regulated by law and amounts to 0.1 µg/L (Directive EU, 2020). Taking this information into account and assuming a daily water intake of 2 liters, a person weighing 70 kg ingests a dose of acrylamide of 0.003 µg/kg body weight per day (Hogervorst, 2009).

Besides the use in water treatment, polyacrylamide finds versatile use in multiple industries, serving as a waterproofing agent in cement used for construction ventures such as dam and tunnel foundations. Additionally, polyacrylamide is used in paper production, color synthesis, and manufacturing of contact lenses. It has also found application in irrigation water to improve soil texture and reduce erosion. Apart from these common applications, polyacrylamide is used as an additive to pesticides to increase viscosity and to enhance the viscosity of media used in hydroponic plant cultivation. It is also present as an additive in cosmetic products (ATSDR, 2012).

It has been demonstrated that heat, sunlight, photochemical reactions, and open environmental conditions affect the depolymerization of polyacrylamide. Analysis of residual acrylamide presence in beans, corn, potatoes, and sugar beets grown in soil treated with polyacrylamide to prevent erosion shows acrylamide levels below 10 ppb (parts per billion) (ATSDR, 2012).

Acrylamide absorbed by plants is largely degraded within the next 18 hours; however, the exact mechanism by which plants degrade it remains unknown (Castle, 1993).

People are exposed to acrylamide through different pathways, including ingestion, dermal and exposure by inhalation. Additionally, exposure can occur from a variety of sources, such as diet, smoking, drinking water, and workplace environments. Workplace exposure typically occurs through inhalation of dust and vaporized particles. Moreover, skin absorption represents another significant route of exposure in occupational settings (Rifai and Saleh, 2020). Because of its solubility in water, acrylamide readily dissolves in the bloodstream, facilitating uniform distribution throughout all organ systems (Doerge et al., 2005).

Numerous instances of neurological disorders have been documented among individuals who were exposed to grouting agents containing acrylamide. One case involved a 30-year-old man in Korea who developed multiple neuropathies while engaged in acrylamide production (Hae-Kwan et al., 1998) Peripheral neuropathy subsequent to exposure to acrylamide-containing grouting agents has been reported in various locations, including a construction site in the UK in 1977 (involving 6 workers), the city of Sinsang in China in 1994 (involving 41 workers), and a tunnel site in Norway in 2004 (involving 24 workers) (Calleman et al., 1994; Kesson et al., 1977; Kjuus et al., 2004). In 1987, the American Environmental Protection Agency issued a warning regarding the dangers associated with airborne exposure and skin contact with acrylamide during chemical grouting activities (McHugh, 1987). Furthermore, the European Union has recommended restrictions on the use of such agents.

In the body, acrylamide is metabolized in two primary ways that are not equally represented. The first, far more common in humans, involves conjugation of acrylamide with glutathione (GSH), while the second method involves the oxidative transformation of acrylamide with cytochrome P450 2E1 (CYP2E1; EC 1.14.13) to glycidamide (Rifai and Saleh, 2020). The second method of inactivating absorbed acrylamide involves the enzyme CYP2E1, a monooxygenase representing one of the evolutionarily best-conserved cytochrome P450 (CYP enzymes). CYP enzymes are predominantly expressed in the granular endoplasmic reticulum of hepatocytes but are also present in cells of most other tissues and are responsible for approximately 75% of drug metabolism reactions (Guengerich, 2008). The enzyme CYP2E1 is a membrane protein characterized by its role in metabolizing a wide range of toxic substances, procarcinogens, and carcinogens entering the body from the external environment. The most common substrates for the CYP2E1 enzyme are polar low molecular weight pollutants, among which acrylamide is included. The inactivation reaction catalyzed by the CYP2E1 enzyme results in the oxygenation of the double bond in the acrylamide molecule, forming glycidamide, which, like acrylamide, exhibits electrophilic reactivity (Rifai and Saleh, 2020).

Acrylamide has the ability to make adducts with proteins as well as DNA, however, it has been shown that acrylamide adducts with proteins are more suitable for monitoring than adducts with DNA because they are not subject to cellular repair mechanisms. Although there are many different proteins that form adducts, hemoglobin (Hb) has been chosen due to its easy accessibility and significant presence in the blood (Törnqvist et al., 2002). The lifespan of hemoglobin is 120 days, and adducts accumulate due to chronic exposure, allowing for the calculation of *in vivo* concentrations of acrylamide and glycidamide for a four-month period prior to blood sampling (Törnqvist et al., 2002). The lowest levels of these hemoglobin biomarkers have been observed in individuals not exposed to acrylamide in the workplace or tobacco smoke (12 - 70 pmol/g globin for acrylamide adducts) (Schettgen et al., 2003). This level of present biomarkers is referred to as background exposure. The average level of Hb adducts in laboratory workers in contact with acrylamide is 54 pmol/g globin, and 152 pmol/g globin in smokers. The global background level is approximately 31 pmol/g, which corresponds to an average daily intake of 0.8 μg/kg body weight (Hagmar et al., 2005). These data indicate that exposure to acrylamide is daily and widespread.

The aim of this study was to investigate whether treatment with acrylamide can affect the expression of the CYP2E1 enzyme in the pancreatic Langerhans islets.

MATERIALS AND METHODS

Thirty juvenile male Wistar rats were housed under standardized conditions of constant lighting (12:12 light/dark photoperiod) and temperature (22 ± 2 °C). They were provided with *ad libitum* access to standard rat pellet food and tap water. All experimental procedures involving animals were ethically approved by the University of Novi Sad Ethical Committee on Animal Experiments (License No. I-2011-03) in compliance with the Guide for the Care and Use of Laboratory Animals set forth by the US National Institute of Health.

Rats aged 23 days were randomly divided into three equal groups (n= 10): one control group and two groups treated with acrylamide. The first acrylamide treatment group received acrylamide (99% purity, Sigma Aldrich Chemicals Co., St. Louis, MO, USA) dissolved in distilled water at a dose of 25 mg/kg body weight. The second acrylamide treatment group received acrylamide dissolved in distilled water at a dose of 50 mg/kg body weight, while the control group received an equivalent volume of distilled water. Acrylamide solutions and distilled water were administered orally via gavage, five days a week with a two-day break, over a period of three weeks. The doses administered were based on prior studies (El-Bohi et al., 2011). Acrylamide was administered in the morning at the same time each day, with no application on the day of experiment termination. After three weeks, both acrylamide-treated and control animals were euthanized by decapitation under diethyl ether vapor anesthesia, and their pancreases were collected for histological processing.

The excised pancreases were fixed in 10% formalin for 24 hours. Subsequently, the pancreases underwent a series of steps including dehydration in alcohol (concentration gradually increased from 70% to 100%), clearing in xylene, embedding in paraffin, and sectioning into 5 μm thick slices. Immunohistochemical staining was performed on these sections to analyze the expression of CYP2E1 enzymes.

The immunostaining procedure followed the Ultravision LP Detection System protocol (TL-125-HD, Thermo Scientific, Runcorn, UK). Briefly, after deparaffinization and rehydration of pancreatic sections, heat-mediated antigen retrieval was conducted in a microwave oven for 10 minutes in 10 mM citrate buffer. Subsequently, sections were incubated in Hydrogen Peroxide Block to inhibit endogenous peroxidase activity and treated with Ultra V block to block nonspecific background staining. Immunohistochemistry was carried out using specific anti-CYP2E1 antibodies (obtained from Abcam, Cambridge, MA, USA). The sections were then incubated with Antibody Enhancer and treated with HRP Polymer. Antibody binding was visualized using a DAB Plus Chromogen mixed with DAB Plus Substrate, and cell nuclei were counterstained with Mayer's hematoxylin. Tris-buffered saline (TBS) pH 7.4 was used for washes and antibody dilutions. Negative controls were obtained by substituting the primary antibody with TBS.

Digital images of immunohistochemically stained pancreatic sections were captured using a Zeiss Imager.A1 light microscope (Zeiss, Göttingen, Germany), equipped with AxioCam MRc5 (Zeiss, Göttingen, Germany). The settings for light and camera were adjusted using AxioVision V4.6 software (Zeiss, Göttingen, Germany).

RESULTS AND DISCUSSION

CYP2E1 is one of several enzymes from the P450 family known to be responsible for the metabolism and bioactivation of various exogenous substances, including acrylamide (Nixon et al., 2014). As a result glycidamide is formed. Enzymes from the P450 family are primarily concentrated in liver tissue, but it is evident that they are also expressed in many extrahepatic tissues, including the pancreas, where the expression of CYP2E1 isoforms is inducible in rats (Norton et al., 1998).

To examine the impact of acrylamide treatment on CYP2E1 expression in the pancreatic islets of Langerhans, we analyzed immunohistochemistry (IHC)-stained pancreatic sections from rats exposed to subchronic doses of 25 or 50 mg/kg body weight of acrylamide. In the IHC-stained pancreatic sections of all animal groups, we observed a gradient in the intensity of CYP2E1 immunoreactivity (Fig. 2).

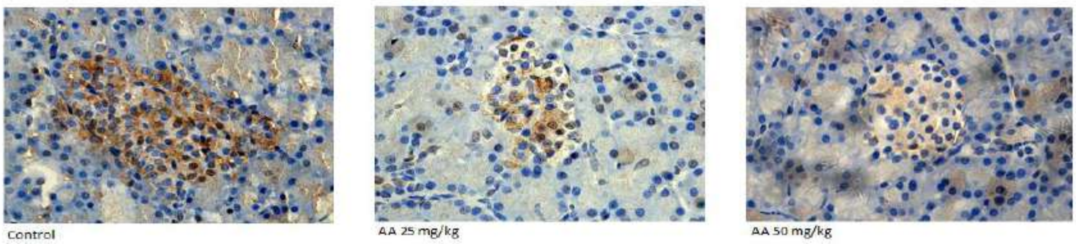

Figure 2. Immunohistochemical staining illustrating the expression of cytochrome P450 2E1 (CYP2E1) in the pancreatic islets of Langerhans of: control rats, rats treated with acrylamide in dose of 25 mg/kg bw and rats treated with acrylamide in dose of 50 mg/kg bw. 400X light microscope magnification.

The administration of 25 mg of acrylamide led to a decrease in the intensity of immunostaining. This observed reduction was corroborated by a significant decrease in the percentage contribution of positive, high positive, low positive and total positive cells (Fig. 3). Similarly, the percentage contribution of positive, high positive, low positive, and total positive cells was significantly reduced in animals exposed to 50 mg of acrylamide compared to the control group ($p<0.05$).

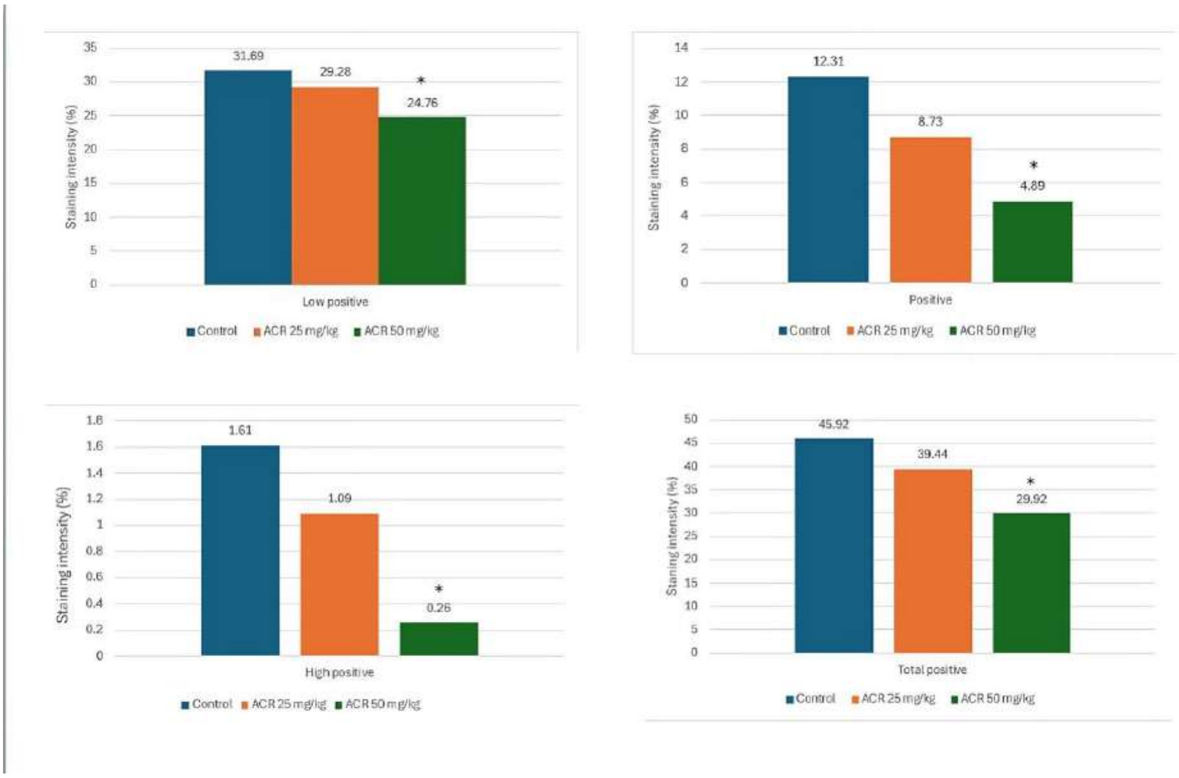

Figure 3. Percentage contribution of low positive, positive, high positive, and total positive immunohistochemical staining of CYP2E1 in control and AA-treated rats in doses of 25 and 50 mg/kg bw. * $p < 0.05$. In statistical analysis, AA-treated animals were compared with the control group.

Following absorption, acrylamide undergoes two primary metabolic pathways: it is either conjugated with reduced glutathione or oxidized to generate the highly reactive genotoxic epoxide intermediate known as glycidamide. Glycidamide exhibits high reactivity and has the capability to form adducts with DNA and hemoglobin, termed GA–DNA and glycidamide–hemoglobin adducts, respectively. The formation of glycidamide–DNA adducts is believed to contribute to mutagenicity, reproductive toxicity, and carcinogenicity (Ghanayem et al., 2005). The conversion of acrylamide to glycidamide is facilitated by the enzyme CYP2E1 in the islets of Langerhans, which catalyzes the oxygenation of the double bond within acrylamide (Prenzler et al., 2012). In our experiment, a dose-dependent reduction in the intensity of the CYP2E1 immunopositive signal observed in immunohistochemistry (IHC)-stained islets of Langerhans in rats subjected to subchronic acrylamide exposure suggests a decrease in CYP2E1 expression following acrylamide application. The downregulation of CYP2E1 induced by acrylamide in animals treated with 25 mg/kg/day, and the significant downregulation observed in animals treated with 50 mg/kg/day, may indicate a cytoprotective response aimed at reducing the formation of the more toxic glycidamide in islets of Langerhans.

CONCLUSION

To conclude, our findings indicate that subchronic treatment with 25 mg/kg and 50 mg/kg of acrylamide affects CYP2E1 expression in the islets of Langerhans in Wistar rats. In the context of occupational safety, these findings underscore the importance of monitoring exposure to acrylamide and its impact on workers in the industry. Further analysis is needed to better understand potential risks and to develop strategies to protect workers from potentially harmful effects. This research highlights the need for implementing adequate workplace safety measures and regularly monitoring the health of employees exposed to acrylamide.

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COST Action CA21149: Reducing acrylamide exposure of consumers by a cereals supply-chain approach targeting asparagine (ACRYRED).

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WORKPLACE SAFETY: ACRYLAMIDE INDUCES APOPTOSIS OF PANCREATIC Β-CELLS

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Abstract: Acrylamide (AA) is a hazardous compound that can be present in many industrial processes. This study aimed to investigate the impact of acrylamide treatment on the transcription of pro-apoptotic Bax and anti-apoptotic Bcl-2 genes, along with assessing the Bax/Bcl-2 ratio in pancreatic β-cells. Since most cells (> 80%) in rodent islets of Langerhans are β-cells, the rat pancreatic insulinoma cell line (Rin-5F) was utilized as a validated β-cell model system. The cells were exposed to 10 mM (IC50) acrylamide concentration at varying time intervals (0.5, 1, 3, 6, 12, 24 h), and real-time PCR was employed to analyze Bax and Bcl-2 gene expression. Statistical analysis using the Mann-Whitney U test revealed significant differences ($p < 0.05$) in relative Bax gene expression, indicating increased mRNA synthesis across all time points compared to control cells. Specifically, treatments at 0.5, 1, 3, 6, 12, and 24 h resulted in 3.13, 2.76, 2.8, 3.42, 3.98, and 3.89-fold higher relative mRNA transcription for Bax, respectively. On the other hand, Bcl-2 gene expression in treated Rin-5F cells showed a 2.75, 2.14, and 2.54-fold increase ($p < 0.05$) only during the 0.5, 1, and 3 h treatments, respectively, with no significant impact observed at 6, 12, and 24 h ($p > 0.05$). Notably, treatment with AA for 12 and 24 h led to a notable increase in the Bax/Bcl-2 ratio (3.5 times and 3 times, respectively) in the Rin-5F cell line, indicating a potential onset of apoptosis in β-cells following prolonged exposure to acrylamide.

Keywords: Acrylamide, Occupational safety, Bax, Bcl-2, Apoptosis

INTRODUCTION

Acrylamide is an organic compound with the chemical formula C_3H_5NO, characterized by a vinyl group ($-CH=CH_2$) and an amide group ($-CONH_2$) in its structure. Acrylamide is a widely recognized monomer with chemical properties that allow it to polymerize easily, forming long chains that are essential in the production of various polymers which find their application in various industries (ATSDR, 2012). Its versatility and effectiveness in polymerization processes make it a valuable component in the manufacturing of plastics, textiles, and paper products as well as water purification, sewage treatment, certain cosmetic and soap formulations and the creation of acrylamide grouting agents (Bušova et al., 2020). However, the industrial use of acrylamide also raises concerns due to its potential health and environmental risks, highlighting the importance of safe handling practices and regulatory oversight in industrial settings.

Occupational exposures typically occur through inhalation of dust and vaporized particles. Moreover, skin absorption represents another significant route of exposure in occupational settings. The presence of acrylamide in the environment is primarily linked to the degradation of polyacrylamide, including degradation in building materials, among other sources (Smith et al., 1996). Various environmental factors, such as heat, light, and outdoor exposure, except for pH, can promote the depolymerization of polyacrylamide into acrylamide (Smith et al., 1996). Due to the potential risks associated with environmental contamination, regulations govern the usage of acrylamide in cosmetics, drinking water preparation, and food packaging materials (ATSDR, 2012).

Acrylamide is a substance that is easily and rapidly absorbed orally from water and food, as well as through skin contact and inhalation in occupational settings (Friedman, 2003). Due to its water solubility, acrylamide dissolves well in blood and is therefore evenly distributed to all organ systems. However, some of absorbed acrylamide molecules are metabolized to glycidamide via pathway that involves the oxidative conversion of acrylamide with cytochrome P450 2E1 (CYP2E1) enzyme (Rifai and Saleh, 2020). As electrophilic molecules, both acrylamide and glycidamide can react with cellular nucleophilic centers such as sulfhydryl (thiol, -SH) and amino ($-NH_2$) groups, forming acrylamide and glycidamide adducts. However, these molecules differ in their affinity towards specific functional groups. Acrylamide shows a higher affinity towards the –SH group, making it more prone to reactions with proteins, while its reactivity towards DNA is lower compared to glycidamide (Bergmark et al., 1993). On the other hand, glycidamide tends to more easily form adducts with the $–NH_2$ group in nucleotide bases, suggesting its greater significance in terms of genotoxicity and carcinogenesis (Gamboa da Costa et al., 2003).

One of the most evident, proven, and extensively documented adverse outcomes of human exposure to acrylamide is the occurrence of neurotoxicity (LoPachin, 2004). Neurotoxicity induces symptoms such as ataxia, weakness of distal skeletal muscles, numbness of the feet and hands, and has been demonstrated in both humans and laboratory animals through numerous studies and experiments. LoPachin et al. (2002) showed that acrylamide neurotoxicity is cumulative in nature. Despite the very low average daily doses of acrylamide intake, on the order of parts per billion (ppb), the cumulative toxicity of acrylamide is significantly important when considering human exposure to this substance, especially in occupational settings.

Acrylamide also has a significant negative impact on reproduction and development (von Stedingk et al., 2011), it is known for its carcinogenic and genotoxic effects, as well as the potential to disrupt the functioning of the endocrine system. Additionally, evidence indicated that acrylamide could induce apoptosis, but the mechanisms are limited (Pang et al., 2023).

Bax and Bcl-2 proteins have a crucial role in regulating the apoptosis process, which is a programmed mechanism of cell death (Korsmeyer et al., 1993). These proteins are part of the Bcl-2 protein family, consisting of proapoptotic (e.g., Bax, Bak) and antiapoptotic proteins (e.g., Bcl-2, Bcl-xL). Bax is a proapoptotic protein that actively contributes to the cell death process. It induces mitochondrial membrane permeabilization and the release of cytochrome c, initiating a cascade of events in the apoptotic pathway. Increased expression of the Bax protein is usually associated with apoptosis activation. On the other hand, Bcl-2 is an antiapoptotic protein that protects the cell from apoptosis. It functions by blocking proapoptotic proteins like Bax and preventing mitochondrial membrane permeabilization. Increased expression of the Bcl-2 protein typically results in the inhibition of the apoptotic process (Korsmeyer et al., 1993).

The balance between Bax and Bcl-2 proteins and their ratio play a crucial role in determining the cell's fate in the apoptotic process. A high Bax/Bcl-2 ratio usually indicates increased apoptosis activation, while a low ratio suggests reduced apoptotic activity and increased cell survival.

The aim of this study was to investigate how treatment with acrylamide, applied in increasing concentrations, affects the transcription of genes for Bax and Bcl-2, as well as the Bax/Bcl-2 ratio in pancreatic β-cells.

MATERIAL AND METHODS

The rat insulinoma β-cell line (*Rattus norvegicus*) Rin-5F (ATCC-CRL-2058) was cultured in RPMI-1640 medium (Roswell Park Memorial Institute medium, Gibco, Paisley, UK) supplemented with 10% fetal bovine serum (FBS) and 50 units/ml penicillin and 50 µg/ml streptomycin. The cell line was maintained under constant conditions at 37°C in a 5% CO_2 atmosphere.

The gene expression of Bax and Bcl-2 in β-cells was assessed using the real-time polymerase chain reaction (RT-qPCR) method.

The Rin-5F cells were cultured into sterile flat-bottomed 6-well microplates and treated with a 10 mM (IC50) concentration of acrylamide at different time intervals (0.5, 1, 3, 6, 12, 24 h). Upon reaching 70% confluency, total RNA was isolated using the RNAqueous®-4PCR Kit (Applied Biosystems, Waltham, MA, USA) and quantified at 260 nm using a BioSpec-nano spectrophotometer (Shimadzu, Hadano, Japan).

To synthesize cDNA, 1 µg of total RNA was reverse transcribed using the High Capacity cDNA Reverse Transcription Kit (Applied Biosystems, Waltham, MA, USA). RT-qPCR analysis was conducted on a MasterCycler RealPlex 4 real-time PCR machine (Eppendorf, Hamburg, Germany) using the Power SYBR® Green PCR Master Mix (Applied Biosystems, Waltham, MA, USA). The amplification protocol included an initial denaturation step at 95°C for 10 min followed by 40 cycles of a 2-step PCR program at 95°C for 15 s and 60°C for 1 min. The primer sequences utilized were: Bcl-2-f: 5'-AAGCTGTCACAGAGGGGCTA-3'; Bcl-2-r: 5'-CTCTCAGGCTGGAAGGAGAA-3'; Bax-f: 5'-CTGCAGAGGATGATTGCTGA-3'; Bax-r: 5'-GATCAGCTCGGGCACTTTAG-3'; β-actin-f: 5'-AGATTACTGCCCTGGCTCCT-3'; β-actin-r: 5'-ACATCTGCTGGAAGGTGGAC-3'. In all RT-qPCR reactions, negative controls without the template were included. The expression levels of the target genes were normalized to the average expression level of β-actin, which served as the housekeeping gene. Data were collected from three experiments conducted in triplicate.

Statistical analysis was conducted using STATISTICA® version 13.0 (StatSoft, Inc). The results are presented as means ± SEM. A one-way analysis of variance (ANOVA), with a Tukey multiple comparison test was employed to compare differences between corresponding means. A significance level of $p < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

The analysis of relative gene expression of Bax in Rin-5F cells treated with 10 mM acrylamide over various time periods showed a statistically significant increase in Bax mRNA synthesis during all treatments ($p < 0.05$) compared to control cells (Fig. 1). Treatments at 0.5, 1, 3, 6, 12, and 24 h resulted in a relative transcription increase of Bax mRNA by 3.13, 2.76, 2.8, 3.42, 3.98, and 3.89 times, respectively.

Similarly, the relative expression of the Bcl-2 gene in treated Rin-5F cells also exhibited a significant increase only during treatments lasting 0.5, 1, and 3 h, by 2.75, 2.14, and 2.54 times, respectively, compared to control cells (Fig. 2).

For a cell undergoing apoptosis, it is characteristic that the ratio between pro- and anti-apoptotic proteins from the Bcl-2 family (Bax/Bcl-2 ratio) increases (Kikuchi et al., 2002). The results of this study showed a significant increase in the transcription of the Bax gene at all treatment points compared to the control. However, treatment of Rin-5F cells with acrylamide also led to a significant increase in the expression of the Bcl-2 gene during the 0.5, 1, and 3-hour treatments. Therefore, the Bax/Bcl-2 ratio in this study did not show almost any difference compared to the control value during the 0.5, 1, and 3-hour treatments. These results support the assumption that apoptosis is not the dominant type of cell death in β-cells during short-term acrylamide treatment. On the other hand, treatment with acrylamide for 12 and 24 hours resulted in a surge in the Bax/Bcl-2 ratio in the Rin-5F cell line, indicating the potential occurrence of apoptosis in β-cells after prolonged exposure to acrylamide, which has more significance in occupational exposure.

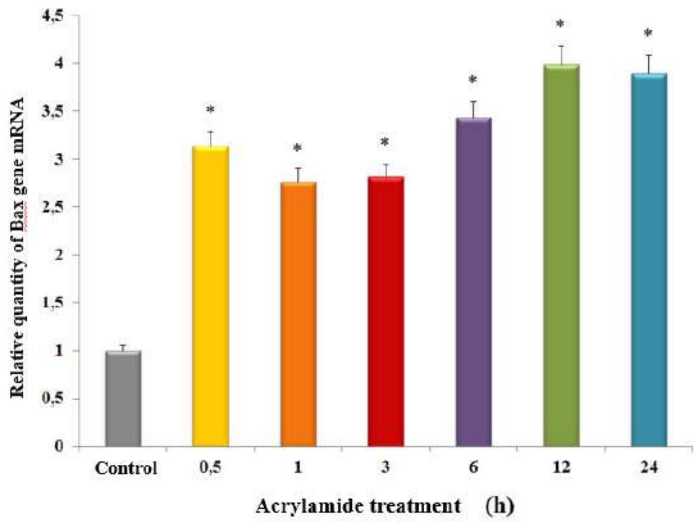

Fig.1. The impact of acrylamide treatment on the relative gene expression of Bax (mean value ± standard error of the results obtained from three independent experiments) after applying acrylamide treatment of different durations (0.5, 1, 3, 6, 12, and 24 h) on Rin-5F cells. The relative quantity of Bax mRNA was analyzed using real-time PCR method. The expression level of Bax gene was standardized relative to the expression of β-actin gene detected in the same sample and expressed as 2^{-dCt}. *$p<0.05$.

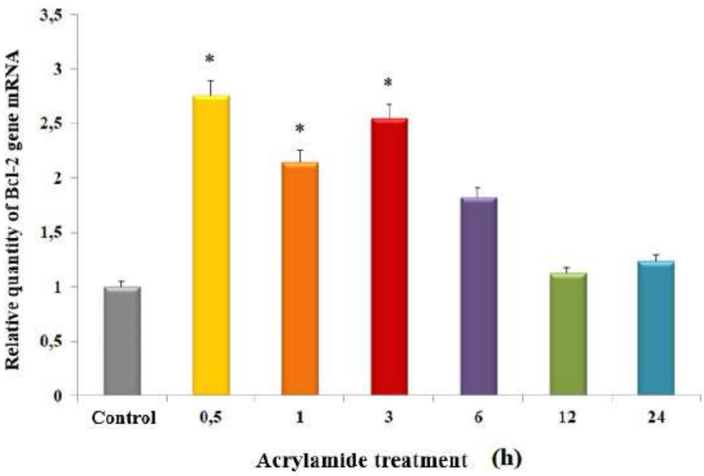

Fig.2. The effect of acrylamide treatment on the relative gene expression of Bcl-2 (mean value ± standard error of the results obtained from three independent experiments) after applying acrylamide treatment of different durations (0.5, 1, 3, 6, 12, and 24 h) on Rin-5F cells. The relative quantity of Bcl-2 mRNA was analyzed using real-time PCR method. The expression level of Bcl-2 gene was standardized relative to the expression of β-actin gene detected in the same sample and expressed as 2^{-dCt}. *$p<0.05$.

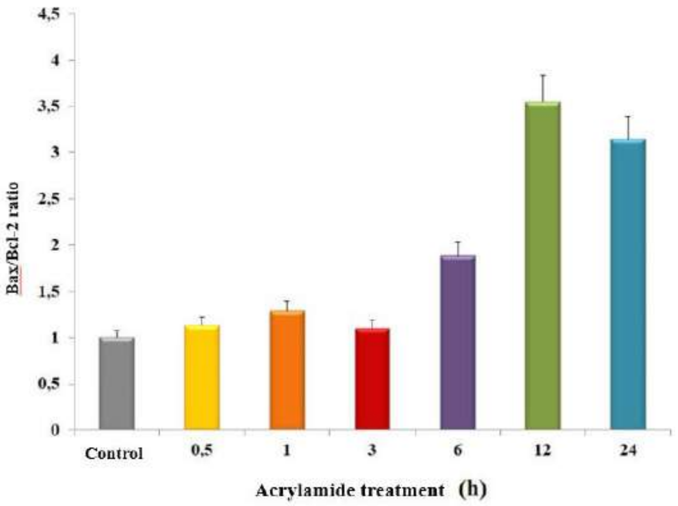

Fig.3. The effect of acrylamide treatment on the Bax/Bcl-2 ratio in Rin-5F cells (mean value ± standard error) treated with 10 mM acrylamide during increasing time periods.

CONCLUSION

Based on the results obtained from the Rin-5F cell line treated with acrylamide, in line with the research objectives, it can be concluded that 10 mM acrylamide treatment during various time intervals influences changes in the relative expression of Bax and Bcl-2 genes. This treatment significantly increases Bcl-2 gene transcription after 0.5, 1, and 3 h of treatment and Bax gene transcription at all treatment points (0.5, 1, 3, 6, 12, 24 h). The treatment with acrylamide for 12 and 24 h resulted in a notable increase in the Bax/Bcl-2 ratio (3.5 times and 3 times, respectively) in the Rin-5F cell line, suggesting a potential onset of apoptosis in β-cells following prolonged exposure to acrylamide. Based on these findings, it is crucial to implement strict safety measures and guidelines in workplaces where acrylamide exposure is possible. Adequate training and awareness programs should be conducted to educate workers about the potential risks associated with acrylamide exposure and the importance of using protective equipment to minimize health hazards.

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MENTAL HEALTH IN TEACHING PROFESSION

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Abstract: This paper encompasses the impact of stress on one of the oldest and most essential professions — teaching. Globally, stress and burnout remain prevalent issues for teachers, contributing to feelings of anxiety and depression. Burnout can have negative impacts on teachers' overall health and is a significant risk factor for both physical and mental well-being. While occupational health is of utmost importance to every career, not all of them obtain equal attention and care. It is an imperative to identify the frequency and factors associated with stress, burnout, anxiety, and depression in teachers to effectively tackle this public health challenge. Teachers have been facing harsh neglect in aspects of mental health, which profoundly affects those who work in a demanding field of sharing and expanding knowledge of the youth. Development of chronic mental illnesses has been rapidly growing. Throughout this paper, it thoroughly inspected the challenges of the teaching profession, the turbulent path through the mental illnesses that are prevalent in the workplace, as well as the opportunities on how to positively affect teachers and advertise healthier means of performing the job.

Keywords: *Stress at workplace, mental health, burnout, teaching profession.*

PROLOGUE AND INTRODUCTION

Teachers worldwide face ongoing challenges with stress and burnout, which can result in anxiety and depression. Burnout can negatively impact teachers' health and contribute to decreased physical and mental well-being. It is crucial to prioritize the psychological and mental well-being of teachers, as it can impact the students they are educating, as well to understand the frequency and factors associated with stress, burnout, anxiety, and depression in teachers to effectively tackle this significant public health issue.

In addition, the level of education and teaching background can also forecast depression, with the highest rates found in teachers with less education and then in those with the most experience. Teacher stress was found to be closely linked to psychological distress, and having social support could help alleviate the impact of stress. As a result, teachers in the high-stress, low-support category were the most prone to anxiety.

Furthermore, this occupation has proven to be extremely stressful, which can result in lower levels of job satisfaction and poor performance at work. One of the most common causes of stress for teachers is their workload. However, there is a lack of systematic understanding regarding the measurement of stress, its global prevalence, the causes of stress, and the associated negative outcomes for teachers (Agyapong et al, 2022).

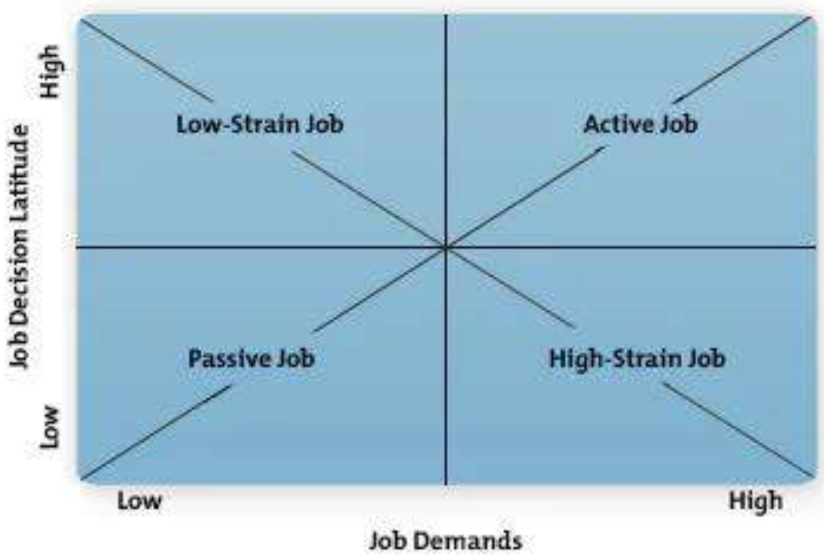

Figure 6. Job Demand-Control-Support Latent Profiles and Their Relationships with Interpersonal Stressors, Job Burnout, and Intrinsic Work Motivation

Mental illness is a factor in teachers' numerous and serious chronic health issues, such as burnout. According to Karasek's model, employees are more likely to experience job stress if there are a lot of psychological demands placed on them and a lack of decision-making discretion on their part. Because work stress is a major risk factor for anxiety and depression, schoolteachers' mental health is an important occupational health issue. Teachers' levels of stress and burnout are linked to mental and physical health issues. Emotional exhaustion, cynical attitudes toward teaching, and lower job satisfaction are all possible outcomes of the stress and emotional demands of this occupation (Borrrelli et al, 2014; Capone et al, 2018).

UNDERSTANDING MENTAL HEALTH

Mental health is made of both positive and negative continuum. Positive mental health includes more than just the absence of mental disorders. It also includes the presence of qualities that are positive. There are three areas it covers: well-being on an emotional, mental, and social level. High levels of well-being are seen in adults who have complete mental health. Therefore, to be flourishing is to be in a state of positive emotion and social and psychological well-being. Adults whose mental health is not complete suffer from low well-being and languish in life. As a result, languishing can be described as emptiness and stagnation, a quiet despair that is analogous to how people describe themselves and life (Capone et al, 2018).

The absence of a mental disorder and the presence of flourishing are two characteristics of mental health. People who are prospering have high levels of emotional, psychological, and social well-being. On the other hand, people who are languishing have low levels of emotional, psychological, and social well-being because they are mentally ill.

It's possible that teachers' mental health would suffer as a result of workplace overstimulation. For instance, teachers who are under a lot of pressure and are having trouble coping are less able to effectively guide, educate, and support students. Anxiety, tension, anger, and frustration with the demands of the job were also found to contribute to teacher stress, which could hinder their ability to perform at their best. Teachers face extraordinary pressure to provide high-quality instruction with fewer resources, which could result in low student performance, a lack of commitment and motivation, and poor or subpar teaching quality (Marais-Opperman et al, 2021).

Positive mental health is different from mental illness, but it is related to it. The presence or absence of mental illness is represented by one continuum, and mental health is represented by the other. It is possible for a person to have both a mental illness (such as a depressive episode, generalized anxiety disorder, or panic disorder) and relatively good mental health at the same time. Because mental health and mental illness are complementary, a combination diagnosis better predicts psychosocial functioning than a single diagnosis does. Due to the high prevalence of occupational stress experienced by educators and education staff, teachers' health is increasingly becoming a global concern. Teachers' reported health issues suggest that teaching is a job that challenges both mental health and illness in a perpetual way (Mérida-López et al, 2017; Stine et al, 2012).

TEACHER'S MENTAL HEALTH

Although it is a part of everyday lives, stress can be debilitating. Stress occurs when people's perceived demands exceed their capacity to deal with them, as was previously explained. Stress is linked to mental health issues like depression, anxiety, and other psychosocial but also psychosomatic issues. Teachers' ability to meet the needs of their students is harmed by perceived stress. They define work stress as any objective condition or change in the workplace that is deemed to be potentially harmful, threatening, difficult, or frustrating, as well as any set of circumstances connected to work that necessitate a change in the individual's ongoing life pattern.

When the demands of the classroom environment exceed teachers' capacity to handle them, they experience stress. Also, teachers who can't keep up with the demands of the classroom are more likely to become overwhelmed, which affects their mental health. Teachers aren't all the same, so even the same work environment might cause them different levels of stress. Teachers' experiences of stress may vary, but they may also have distinct stress profiles that may be linked to their coping mechanisms. (Marais-Opperman et al, 2021)

t is essential to emphasize that teachers' psychological and mental health are of the utmost importance because it has an indirect impact on their students. There are three major overlapping factors that contribute to the stress that teachers experience: anxiety, depression, and burnout, all of which can have a negative impact on teachers' health, well-being, and productivity.

Workload, student behaviour, and employment conditions predict anxiety and perceived stress. Anxiety is exacerbated primarily by a severe lack of administrative support, and among teachers can be exacerbated by stress, which in turn can cause rage. Depression is thought to be the leading cause of work-related disability worldwide and can result in numerous deficiencies. Teachers' health, productivity, and function can all be significantly impacted by depression, which can also have a significant impact on their personal and professional lives. Depression sufferers frequently have trouble meeting demands related to productivity, time management, and interpersonal relationships. Psychological issues, decreased work quality, increased sickness absences, and work disability can all have a significant impact on worker productivity (Agyapong et al, 2022).

First response: stress.

When it becomes chronic, stress, which was once a normal response to distressing or threatening outcomes, becomes pathological. It is a risk factor for developing other psychiatric illnesses, such as anxiety and depression, and chronic stress can impede daily functioning and emotional equilibrium. Long-term teacher stress is correlated positively with intention to leave the teaching profession and negatively with job satisfaction.

It may also lead to withdrawal behaviours, such as leaving the workplace physically or psychologically. Inappropriate rage, an increase in alcohol and drug use, excessive anxiety, mental exhaustion, and burnout are all symptoms of chronic stress, which can also indicate an increase in depression. When a person believes that they are unable to meet an external demand, they experience stress. Demoralization and a shattered sense of self-consistency can be caused by teacher stress (Agyapong et al, 2022).

Daily job stressors like student disruptiveness have been linked to negative effects on mental health for teachers. Epidemiological evidence demonstrates that teachers have a significantly higher rate of mental health issues than workers in other occupations. Workplace stress has been identified as a cause of these issues, whether it comes from students or organizational circumstances. Teaching, for instance, has one of the highest turnover rates among all occupations that require a college degree, surpassing that of nurses.

Some of these stressors are: fighting, disruptive behavior, and indifference from students; administrators who do not support and supervisors who place excessive restrictions on teacher autonomy. Teachers have mental health disorders and high levels of distress at a higher rate than members of other groups, according to the majority of the epidemiological studies mentioned above. Teachers are more likely than members of other occupational groups to be exposed to violence, and exposure to violence is a risk factor for mental health issues. (Schonfeld et al, 2017)

Second response: burnout.

Teachers' psychological health is affected by burnout and depression, which can have a negative impact on their personal and professional lives. Workplace emotional and interpersonal stressors can lead to burnout over time. From a psychosocial point of view, burnout has three parts: a sense of personal and professional inefficiency, cynicism, and emotional exhaustion. Emotional exhaustion and de-personalization (also known as cynicism) are thought to be the most important aspects of burnout out of these three. According to studies on teacher burnout, the primary causes of burnout are emotional exhaustion and depersonalization. De-personalization, a term used to describe teacher burnout, is negative, pessimistic feelings one has toward one's colleagues or students; Physical exhaustion, which includes emotional exhaustion, is characterized by chronic fatigue and low energy. (Capone et al, 2018)

Emotional exhaustion, depersonalization, and a diminished sense of personal accomplishment in relation to the job—also known as a lack of professional efficacy—are frequently referred to as the burnout syndrome. Currently, it is believed that chronic inability to deal with challenges in the workplace leads to burnout. Burnout is thought to be primarily caused by emotional exhaustion. Health issues and worse student outcomes are linked to burnout. (Schonfeld et al, 2017)

PREVENTIVE MEASURES AND SUPPORT

The situation is also complicated by the high rate of mental illness stigma and the weak interactions between the mental health and public health fields. However, it is generally agreed that mental health is essential for quality of life and must be viewed as much more than just mental illness absence. Similarly, mental health relies heavily on an individual's physical, social, and emotional well-being. Work with mental health is connected to both the prevention of mental illness and disorders and the promotion of well-being and positive mental health based on this understanding. There is a connection between coping with stress and individual adaptation (Marais-Opperman et al, 2021; Schonfeld et al, 2017).

An international consensus meeting to agree on common scales for assessing teachers' stress, burnout, anxiety, and depression would be beneficial for researchers, educators, and policymakers. In addition to simplifying the definition of stress, such a global consensus meeting can serve as a forum for addressing other methodological issues pertaining to research and innovations involving elementary and secondary school teachers. Additionally, the fact that a number of high-quality studies have found a particularly high prevalence of stress, burnout, anxiety, and depression among teachers suggests that these psychological issues are widespread and require special consideration on a policy and practice level.

A significant step toward addressing these issues among teachers is the identification of these risk factors. Interventions aimed at the personal well-being of teachers must be prioritized and promoted in schools. In order to address stress and burnout, as well as anxiety and depression, it is important to test and implement interventions designed to improve teachers' well-being and ability to cope. This could include programs that use meditation techniques or text-based support, as well as school-based awareness and intervention programs that look for the early signs of teacher stress and burnout (Agyapong et al, 2022).

The education department ought to take into consideration the suggestions below to enhance the working environment and mental health of teachers. To begin, teachers must become aware of their own stress types, coping mechanisms, and mental health in order to develop personal control strategies for dealing with a stressful environment. The learned response to stress known as helplessness is associated with avoiding stressful situations and placing blame on oneself. By focusing on the type of stress they experience and the ways they deal with it, educators ought to improve their capacity to recognize and anticipate control in the future.

A program focusing on learned hopefulness can accomplish this. Second, a contextual approach will be necessary to address teachers' occupational stress and flourishing, for instance, the schools' management's capability approach. Positive psychological interventions alone will not be enough to improve teachers' abilities—that is, their repertoire of skills and options to influence their functioning (Marais-Opperman et al, 2021).

Coping

A person's cognitive and behavioural efforts to deal with demands posed by person-environment interactions and everyday issues are all part of coping. Problem-focused and emotion-focused thoughts are the two primary types of stress coping strategies. Specifically, problem-focused coping employs tactics like planning, active coping, and suppressing competing activities to manage and modify the actual problem. Strategies like emotional support, acceptance, denial, and positive reinterpretation are all part of emotion-focused coping, which aims to lessen the stress.

Emotion-focused and problem-focused coping can work together, but when they're needed, people use both. Problem-focused coping is more commonly used and is more often linked to positive changes and success in dealing with stressors. It is in question whether some coping mechanisms are superior to others inherently; Simply put, effective coping necessitates a balance between situational assessments and the selection of coping responses. People's responses to stressful situations are highly individual and highly interpersonally variable.

Teachers' approaches to stress management also vary, and the impact of stress on their mental health is less well understood. In order to overcome obstacles, they face, teachers need a variety of skills. They manage and adapt to stressful conditions using cognitive, emotional, and behavioural coping strategies to reduce perceived stress.

Their coping strategies, personality traits, and educational environment all interact to influence the degree to which situations are perceived as stressful. Additionally, the teachers' stressors depended on how their personality, values, skills, and circumstances interacted with one another. The fact that not all teachers perceive stressful situations or experience the stressors typically associated with chronic stress in the same way or to the same extent could be explained by this variation in teachers' coping skills. Additionally, this variation may help to explain why some teachers are able to adapt to their stressful work environment (Marais-Opperman et al, 2021).

It has been suggested that meditation techniques can reduce psychological distress, fatigue, and burnout. For instance, it has been suggested that practicing mindfulness can help teachers deal with stress at work, feel more effective, and avoid burnout. The evidence-based, one-of-a-kind, and cutting-edge method of providing psychological interventions to people with mental health issues in a convenient, low-cost, and easily accessible manner is provided by mobile text technology.

To meet the psychological needs of teachers, mobile text-based programs can be easily implemented at the school level. The development, implementation, monitoring, and evaluation of intervention programs aimed at enhancing teachers' mental health outcomes must be the subject of future research. The significance of assisting educators in enhancing their job satisfaction, mental health, and productivity at work, as well as reducing depression and burnout (Agyapong et al, 2022; Capone et al, 2018).

CONCLUSION

There has been a significant rise in mental health concerns within teachers, however it has been kept away from the appropriate attention. This topic requires further development and research in order to provide teachers with the necessary care and support they require in any shape or form, whether by administration, colleague, and similar. The efforts provided by the teachers and the results they yield are in a great imbalance which further spirals their mental health.

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ABSENTEEISM – ANALYSIS AND CONTROL

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Abstract: Modern society and the world of work are in a phase of constant evolution. Changes in the structure of employment and organization of work, in the distribution of industry and occupations, and demographic changes in the workforce have led to pronounced consequences for the health and work ability of employees, such as absenteeism and presenteeism. Absenteeism includes short-term and long-term, planned and unplanned absences from the workplace, while presenteeism is defined as workers coming to work despite the existence of objective reasons for absence. The prevalence of absenteeism in EU countries is 3-6%, while the costs reach 2.5% of gross national income. Factors that influence the characteristics and frequency of absence from work operate at three levels: social, organizational and individual. The most common cause of temporary incapacity for work is an employee's illness or injury. Effective prevention and control of absenteeism requires the will and cooperation of all participants in the work process, from employers, management, employee representatives and the employees themselves. In addition, persons in charge of employee safety and health, occupational health services, psychologists, social workers and selected employees' doctors also play an important role.

Key words: *Absenteeism; presenteeism; Safety and Health at Work; Prevention; Control*

INTRODUCTION

Contemporary society and the world of work are in a phase of constant evolution. With the introduction of computerization and globalization, the primary concept of production and distribution of goods through the development of industry is gradually, and then increasingly, changing. Service activities become dominant, and the focus of progress is on the possession and timely application of information, knowledge and creativity in order to create value.

Today, every other worker in economically and technologically developed countries is employed in jobs where information is a basic means, tool or goal, and it is believed that in just a few years almost 80% of workers will be tasked with turning information into knowledge. In the business world, abstract values such as information, emotions, interpersonal relationships and service will increasingly determine the value of a product. This does not mean that the classic production of goods will lose its importance, but that society no longer views production and use as separate segments, but as a single product on the market.

The offer of a wide range of individually adapted products, with respect to precisely defined quality standards and deadlines for production and delivery, shortened cycles from creation to sale, the tendency to reduce legal regulations and restrictions are the characteristics of the modern international market. Globalization and liberalization of production, trade and labor are accompanied by rapid (not always adequately controlled) technological progress and great competition.

Success in the modern world of work depends on modern workers, who possess knowledge, creativity and are able to quickly adapt to new trends. Therefore, the health and safety of people who work and know how to work is a prerequisite for a company to survive in the era of the modern service economy (Litchfield et al, 2016; European Agency for Safety and Health at Work, 2000).

Basic work changes affecting worker health and safety can be classified into three interrelated categories (European Agency for Safety and Health at Work, 2000):

a) Changes in the employment structure and work organization
b) Changes in the distribution of industries and occupations
c) Demographic changes in the workforce

One of the most significant changes in the modern world of work is the change in the structure of employment, with an impact on the temporal and spatial dynamics, intensity and security of the employment relationship. There is an expansion of alternative, non-standard forms of labor relations, such as self-employment, contracts for the performance of temporary and occasional jobs, part-time contracts and fixed-term contracts. This kind of employment is characterized by a short (time-precisely defined) duration of the contract, the uncertainty of extending the employment relationship, and the limitation of mutual obligations and responsibilities between workers and employers. The trend developed with large layoffs by international companies that moved the center of activity to regions with cheaper labor. A large part of the workforce experiences marked insecurity and loss of control over the work process, with the consequent need to work in more than one workplace. The average working hours of workers are increasing, and the frequency of shift and night work is also increasing. Work in the informal economy is pronounced.

Changes in the distribution of industries and occupations are the result of a decrease in the frequency of employment in classic, physically demanding activities (mining, forestry, construction) at the expense of growth in the service sector, with changes in health risks at workplaces and the appearance of new harms and dangers (psychosocial factors, nanoparticles, radiofrequency and ionizing radiation, new biological and chemical agents).

In the last 30 years, there has been a noticeable trend of growth in the employment of women and young workers, especially on fixed-term contracts, as well as an increase in the average age of the workforce. The presence of an older workforce is to some extent conditioned by the improvement of preventive medical measures and the extension of the average life expectancy, but perhaps a more significant factor is the impossibility of maintaining the current model of pension insurance in the modern world of work.

The aforementioned changes led to pronounced consequences for the health and working ability of employees in the previous time period.

All this was followed by the COVID-19 pandemic, a classic example of a global crisis that led to a major reorganization of work systems throughout the world. Multinational and national companies, despite the existence of work plans in crisis situations (*Disaster preparedness plans*), initially suffered pronounced fluctuations in the quality and quantity of work activities, primarily due to drastic movement restrictions, a high rate of absenteeism and problems in organizing work from home in a lot of production branches.

Very quickly, two populations of workers were profiled in pandemic conditions (Bradaš et al, 2020):

Workers who had to work on the employer's premises functioned under the regime of work obligation or in a regular employment relationship under special conditions. First of all, the so-called "workers on the front line" (health workers, police, army, communal services, workers in vital electricity and water supply systems...), as well as employees in production activities that require work on the employer's premises. The work obligation in Serbia is regulated by the Law on Defense (Službeni glasnik RS, 2018) and the Law on Military, Work and Material Obligation (Službeni glasnik RS, 2018) and as a rule excludes some of the basic labor rights to limited working hours, daily, weekly and annual leave, which with continuous exposure to COVID 19 positive persons had a significant impact on the health of health workers and auxiliary personnel in health care.

Workers who partially or completely switched to working from home included persons with established chronic diseases, persons older than 60 years, pregnant women, parents of children up to 12 years of age, especially if they are single or if the other parent has a work obligation. In addition to workers who worked in similar conditions even before the pandemic (self-employed, agricultural and productive households, etc.), employees from the public sector (education, state administration, social insurance) and the private sector (service activities, banking, insurance companies, programmers, IT experts, technical support, etc.).

During the pandemic, both categories of workers suffered significant health consequences caused by the new way of working, the pandemic and inadequate interpretations and application of legal and by-laws during the state of emergency (Bradaš et al, 2020).

Covid-19 infection, in asymptomatic, minimally symptomatic or very pronounced form, has led to acute and chronic health disorders, with often long-term and permanent consequences on the physical, but also on the psychological, social and emotional level of both workers and their family members. After the official end of the pandemic, a significant number of workers (front-line workers, but also workers who worked from home) still have problems returning to the jobs they worked at before Covid, primarily due to mental health disorders (or the fear of such disorders), which leads to frequent or prolonged absence from work (Sitarević et al, 2023).

Absenteeism and presenteeism represent only one of the manifestations that point to serious problems brought about by the evolution of the concept of a global market economy based on the possession and application of information.

Absenteeism

Absenteeism comes from the Latin word *absens* which means to be absent from the place where one really belongs. Absenteeism is a phenomenon that exists to a greater or lesser extent in every organization or institution. The term absenteeism mainly refers to work absenteeism, which is absence from work regardless of the reason, i.e. any failure of an employee to report or remain at work as scheduled, regardless of personal reasons (Edwards et al, 2010).

In the broadest sense, work absenteeism includes planned and unplanned absences from the workplace (Tešić, 2017).

Planned absences are absences that are foreseen in the company's work plan and are carried out with the agreement of the employer and the employee who is absent. These include annual vacations, absences during national and religious holidays, for continuing education, days off after duty and extended work, visits to the doctor due to regular preventive and systematic examinations, maternity leave. Planned absenteeism has less impact on the company, less burden on the budget, enables adequate and timely substitution of the absent worker and adjustment of the work process.

In contrast to planned absenteeism, unplanned absenteeism (absenteeism in the narrower sense of the word) is an unplanned, unannounced absence of an employee from the work process, the occurrence, duration and outcome of which cannot be predicted and therefore has a great impact on the work process, productivity and work organization. These include inability to work due to illness or injury, maternity leave, removal from the workplace (self-initiated, misdemeanor), absence due to death or illness of a family member, moving, birth of a child, etc.

In relation to the duration, one can define micro-absenteeism, which lasts less than one day (being late for work, leaving early, extended and unplanned breaks) as well as macro-absenteeism, lasting longer than one working day.

The informal division of absenteeism is into the so-called "*white" absenteeism* - due to objective reasons (e.g. illness or injury), "*gray*" absenteeism - psychological or psychosomatic nature, harder to objectify complaints, "*black*" absenteeism (without a real basis), "*appreciative* " (caused by worker dissatisfaction), absenteeism for personal reasons and for social reasons.

A special variety of absenteeism is *presenteeism* (apparent presence), which is defined as the arrival of workers to work despite the existence of objective reasons for absence (health disorder, illness of a family member...) accompanied by a drop in work efficiency due to the inability to perform work tasks (Lohaus et al, 2019). Presenteeism is closely related to absenteeism on several levels. First of all, it is a hidden form of absenteeism, which in most situations will lead to the worsening of the underlying illness and longer absences from work, or it is a short-term sick leave terminated prematurely, which is followed by low-quality and ineffective work. Presenteeism was previously based on extremely strong motivation of employees and the desire to maintain a high level of productivity of the company, and in the modern world of work, presenteeism is mainly caused by the fear of losing a job or reducing earnings, an ineffective health care system, but also personal and social cultural attitudes.

Causes of absenteeism

Absenteeism in the narrower sense of the word is based on the employee's inability to perform work due to force majeure or lack of motivation to work (Tešić, 2017; Arsić, 2018).

Factors influencing the characteristics and frequency of absence from work operate at three levels:

Macro level (general economic situation, unemployment rate, migration, social policy, legal determinants of old-age and disability pensions, workers' rights to temporary incapacity for work, quality of health care and insurance, major social and climate changes)

Enterprise level (type of activity, working conditions, needs for workers, availability of workers on the labor market, workplaces with increased risk, special health conditions, safety and health at work, interpersonal relations, work quality control)

Individual level (gender, age, occupation, type of employment contract, length of service, job satisfaction, psychophysical characteristics, family status, chronic diseases, addictions).

The most common cause of temporary inability to work is absence due to an employee's illness or injury, so-called sick leave.

Assessment of the need for sick leave is the most common form of assessment of temporary work ability and in Serbia is primarily the responsibility of selected employee doctors (authorized by the Republic Health Insurance Fund, RFZO), with the potential consultation of doctors specializing in various specialties, psychologists and, only in certain cases, doctors specializing in occupational medicine .

Selected doctors have the right to independently prescribe sick leave for up to 30 (15-60?) days, and in case of need for longer sick leave, employees with additional medical documentation are referred to the first-level commissions of the RFZO or, in case of non-compliance and appeals, to the second-level commissions of the RFZO. The length of temporary incapacity for work exceeding 30 days, in accordance with the Law on Health Insurance and the Rulebook on Medical-Doctrinal Standards for determining temporary incapacity for work, and upon the proposal of the selected doctor, is determined by the expert-medical bodies of the Republic Fund (Vidaković et al, 2003; RFZO, 2011).

The right to sick leave in Serbia is regulated by the Labor Law, while the right to compensation for wages during temporary incapacity for work is determined by the Health Care Law. According to Article 116 of the Labor Law, every employed person (formally employed, regularly paying contributions for mandatory health insurance) has the right to compensation for sick leave up to 30 days, at least in the amount of 65% of the average salary in the previous 12 months before the month in which the temporary inability to work. Sick pay cannot be lower than the minimum wage if the inability to work is caused by an illness or injury outside of work. In addition to this right, the employee can also have sick pay in the amount of 100% of the average salary in the previous 12 months, which cannot be lower than the minimum salary if the inability to work is caused by an injury at work or an occupational disease. The right to compensation can be exercised if it is a question of temporary inability to work due to illness or complications related to maintaining a pregnancy, caring for a sick member of the immediate family, if the mother/father is designated as the companion of a sick insured person referred for treatment or medical examination in second place, i.e. while staying as a companion in a stationary health facility.

The Labor Law specifically regulates maternity leave and leave from work for child care. The total duration of this leave can last a total of 365 days. After maternity leave and leave from work for child care expire, one of the parents can exercise the right to leave from work for special care of the child if the child needs special care due to a severe degree of psychophysical disability. This form of absence can last at most until the child reaches five years of age (National Organization for Rare Diseases of Serbia).

Absenteeism costs include direct costs (compensations to employees during sick leave, annual vacations, maintenance of pregnancy, maternity leave, other benefits stipulated by collective agreements), administrative costs (calculation of wages and other benefits, activities of the occupational health service, costs of court cases) and indirect costs (education and earnings of replacement workers, overtime work of regular workers, interruptions and omissions in work, turnover of workers).

In accordance with the Law on Health Insurance, salary compensation for insured persons temporarily prevented from working for the first 30 days of the disability is provided by the employer from its own funds, and from the 31st day salary compensation is provided by the

Republic Health Insurance Fund from mandatory health insurance funds. Only in case of temporary incapacity for work due to occupational illness or injury at work, compensation for the entire period of incapacity for work is provided by the employer (Republički fond za zdravstveno osiguranje, 2017). According to the available data from 2017, the average expenditures of the RFZO for temporary incapacity for work amounted to about 10 billion dinars on an annual basis (Republički fond za zdravstveno osiguranje, 2017).

Prevalence of absenteeism

The main sources of information on absenteeism are data from national institutions for health insurance as well as data from large epidemiological surveys of the workforce.

According to research by the European Foundation for the Improvement *of Living and Working Conditions (Eurofound*) conducted in 2010 in 27 countries of the European Union and Norway, the estimated prevalence of absenteeism ranges from 3-6% of working time, with a higher frequency among women and older workers, while the costs of absenteeism reach 2.5% of the gross national income. The main causes of absenteeism in the EU are health disorders, predominantly of the musculoskeletal and respiratory systems (Edwards et al, 2010; Gimeno et al, 2004; Johns et al, 2015).

According to the data of the RFZO for several years back, in 2013 a total of 276,950 cases of temporary inability to work were recorded in Serbia. In 2014, that number jumped to 283,199. During 2015, the figure further increased to 299,156. This statistic refers only to sick days longer than 30 days, for which benefits are paid from the health insurance fund, while shorter ones, which are paid by the employer, are not recorded by anyone.

According to the official report of the RFZO (Republički fond za zdravstveno osiguranje, 2017): "In the name of salary compensation, the Republican Fund for Health Insurance paid out funds in the amount of 5,976 .214,044.55 dinars, i.e. 16.2% more than in the same period of 2016.

In the period from 01.01.2017. until 30.06.2017. the medical commissions of the Republic Fund assessed the length of temporary incapacity for work in 135,876 cases, which is 4.9% less than in the same period of the previous year. The largest number of insured persons was prevented from working due to illness or injury outside of work (69.1%), illness or complications related to maintaining pregnancy (22.9%), occupational illness or injury at work (7%), care of a sick member of the immediate family (0.9%) and other reasons for inability to work (0.1%).

The most common diagnoses of temporary disability were pregnancy, childbirth and midwifery (23.9%), injuries, poisoning and the effects of external factors (20%), diseases of the musculoskeletal system and connective tissue (11.9%) and tumors (11%). Comparing the temporary disability for work in the period 01.01. until 30.06.2017. year with the same period in 2016, it is concluded that the number of cases decreased, namely for diagnoses from the groups of pregnancy, childbirth and midwifery (62%), and the number of cases for diagnoses from the groups of injury, poisoning and the effects of external factors increased (11, 4%), diseases of the musculoskeletal system and connective tissue (7.3%) and tumors (0.5%). When it comes to the causes of temporary incapacity for work, an increase is recorded in incapacity for work due to illness or injury outside of work, incapacity for work due to injury at work or occupational disease and incapacity for work due to caring for a sick member of the immediate family, and incapacity for work due to illness or complications in connection with the maintenance of pregnancy and other reasons for being unable to work, there is a decrease".

A big challenge is the invisible part of absenteeism and presenteeism, in the sector of the informal economy and the self-employed. This category of employed persons is mainly engaged in work-intensive jobs with low wages and in conditions that do not guarantee safety and health at work, as well as exercising the right to social insurance, paid leave from work and annual vacation.

It is estimated that a fifth of the total number of employees worked in the informal economy in Serbia during 2019 (236,900 in the service sector, 219,300 in agriculture, 44,500 in construction and 28,500 in industry). In relation to the total number of employees in the agriculture sector, almost half were informally employed, while in the construction sector every third employee was informally engaged. Observed according to age groups, the highest participation of employees in the informal economy is among employees aged 65 and over (60%) and young people aged 15-24 (24.3%). Out of a total of 567,900 self-employed without employees, 46.6% of them worked in the informal sector (Bradaš et al, 2020).

The consequences of absenteeism are expressed at all three levels (society, company, individual). From the company's point of view, labor costs are rising significantly, primarily due to unrealistically high costs of employee wages, while the number of workers is suboptimal. The remaining employees are overworked, hiring quality replacements is often not achievable in a short period of time. As a result, the business suffers and the organization does not achieve the set goals, which means that service users, employees and the management of the company suffer. The decrease in the quantity and quality of work reduces the company's earnings, which increases the dissatisfaction of workers and clients. Staff turnover increases and a vicious circle is created that leads the company to ruin in a demanding and competitive market.

Absenteeism control

In order to effectively deal with the problem of absenteeism, there must be the will and cooperation of all participants in the work process, from employers, management, employee representatives and the employees themselves. In addition, persons in charge of employee safety and health, occupational health services, psychologists, social workers and selected employees' doctors also play an important role.

The first step is to recognize the problems and costs of absenteeism. In a large number of organizations, absenteeism is a daily phenomenon, which is mentioned, routinely recorded, and complained about by the people in charge of organization and performance of work, but there is no systematic approach to studying the extent and causes of the problem, nor in finding a solution.

Absenteeism comes to the fore only in situations where there are serious work stoppages, when the remaining employees cannot respond to the demands of employers, in cases of complaints and termination of contracts by clients. The limit of tolerance is significantly lower in private, small and medium-sized enterprises. Then employers generally resort to drastic measures that further aggravate the problem, such as mass sick leave checks, checking whether absent workers are on home treatment (by other workers or hired private detectives), reducing wages or benefits for workers who are frequently absent from work, or incentives (financial, promotion, additional benefits) in case of not going on sick leave or shortening sick leave (presenteeism). Instead of solving the problem, it only gets worse, presenteeism leads to severe absenteeism, unequal treatment of workers causes poor interpersonal relations, inadequate horizontal and vertical communication with a further decrease in work efficiency and an increase in costs.

A proper approach to absenteeism, on the other hand, requires a responsible employer who will apply adequate measures in order to solve the problem in the long run.

It is necessary to determine the frequency, characteristics and costs of absenteeism at the level of the work organization. Parameters of frequency and duration of absence at work can be calculated as follows (Nedić, 2012):

$$\textbf{a) Percentage of daily absence from work} = \frac{\text{Total number of lost working days}}{\text{Average number of employed workers} \times \text{number of working days in the year}} \times 100$$

Eligibility criteria:

up to 3.0 % = low absenteeism

3.1- 4.5 = moderate (increased absenteeism)

4.6 - 6.0 = high absenteeism

6.1% and more = extremely high absenteeism

b) Average rate of absence cases from work to 100 workers = $\dfrac{\text{Number of cases of absence from work}}{} \times 100$

Average number of employed workers

Eligibility criteria:

up to 50.0 per 100 employed workers - low frequency rate

50.1 -100.0 per 100 employed workers - increased frequency rate

100.1 -200.0 per 100 employed workers - high incidence rate

200.1 and more per 100 employed workers - an extremely high incidence rate

$$\textbf{c) Number of lost working days per case of sick leave} = \frac{\text{Number of lost working days}}{\text{Number of cases of absences}}$$

$$\textbf{d) Number of lost working days per one employed worker} = \frac{\text{Number of lost working days}}{\text{Average number of employed workers}}$$

After determining the extent of absenteeism, it is necessary to determine the most common causes of absenteeism. Sources of information are, to a lesser degree, remittances from employees, and more important are communication with occupational health services, psychologists and social workers, who can indicate trends in absenteeism, both sick leave and other forms, without revealing personal data of employees. Data can be collected secondarily from the workers themselves, through anonymous surveys of workers' attitudes towards work, absenteeism, aspects of work organization, job satisfaction, professional communication, working conditions.

It is necessary to identify crisis points in the organization where the absence of employees can quickly threaten the process and quality of work, and to prepare replacements in time through the education of existing staff or the recruitment of new staff. It is necessary to create a system of timely collection and processing of data on absenteeism and the phase of activation of measures to protect against the negative effects of absenteeism.

Given that one of the main causes of absenteeism and presenteeism is the health of employees, it is necessary to improve measures to protect the health of workers, both through improving working conditions and improving medical measures, such as regular, extraordinary and systematic examinations. If possible, the company can conclude a contract with a health service (factory doctor, occupational medicine service, private doctor's office under contract). In that case, workers in case of health disorders would be initially examined by the doctor in charge of the given organization (and not by the chosen doctor), who would assess the need for further diagnostics and therapy. With the financial help of the employer, employees could complete additional examinations earlier, thereby receiving quality help earlier, and the doctor in the organization, in cooperation with the occupational safety and health service, could advise the patient on matters of return to the collective, professional rehabilitation or change of workplace . The support of psychologists and social workers can improve the quality of vertical and horizontal communication of employees, indicate the direction of motivation, effective mechanisms of stress reduction and social support of employees (Edwards et al, 2010; Tešić, 2017; Lohaus et al, 2019; Mihalković, 2017).

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BUILDING A CIRCULAR FUTURE IN SOUTHEAST EUROPE: A ROADMAP FOR SUSTAINABLE CONSTRUCTION PRACTICES

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Abstract: The objective of our study is to assess the feasibility of implementing circular economy (CE) concepts in the construction sectors of Serbia, Bulgaria, and Romania. Southeast European nations, especially Romania, possess significant potential for environmental and economic advancement due to his 33% adoption of circular economy methods in the Construction sector. As the Construction industry is not only using 3 billion tons of natural raw material annually but also generate 40% of the total waste generated worldwide. We contend that by adopting CE practices, these nations can substantially diminish pollution, promote resource efficiency, and cultivate sustainable development. CE activities such as deconstruction, material reuse, easy to maintain, and waste minimization provide a revolutionary perspective. They not only mitigate the environmental impact of the building industry by decreasing resource usage and pollution, but also generate economic prospects. The implementation of CE innovation in building materials and processes has the potential to result in reduced construction costs across the whole lifespan of a project. In addition, a circular construction sector stimulates employment by generating new job opportunities in waste management, material refurbishment, and deconstruction services, so enhancing overall workforce participation. Nevertheless, harnessing this capacity necessitates a comprehensive and diverse strategy. Governments have a crucial role in implementing rules that provide incentives for investors and construction companies to adopt circular processes. These could include tax incentives for utilizing recycled materials, financial support for deconstruction training, and rules that encourage trash reduction. This study explores the distinct difficulties and possibilities encountered by each nation in Southeast Europe. Southeast Europe can establish itself as a frontrunner in sustainable construction by adopting CE. This will lead to a cleaner environment, a prosperous economy with more jobs, and improved resource efficiency and health and safety standards for construction workers.

Keywords: *Circular Economy; Southeast Europe; Construction sector; Sustainability.*

INTRODUCTION

The construction industry, a cornerstone of civilization and progress, is facing a stark reality. Its reliance on a linear "take-make-dispose" model, responsible for a staggering 3 billion tons of raw material consumption and 40% of global waste generation annually, is simply unsustainable (Ghaffar et al., 2020a). This research delves into the transformative potential of the circular economy (CE) as a solution for the burgeoning Southeast European nations of Serbia, Bulgaria, and Romania. It explores the feasibility, challenges, and opportunities associated with implementing CE principles in the region's construction sector, paving the way for a more sustainable future (Leider and Rashid, 2016).

The construction industry is a double-edged sword. While it provides the critical infrastructure and shelter that underpins human societies, its environmental impact is undeniable. The insatiable demand for raw materials – from concrete and steel to timber and glass – exerts immense pressure on natural resources. These extraction processes often disrupt ecosystems, cause deforestation, and contribute to greenhouse gas emissions. Furthermore, the construction industry generates a colossal amount of waste throughout its lifecycle. Demolition debris, construction waste from unused materials, and end-of-life building components contribute significantly to overflowing landfills and environmental pollution. This waste often contains hazardous materials like asbestos, lead, and harmful chemicals, posing significant health risks for workers and communities alike. The traditional "take-make-dispose" model prevalent in construction necessitates a transformative shift (Geissdoerfer et al., 2020).

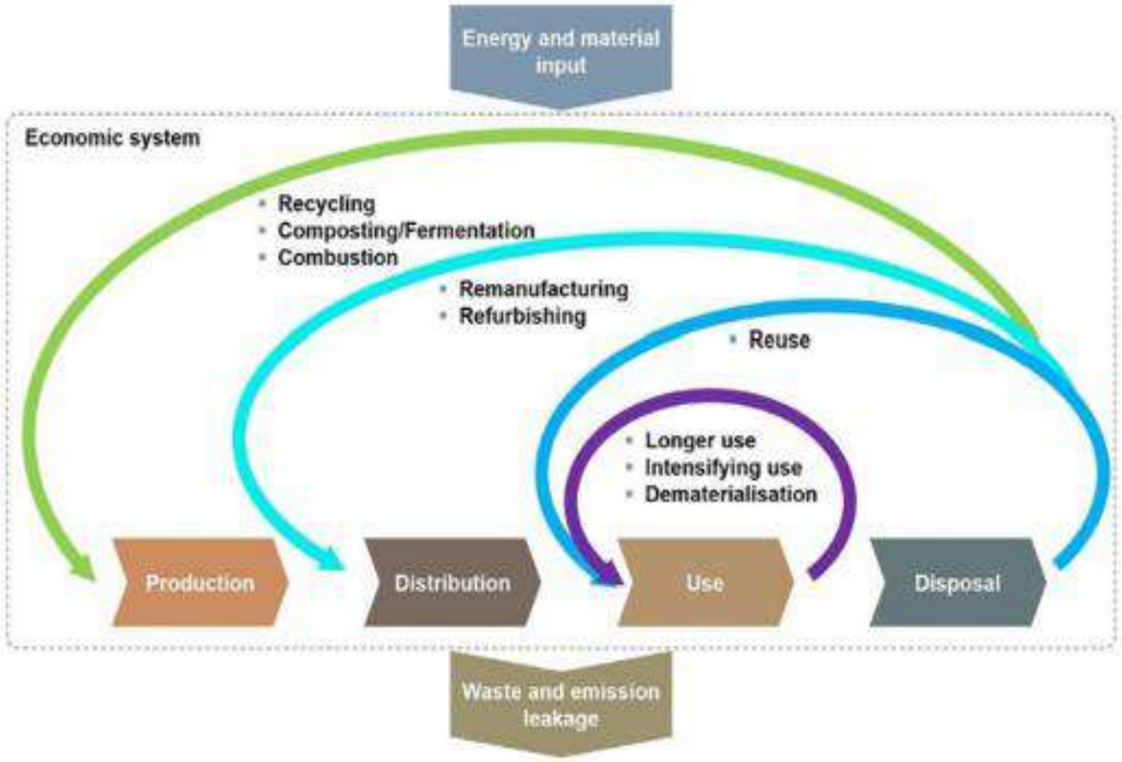

Figure 1. Circular economy model (Geissdoerfer et al., 2020).

The circular economy (CE) offers a compelling alternative, emphasizing the reduction of waste, the circulation of materials at their highest value, and the regeneration of natural resources. CE principles encourage a closed-loop system where materials are retained within the economic system rather than being discarded at the end of their lifespan (Ghisellini et al., 2016). This involves practices like: Deconstruction (Dismantling buildings in a controlled way to salvage and reuse valuable materials like bricks, timber, and metals) and Material Reuse (Reintroducing salvaged materials into new construction projects or repurposing them for different applications). Design for Easy Maintenance (Extending the lifespan of buildings through innovative design that facilitates repairs and upgrades, minimizing replacement needs). Waste Minimization (Implementing strategies like prefabrication, modular construction, and efficient material utilization to reduce waste generation at the source).

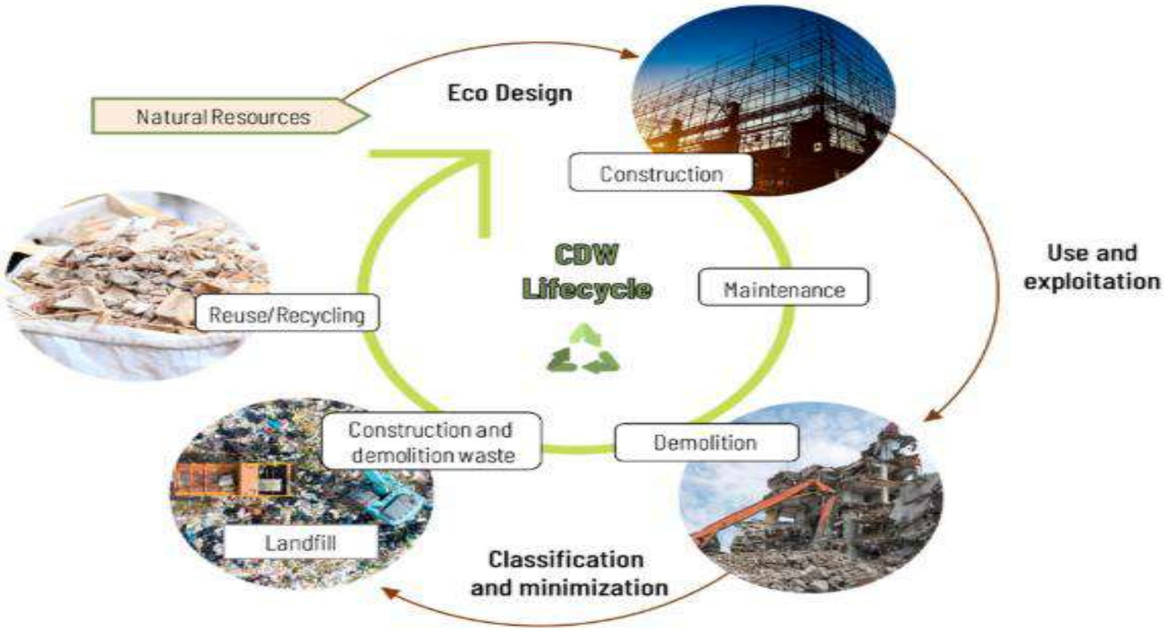

Figure 2. Circular economy in construction sector (Bullejos, 2009).

Southeast European nations like Serbia, Bulgaria, and Romania stand to gain immense advantages by embracing CE principles in their construction sector. Here's a closer look at the potential benefits: Environmental Sustainability: CE practices lead to a significant reduction in resource extraction, lowering environmental impact and contributing to climate change mitigation efforts. By prioritizing waste reduction and material reuse, the building sector's contribution to landfill waste diminishes, leading to cleaner air, soil, and water resources (Prieto-Sandoval et al., 2018). Economic Growth: The focus on material reuse and refurbishment creates new business opportunities in areas like deconstruction services, material recovery and processing and innovative building product development. Additionally, the use of recycled materials can potentially lower construction costs, making projects more affordable and increasing investment in sustainable infrastructure (Kamal et al., 2019). Resource Efficiency: CE promotes a shift from a "virgin material first" approach to maximizing the value of existing resources. This fosters resource security, minimizing dependence on volatile global markets for raw materials. Innovation: The transition to a circular construction sector necessitates innovation in building materials and processes. This fosters the development of new technologies like prefabrication, modular construction, and life-cycle assessment tools, leading to advancements in the overall efficiency and sustainability of the industry. Employment Opportunities: Implementing CE principles creates new jobs in areas like deconstruction, material refurbishment, waste management, and the development of innovative building products and services (Sui et al., 2020). This fosters a more diversified and skilled workforce, contributing to economic growth and social well-being.

While the potential benefits of CE are undeniable, the Southeast European nations present unique challenges and opportunities for implementation. Serbia: With a growing construction industry but limited experience with CE practices, Serbia holds significant potential. Policy incentives for using recycled materials, coupled with investment in deconstruction training programs, can provide a crucial impetus (Soltmann et al., 2015; Vranjanac et al, 2023). Bulgaria: Bulgaria boasts a relatively mature recycling industry, presenting a solid foundation for adopting CE principles in construction. However, overcoming resistance from established construction companies accustomed to traditional practices remains a challenge. Romania: Romania's potential for CE implementation is particularly high, with estimates suggesting a 33% adoption rate achievable in the construction sector. However, overcoming bureaucratic hurdles and fostering collaboration between government, industry, and academia is key.

RESULTS AND DISCUSSION

Data is taken from the Flash Eurobarometer 498 survey released in their report for November-December 2021 SMEs, green markets and resource effiency on Basic bilingual questionnaire by Ipsos European Public Affairs and we have taken data for only Southeast European countries (Serbia, Romania, and Bulgaria) that shows different levels of reported changes in specific practices concerning SMEs and resource efficiency.

Table 1: Circular Economy Practices in SMEs' of Southeast European Countries

	Selling your residues and waste to another company			Recycling, by reusing material or waste within the company			Designing products that are easier to maintain, repair or reuse		
	Serbia	Romania	Bulgaria	Serbia	Romania	Bulgaria	Serbia	Romania	Bulgaria
Agri-food	8	8	72	2	3	65	6	4	42
Construction	**47**	**80**	**515**	**37**	**89**	**740**	**23**	**68**	**460**
Cultural and creative industries	4	15	68	6	13	122	5	10	70
Digital	4	4	47	10	10	115	2	10	84

Electronics	3	1	40	0	3	55	1	2	49
Energy - renewables	7	9	81	8	9	97	7	7	60
Health	2	2	19	4	4	34	3	1	16
Mobility - Transport - Automotive	31	27	259	15	27	293	12	21	152
Retail	42	68	344	32	56	581	17	41	291
Textile	8	11	27	6	7	48	4	8	40
Tourism	1	1	7	0	3	12	0	1	7
Not applicable	13	15	291	12	11	377	7	13	179

Source: The Flash Eurobarometer 498 survey, November-December 2021

From Table 1, all the sectors are complying the CE practices in southeast European countries but the share of Construction sector is more than any other sector. We can say that Bulgaria had the largest recorded rise in selling residues and garbage to another company in construction sector as well as other industries, followed by Romania and then Serbia. Nevertheless, all three countries have a significant amount of small and medium-sized enterprises indicating growth in this behavior. Bulgaria is dominating in all green initiatives as their number of firms are 10 times higher than Romania and Serbia which are recycling through the reuse of materials or garbage within the company as well as selling residues to other companies or designing products which can be repair or reused. However, if we look towards the ratio of SMEs in all three countries according to turnover in last two years (2019 - 2021) is different to each other. To check that, whether the SMEs' practicing CE also have increase in their turnover, so that we can recommend the policy accordingly to the lawmakers in southeast European countries.

Table 2: Change in Revenue due to Circular Economy Practices in SMEs' of SE EU Countries

Over the past two years, has your company's annual turnover increased, decreased or remained unchanged? Due to Circular Economy practices			
	Serbia	Romania	Bulgaria
Increased	236	383	3114
Decreased	96	229	1845
Remained unchanged	127	131	1749
Not applicable	1	13	57
Don't know/No Answer	6	9	234

Source: The Flash Eurobarometer 498 survey, November-December 2021

According to the data in Table 1, a substantial number of enterprises in Bulgaria (3114), Romania (383), and Serbia (236) experienced a growth in their turnover because of implementing Circular Economy methods. This implies that circularity could have a beneficial effect on the economy. Additionally, there are companies who have reported a decline or no alteration in their turnover. A significant proportion of enterprises in Bulgaria either lacked knowledge or declined to provide an answer to the question. This may suggest a deficiency in awareness or challenges in quantifying the influence of circularity on their operation. In general, the table offers intriguing insights about the perceived influence of Circular Economy on firm revenue in Southeast Europe. Therefore, it can be inferred that the implementation of corporate environmental standards has led to an increase in the rate at which companies are replaced or changed in the past two years. However, we must delve further into determining which types of SMEs possess the capacity to embrace CE practices. Therefore, we will categorize them based on the aggregate revenue generated by each company in the year 2020.

Source: The Flash Eurobarometer 498 survey, November-December 2021

Figure 3. SMEs' of Southeast European Countries total turnover in 2020

From Figure 3, SMEs' total turnover in 2020, the data provides insights into how businesses in Serbia, Romania, and Bulgaria are implementing sustainable practices. The majority of larger businesses with annual revenue above two million euros sell garbage and residues to other businesses, mostly in Bulgaria, and less in Romania, and Serbia. Larger SMEs are more likely to recycle, particularly by reusing trash or resources inside the company. Out of all turnover categories, Bulgaria has the highest recycling rates. Larger SMEs are more involved in producing products that are easier to maintain, repair, or reuse; Bulgaria leads all turnover categories. These findings show that the commitment to implementing sustainable practices increases with business turnover, with Bulgaria continuously leading the way in this regard. In conclusion, we can say that SMEs' of Total turnover between 1 to 50 million euros are the best performer in CE practices.

CONCLUSION

Our examination of construction in Southeast Europe indicates a positive outlook for the implementation of Circular Economy (CE) strategies, especially among small and medium-sized firms (SMEs). Although all three nations (Serbia, Romania, and Bulgaria) show considerable involvement of the construction sector in the circular economy, Bulgaria stands out for its leadership in selling wastes, product reusability, and recycling. Nevertheless, there is still a lack of understanding, as certain companies remain uncertain about the consequences. In order to tap into this potential, policymakers have the ability to develop specific assistance programs and provide financial incentives for small and medium-sized enterprises (SMEs). They can also establish platforms for exchanging expertise and examine Bulgaria's achievements in order to provide customized recommendations. Enhanced data collecting is equally essential. Companies, however, should perceive CE as a strategic benefit, cooperate within the industry, and monitor the consequences of their actions. Through the cultivation of a nurturing atmosphere, the exchange of knowledge, and cooperation, Southeast Europe has the ability to fully realize the advantages of circularity in building. This will result in a more sustainable and resource-efficient future for the area, as well as contribute to a worldwide transition towards a circular economy.

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ASSESSING CIRCULAR ECONOMY TRANSITION IN CITIES

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Abstract: The transition to a circular economy (CE) represents a fundamental shift from the traditional linear economy of "take, make, dispose" to a more sustainable model focused on "reduce, reuse, and recycle". This is especially important for cities due to their dense populations, significant resource consumption, and waste generation. Therefore, this paper aims to assess the progress and challenges of implementing CE principles in urban environments. Through a multi-faceted analysis of case studies, policy frameworks, and technological innovations, this paper provides a comprehensive overview of the current state of CE transition in cities and offers strategic recommendations for enhancing this transformation.

Keywords: *circular economy, circular cities, transition*

INTRODUCTION

Urban areas are pivotal in driving the transition to a CE due to their dense populations, significant resource consumption, and waste generation. Namely, 55% of the world's population resides in urban areas (a figure that continues to rise), cities account for only 3% of the Earth's land surface, yet they consume 75% of global resources and generate 60-80% of total greenhouse gas emissions (GHGs) (McCue, 2022). As cities face increasing pressures from climate change, resource depletion, and waste management issues, fostering a regenerative and equitable transition in urban centers by adopting CE principles has become essential for sustainable development. The CE concept, which prioritizes resource efficiency, waste reduction, and material reuse (Vranjanac et al., 2023), provides a framework for cities to address these challenges while promoting economic growth and environmental sustainability.

The shift towards a CE involves rethinking traditional production and consumption patterns. Instead of following a linear model of "take, make, dispose" cities are encouraged to adopt a circular approach that emphasizes "reduce, reuse, and recycle" (Marković et al., 2020). This transition requires systemic changes across various sectors, including construction, energy, mobility, and food systems. Implementing CE principles in urban environments can lead to numerous benefits, such as reduced GHGs, decreased reliance on finite resources, enhanced biodiversity, and improved public health and well-being (Ellen MacArthur Foundation, 2019; EC, 2020).

However, the transition to a CE in cities is not without its challenges. Cities must navigate complex regulatory environments, secure adequate funding, and foster collaboration among diverse stakeholders, including government agencies, businesses, and residents. Additionally, technological advancements and innovative business models play a critical role in enabling the CE transition. For instance, digital platforms for sharing economy models, advanced recycling technologies, and smart city solutions can enhance resource efficiency and support circular practices (EEA, 2016).

The Circular Cities Declaration Report 2024 highlights the progress and challenges faced by cities in Europe as they implement CE strategies. The report, based on submissions from 54 cities encompassing over 16 million inhabitants, provides valuable insights into how cities are embedding CE principles into their policies and practices. Key findings indicate that while many cities have developed CE strategies, significant efforts are still needed to improve the measurement, reporting, and integration of CE principles across various sectors (CE Foundation, Ellen MacArthur Foundation & ICLEI Europe, 2024).

This paper explores the extent to which cities are embracing CE practices and identifies the key factors influencing their success. Through a multi-faceted analysis of case studies, policy frameworks, and technological innovations, this study aims to provide a comprehensive overview of the current state of CE transition in cities and offer strategic recommendations for enhancing this transformation.

THEORETICAL BACKGROUND AND LITERATURE REVIEW

The concept of a CE has gained prominence over the past decade, with numerous studies highlighting its potential environmental, economic, and social benefits. The CE is fundamentally about closing material loops, thereby minimizing waste and reducing the need for virgin material extraction. This is well depicted in Figure 1.

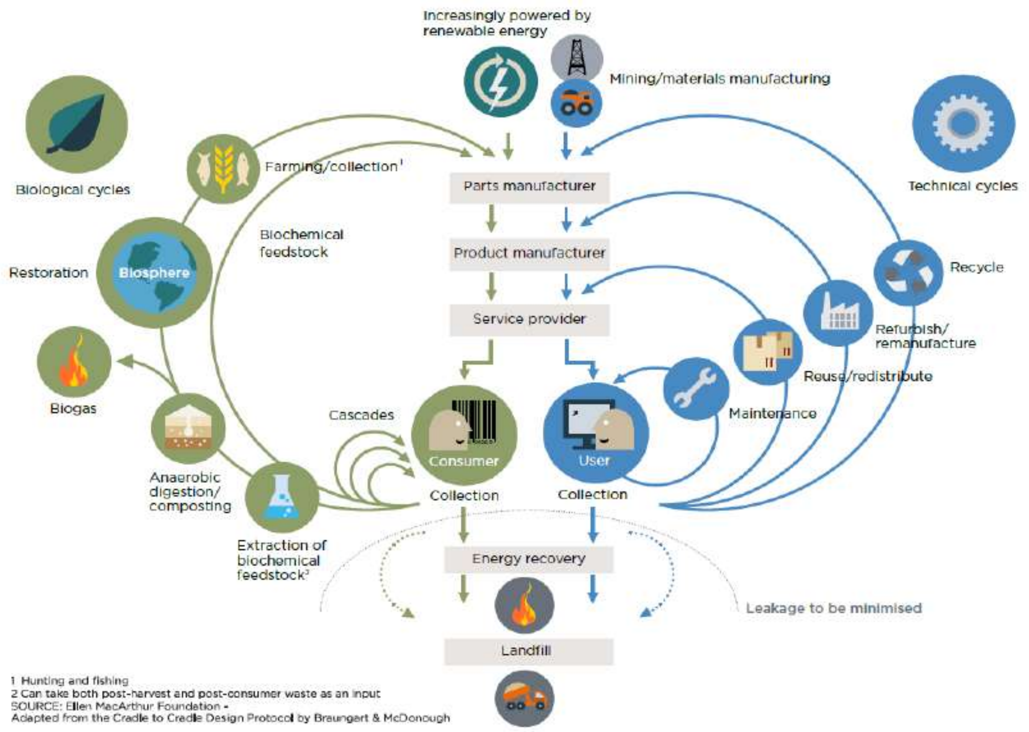

Figure 1. **CE systems** *(Source: Ellen MacArthur Foundation, 2015, p. 2)*

The diagram illustrates how materials and products can be maintained in a continuous cycle at their highest possible value for as long as possible. It is divided into two sections: the technical loop, on the right, and the biological loop, on the left. The CE challenges the traditional linear value chain, which starts with resource extraction and ends with waste generation. Instead, resources that would typically become waste can be reintroduced at various points in the value chain, entering production once more, or they can become inputs for an entirely new cycle.

Previous research has focused on various aspects of CE, including material flow analysis (MFA), policy implications, and business model innovations. However, there is a need for a more integrated approach that considers the unique challenges and opportunities presented by urban settings.

MFA is a key tool used to understand the flow of materials within an economy and identify opportunities for reducing waste and improving resource efficiency. Several studies have demonstrated the effectiveness of MFA in identifying hotspots for intervention and designing circular strategies. For instance, a study by Millette et al. (2019) demonstrated that MFA is a valuable tool for identifying opportunities and challenges in transitioning to a CE for plastics. Also, Pauliuk (2018) underscores the significance of MFA in the context of CE standards and provides detailed recommendations for its integration into organizational practices through a proposed dashboard of quantitative system indicators. Additionally, another study by Haas et al. (2015) emphasized the importance of closing material loops in urban areas to reduce the environmental impact of cities.

The transition to a CE requires supportive policy frameworks at both national and local levels. Effective policies can provide the necessary incentives for businesses and individuals to adopt circular practices. The European Union (EU) has been at the forefront of promoting CE through comprehensive policy measures, including the Circular Economy Action Plan (EC, 2020). This plan outlines various legislative and non-legislative measures aimed at fostering a CE across Europe. Research by Kirchherr et al. (2018) highlights the critical role of policy in driving the CE transition, emphasizing the need for regulatory clarity, financial incentives, and public awareness campaigns.

Innovative business models are essential for the successful implementation of CE principles. Business models that emphasize product-as-a-service, extended producer responsibility, and collaborative consumption can significantly contribute to circularity. Bocken et al. (2016) identified various circular business model patterns, such as product life extension, resource recovery, and sharing platforms, which can help businesses transition towards a more circular approach. Additionally, research by Lewandowski (2016) provides a framework for designing circular business models, highlighting the importance of value creation and delivery in a CE.

Urban areas present unique challenges and opportunities for the implementation of CE principles. Although cities are characterized by high population densities, significant resource consumption, and substantial waste generation, they also offer concentrated markets, infrastructures, and innovation hubs that can facilitate the transition to a CE. A study by Williams (2019) explores the concept of circular cities, emphasizing the need for integrated urban planning, stakeholder engagement, and innovative financing mechanisms to support circular initiatives. The Circular Cities Declaration Report 2024 provides further insights into the progress and challenges faced by European cities in their CE journeys, highlighting the importance of measurement, reporting, and nature-positive actions (CE Foundation, Ellen MacArthur Foundation & ICLEI Europe, 2024).

Effective measurement and reporting are crucial for tracking the progress of CE initiatives and demonstrating their impact. Several frameworks and tools have been developed to help cities and businesses measure circularity. The Ellen MacArthur Foundation (2015) introduced the Circularity Indicators Project, which provides a comprehensive set of indicators to assess the circularity of products and systems. Furthermore, research by Moraga et al. (2019) reviews various methodologies for measuring CE performance, emphasizing the need for standardization and comparability of metrics.

METHODOLOGY

This study employs a mixed-methods approach, combining qualitative and quantitative data to assess the transition to a CE in cities. Data sources include academic literature, policy documents, and case studies from cities that have implemented CE initiatives. The analysis focuses on key indicators such as waste reduction, recycling rates, resource efficiency, and economic impact.

CASE STUDIES

Amsterdam

Amsterdam is a leading example of CE transition, with a comprehensive strategy aimed at becoming fully circular by 2050. The city's Circular Amsterdam program focuses on several key areas, including urban mining, circular construction, and sustainable food systems. The goal is to halve the use of primary raw materials by 2030. The MFA in Amsterdam provides insights into the material flows in the city, identifying where value can be added and where materials are wasted. This analysis is a part of the City Circle Scan and supports the development of circular construction and organic residual flow chains (Metabolic, 2017). One notable project is the De Ceuvel, a sustainable workplace for creative and social enterprises, built using recycled and upcycled materials (Metabolic, 2014). According to Kootstra et al. (2019), circular construction concepts in Amsterdam could reduce material use by 20%, transport kilometers by 21%, and land use by 20%, whereas demountable constructions may increase these factors.

Copenhagen

Copenhagen aims to become the world's first carbon-neutral capital by 2025, integrating CE principles into its sustainability strategy. The city's Resource and Waste Management Plan 2024 outlines ambitious goals for recycling and waste reduction (tripling the amount of reuse and achieving a 70% recycling rate for household waste). Key initiatives include the construction of the Amager Bakke waste-to-energy plant (this plant processes 400,000 tons of waste annually, generating electricity and district heating for 150,000 homes (Power technology, 2013) and circular construction practices in the city's North Harbor development project (this project aims to recycle 60% of all construction materials) (City of Copenhagen, 2019).

Tokyo

Tokyo has adopted a holistic approach to CE, integrating circular principles into its urban planning and development strategies. The city's initiatives include promoting the reuse of construction materials, implementing advanced recycling technologies, and encouraging sustainable consumption patterns among residents. Tokyo's Zero Emission Tokyo Strategy aims to reduce CO_2 emissions by 30% by 2030 compared to 2000 levels, reduce energy consumption by 38%, reduced food waste by 50%, and increase the municipal solid waste recycling rate to 37% (Tokyo Metropolitan Government, 2020).

Turku

Turku is a founding signatory of the Circular Cities Declaration and has been at the forefront of the circular transition since the launch of Circular Turku in 2021. A cooperation project between the municipality, Finnish Innovation Fund Sitra, ICLEI, and other leading organizations, Circular Turku has developed a roadmap with over 200 stakeholders on five priority topics: food, construction, mobility, energy, and water. The CE is at the core of Turku's climate policy, aiming to achieve climate neutrality by 2029 (CE Foundation, Ellen MacArthur Foundation & ICLEI Europe, 2024).

ANALYSIS – DRIVERS AND BARRIERS

The case studies of Amsterdam, Copenhagen, Tokyo, and Turku reveal several critical success factors for the CE transition in cities. Effective policy frameworks, stakeholder collaboration, and technological innovations are paramount. For example, Amsterdam's MFA provides a data-driven foundation for prioritizing circular initiatives, while Copenhagen's waste-to-energy plant demonstrates the potential of integrating circular practices into existing infrastructure.

Turku's collaborative approach, involving over 200 stakeholders, highlights the importance of community engagement and multi-stakeholder partnerships. Tokyo's advanced recycling technologies and sustainable consumption initiatives show that technological innovation, combined with public awareness, can significantly drive the CE transition.

The data and figures provided underscore the tangible benefits of adopting CE principles, such as significant reductions in waste and CO_2 emissions, increased local food production, and enhanced resource efficiency. These examples can serve as models for other cities aiming to transition to a CE, demonstrating the importance of a holistic and integrated approach.

Policy Frameworks

Effective policy frameworks are crucial for facilitating the CE transition in cities. National governments and supranational entities, such as the EU, play a significant role in setting the agenda for the CE. For instance, the EU’s Circular Economy Action Plan outlines a comprehensive strategy for transitioning to a CE across member states, including legislative measures, funding opportunities, and targets for waste reduction and resource efficiency (EC, 2020). Such policies provide a cohesive framework that guides local governments in their CE efforts, while they are at the forefront of implementing CE initiatives, tailored to their specific urban contexts. Cities like Amsterdam and Copenhagen have developed their own CE strategies, which align with broader national and supranational policies while addressing local needs and opportunities.

Despite the presence of supportive policy frameworks, cities face several challenges in implementing CE initiatives. These include regulatory barriers, financial constraints, and coordination and integration. Existing regulations often favor linear economic models, creating obstacles for circular practices. For example, zoning laws and building codes may not accommodate innovative circular construction methods. Additionally, Implementing CE initiatives requires significant investment in new technologies, infrastructure, and business models. Cities may struggle to secure the necessary funding, particularly for large-scale projects. Finally, effective implementation of CE requires coordination across multiple sectors and government departments. This can be challenging due to siloed operations and differing priorities.

Apart from the policy framework, technological advancements play a significant role in enabling the CE transition. Advanced recycling technologies are crucial for transforming waste into valuable resources. These technologies enable the efficient sorting, processing, and repurposing of materials, thereby reducing waste and conserving natural resources. Technological advancements also enable the development of circular innovations at various levels, from individual products to entire supply chains, fostering a more sustainable economic system (Jakobsen et al., 2021). Digital platforms and smart technologies are transforming the way cities manage resources and engage with citizens. These innovations facilitate the monitoring, optimization, and coordination of circular activities.

The success of CE initiatives also depends on social acceptance and economic viability. Social factors, including public awareness, community engagement, and behavioral change, play a critical role in the adoption of circular practices. Economic factors, such as the development of new business models, job creation, and financial incentives, are also crucial for the sustainable implementation of CE principles. Economic incentives, such as tax breaks, subsidies, and grants, encourage businesses to invest in circular technologies and practices. Governments can drive the transition by making it financially advantageous for companies to adopt circular models (Aloini et al., 2020).

CONCLUSION

The transition to a CE in cities is a complex but necessary process for achieving sustainable development. Despite the potential benefits, cities face several challenges in transitioning to a CE. These include limited financial resources, regulatory barriers, technological limitations, and the need for cultural and behavioral change. Addressing these challenges requires a coordinated effort among stakeholders, including governments, businesses, and citizens.

Based on the findings of this study, the following recommendations could be proposed to enhance the transition to a CE in cities: 1) Developing comprehensive and cohesive policy frameworks that support CE initiatives; 2) Investing in research and development to drive technological innovation; 3) Fostering public-private partnerships to leverage resources and expertise; 4) Promoting community engagement and education to build support for CE practices; 5) Encouraging the development of circular business models that are economically viable and environmentally sustainable.

By examining case studies and identifying key success factors, this paper provides valuable insights into the current state of CE transition and offers strategic recommendations for enhancing this transformation. Future research should focus on developing integrated approaches that consider the unique challenges and opportunities presented by urban environments.

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INCORPORATING INNOVATIVE NEXUS APPROACH IN URBAN RESILIENCE PLANNING

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Abstract: Urban resilience planning has become a focal point in contemporary urban development due to the increasing frequency and intensity of environmental, social, and economic challenges faced by cities worldwide. Incorporating an innovative nexus approach offers a comprehensive framework to address these multifaceted challenges by integrating various sectors, such as water, energy, and food (WEF) systems, into a cohesive planning strategy. This paper explores the concept of the nexus approach, its relevance to urban resilience, and its potential benefits in creating more sustainable and resilient urban environments.

Keywords: *nexus approach, urban planning, resilience, WEF nexus*

INTRODUCTION

Urban areas are increasingly becoming the epicenters of population growth, economic activities, and innovation. However, they are also at the forefront of facing complex and interconnected challenges such as climate change, resource scarcity, and social inequalities. Traditional urban planning approaches often address these issues in isolation, leading to fragmented and sometimes counterproductive solutions. To tackle these multifaceted challenges effectively, there is a growing recognition of the need for an integrated approach that considers the interdependencies between various urban systems. This is where the innovative nexus approach becomes highly relevant.

The nexus approach, particularly the water-energy-food (WEF) nexus, highlights the interconnections and interdependencies between critical resource systems. It emphasizes that actions in one sector often have significant implications for the others, and therefore, integrated management strategies are essential for optimizing resource use and achieving sustainable development. By considering the WEF nexus, urban resilience planning can be more comprehensive and effective, ensuring that cities are better equipped to withstand, adapt, and thrive in the face of various shocks and stresses. Integrating WEF systems into decision-making requires considering interactions, data availability, and implementation feasibility (Veldhuis & Yang, 2017).

Urban resilience refers to the capacity of urban systems, communities, and individuals to survive, adapt, and grow despite experiencing chronic stresses and acute shocks. Chronic stresses include long-term issues such as climate change, economic inequality, and infrastructural decay, while acute shocks refer to sudden events like natural disasters, economic crises, or pandemics. The nexus approach contributes to urban resilience by fostering cross-sectoral collaboration, promoting efficient resource use, and enhancing the adaptability of urban systems.

This paper explores the concept of the nexus approach in urban resilience planning, examining its relevance, implementation strategies, and the benefits it offers for creating more sustainable and resilient urban environments. By drawing on case studies from various cities around the world, this paper demonstrates how the nexus approach can be effectively integrated into urban resilience planning, highlighting both the challenges and opportunities involved in this process. The discussion aims to provide insights and practical recommendations for policymakers, urban planners, and other stakeholders involved in urban resilience and sustainable development initiatives.

The findings of this study will contribute to the growing body of literature on innovative approaches to urban resilience planning and help inform policymakers and urban planners on the importance of adopting a nexus approach. By promoting collaboration and synergies between different sectors, cities can build more resilient, sustainable, and adaptive urban systems to withstand the challenges of the 21st century.

THE NEXUS APPROACH IN URBAN RESILIENCE PLANNING

The nexus approach is based on the idea that WEF systems are closely linked and should be managed in an integrated manner to achieve sustainable development. In urban resilience planning, this approach emphasizes the interdependencies between these systems, advocating for integrated management strategies to optimize resource use and enhance overall urban resilience (Hoff, 2011). In urban areas, these systems are particularly interconnected, with water used for energy production, food production, and various other purposes. By understanding these interdependencies and considering them in urban resilience planning, cities can develop more effective strategies to address the challenges they face.

Urban resilience refers to the capacity of urban systems to withstand, adapt, and thrive amidst various shocks and stresses, including natural disasters, climate change, and socio-economic disruptions (Meerow et al., 2016). By considering the interconnections between WEF systems, the nexus approach promotes more efficient and sustainable resource management. It is particularly relevant in this context because it offers a holistic perspective that integrates the management of critical resources – water, energy, and food – into a unified framework. This integration is crucial for several reasons: 1) holistic resource management; 2) enhanced adaptability; 3) risk mitigation; 4) sustainability and efficiency.

One key aspect of the nexus approach is the recognition of trade-offs and synergies between WEF systems. For example, improving water efficiency in agriculture can reduce water consumption and energy use, while also increasing food security. By considering these interactions and seeking to maximize synergies, cities can develop more sustainable and resilient systems.

Holistic Resource Management

The nexus approach promotes a holistic view of resource management, recognizing that the efficient and sustainable management of WEF systems is interconnected. Traditional urban planning often addresses these systems in isolation, leading to inefficiencies and missed opportunities for synergy. For example, integrated water management strategies that incorporate wastewater recycling and rainwater harvesting can significantly reduce the energy required for water treatment and distribution. Similarly, sustainable agricultural practices that optimize water use can enhance food security while reducing the energy footprint of food production (Weitz et al., 2014).

By considering the interdependencies between these systems, the nexus approach ensures that resource management strategies are mutually reinforcing, leading to more sustainable and resilient urban environments. This holistic perspective is essential for cities to effectively manage their resources in the face of increasing demand and environmental pressures.

Enhanced Adaptability

Urban systems are constantly evolving, and the ability to adapt to changing conditions is a key aspect of urban resilience. The nexus approach enhances adaptability by promoting integrated planning and flexible management strategies that can respond to multiple stressors simultaneously. For example, renewable energy projects that incorporate water conservation measures can help cities adapt to both energy and water scarcity. This adaptability is crucial for cities facing the dual challenges of climate change and rapid urbanization (Bazilian et al., 2011).

Furthermore, the nexus approach encourages the use of innovative technologies and practices that enhance the resilience of urban systems. For instance, smart grids, precision agriculture, and water-efficient technologies provide new tools for managing the complex interdependencies between water, energy, and food systems. These technologies enable cities to monitor and respond to resource demands more effectively, enhancing their capacity to adapt to changing conditions and unforeseen events.

Risk Mitigation

One of the key benefits of the nexus approach is its ability to identify and mitigate risks arising from sectoral interdependencies. Urban systems are often vulnerable to cascading effects, where disruptions in one sector can trigger failures in others. For example, a drought can lead to water shortages, which in turn can affect energy production and food supply chains. By adopting a nexus approach, cities can develop integrated risk management strategies that address these interdependencies and reduce overall vulnerability (Endo et al., 2015).

Integrated risk management involves identifying critical interdependencies, assessing potential risks, and developing coordinated response strategies. For example, ensuring the stability of food supply chains through coordinated water and energy management can reduce the vulnerability of urban populations to food insecurity during crises. Similarly, integrating water and energy planning can enhance the resilience of infrastructure systems to extreme weather events, reducing the risk of service disruptions and economic losses.

Sustainability and Efficiency

Sustainability is a core principle of the nexus approach. By optimizing the use of water, energy, and food resources, the nexus approach promotes sustainability and efficiency in urban systems. This optimization is achieved through the adoption of integrated management practices that minimize waste, reduce resource consumption, and enhance the resilience of urban systems. For example, water-efficient agricultural practices can reduce the water footprint of food production, while energy-efficient technologies can lower the energy demand of water and food systems (Scott et al., 2011).

The nexus approach also encourages the use of renewable resources and sustainable practices that enhance the long-term sustainability of urban systems. For instance, integrating renewable energy sources into urban planning can reduce greenhouse gas emissions and enhance energy security. Similarly, promoting urban agriculture and green infrastructure can enhance food security and improve the resilience of urban ecosystems.

Incorporating the nexus approach into urban resilience planning involves a number of steps. First, cities must conduct a comprehensive assessment of their WEF systems, including identifying vulnerabilities and potential points of failure. This assessment should consider both current conditions and future trends, such as population growth and climate change.

Next, cities can develop integrated strategies to address these vulnerabilities and enhance resilience. This may involve implementing measures to improve water and energy efficiency, increase local food production, or enhance cross-sectoral collaboration. By considering the interactions between WEF systems, cities can develop more effective and sustainable solutions.

IMPLEMENTING THE NEXUS APPROACH IN URBAN RESILIENCE PLANNING

Several cities worldwide have already begun to incorporate the nexus approach into their urban resilience planning. For example, the city of Rotterdam in the Netherlands has developed a comprehensive resilience strategy that includes measures to enhance water management, energy efficiency, and local food production. By considering the interconnections between these systems, Rotterdam has been able to develop more integrated and effective resilience measures (Spaans & Waterhout, 2017).

Rotterdam's resilience strategy is a prime example of the nexus approach in action. The city's strategy includes innovative solutions for water management, such as water plazas and green roofs that enhance stormwater management and reduce the urban heat island effect. Additionally, Rotterdam has focused on improving energy efficiency through the adoption of renewable energy sources and enhancing local food production through urban agriculture initiatives. These measures are part of a broader effort to create a sustainable and resilient urban environment that can adapt to and thrive in the face of various challenges (Spaans & Waterhout, 2017).

Similarly, the city of Cape Town in South Africa has implemented a number of initiatives to address water scarcity and enhance resilience. Cape Town's response to water scarcity demonstrates the effectiveness of the nexus approach in enhancing urban resilience. During the severe drought from 2015 to 2018, the city implemented a range of initiatives to improve water efficiency in agriculture, reduce energy consumption, and increase local food production. The city implemented water-saving technologies, diversified water sources, and promoted water-sensitive urban design, demonstrating the effectiveness of integrated planning in enhancing urban resilience (Enqvist & Ziervogel, 2019). By considering the interdependencies between WEF systems, Cape Town has been able to develop a more integrated and effective response to the challenges posed by climate change and resource scarcity (Ziervogel, 2019).

CHALLENGES AND OPPORTUNITIES

Implementing the nexus approach in urban resilience planning is not without challenges. These include 1) institutional silos; 2) data and knowledge gaps; 3) financial constraints; 4) political and social resistance.

One of the primary challenges in implementing the nexus approach is the existence of institutional silos. Different sectors, such as water, energy, and food, are often managed by separate departments or agencies, each with its own policies, goals, and priorities. This fragmentation can hinder effective collaboration and coordination, leading to disjointed planning and implementation efforts (Scott et al., 2011). Overcoming these silos requires fostering interdepartmental communication, creating cross-sectoral governance structures, and aligning policies and objectives across sectors.

Effective nexus planning requires comprehensive data and a deep understanding of the interdependencies between systems. However, data availability and quality can be inconsistent, particularly in developing countries or smaller municipalities. Knowledge gaps regarding the complex interactions between water, energy, and food systems further complicate the development of integrated strategies (Howells et al., 2013). Addressing these gaps involves investing in data collection and analysis, fostering research on nexus interdependencies, and developing tools and models to support integrated planning.

Integrating nexus approaches into urban planning often requires significant investment in infrastructure, technology, and capacity building. Financial constraints can be a major barrier, especially for resource-constrained cities facing competing priorities and limited budgets (Biggs et al., 2015). Securing funding from diverse sources, including public-private partnerships, international development agencies, and innovative financing mechanisms, is crucial to overcoming these constraints.

Implementing integrated approaches can face resistance from political entities and social groups that may be accustomed to traditional, sector-specific planning. Changes in policies and practices can be met with skepticism or opposition, especially if the benefits are not immediately apparent or if they disrupt existing power dynamics and interests (Smith & Stirling, 2010). Building political will, engaging stakeholders, and demonstrating the long-term benefits of the nexus approach are essential to overcoming this resistance.

Despite these challenges, the nexus approach offers significant opportunities for enhancing urban resilience, including innovative technologies, policy integration, and community engagement (Schneidewind & Augenstein, 2016).

Developing coherent policies that promote cross-sectoral collaboration and integration is a key opportunity for enhancing urban resilience. Integrated policies can create synergies between sectors, align objectives, and streamline planning and implementation processes. For instance, policies that promote renewable energy and water conservation can simultaneously address energy security and water scarcity, leading to more resilient urban systems (Rasul & Sharma, 2016).

Engaging local communities in the planning process ensures that strategies are responsive to local needs and contexts. Community involvement enhances the acceptance and effectiveness of nexus-based interventions, as local knowledge and perspectives are incorporated into decision-making. Participatory approaches also build social capital and strengthen community resilience, making urban areas more adaptable and responsive to change (Matson et al., 2016).

CONCLUSION

The socio-environmental conditions in countries worldwide are deteriorating due to the increasing impact of climate change in urban areas, leading to issues such as urban heat islands, droughts, floods, heatwaves, and wildfires. These problems are worsened by rapid urbanization, unsustainable land use changes, and the exploitation of natural resources, putting the future of our cities at risk and threatening their long-term sustainability and resilience.

In response to these challenges, cities around the world are increasingly adopting innovative approaches to urban resilience planning. One such approach is the nexus approach, which recognizes the interconnectedness of WEF systems in urban areas. By integrating these systems and considering their interdependencies, cities can create synergies between different sectors and stakeholders, and develop more holistic and sustainable resilience strategies, leading to more effective and resilient urban systems. Case studies from cities that implemented this approach demonstrate the potential benefits of this approach and highlight the importance of considering the nexus in urban resilience planning. By embracing the nexus approach, cities can enhance their resilience and create more sustainable and liveable urban environments for the future.

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SPATIAL PARAMETERIZATION OF COMBINED OFFSHORE RENEWABLES ARRAY

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Abstract: Arrays of offshore renewables are being studied by academia to justify them economically in real-world applications by private sector entities. Offshore renewables' initial and levelized costs are significantly higher than their on-land counterparts. Therefore, energy density per unit area should be dramatically increased and/or cost lowered. However, concurrent knowledge of offshore industries other than renewable energy, such as fish farms, offshore oil platforms, and marine shipping, implies that lowering costs will not be sufficient. In order to increase the energy density per unit area, multiple offshore renewable energy systems relying on different physics should be combined in three-dimensional space, thus creating an array. Also, systems and structures of other marine industries can be included in the concept to benefit from their readily present infrastructure. Such arrays are the subject of scientific and engineering investigation and assessment since hydrodynamics, aerodynamics, mechanics, and economics are involved. The topic is highly multidisciplinary. In this work, we reflect on the present situation and project future aspects.

Keywords: *Economical Analysis; Energy Storage; Fish Farming; Hybrid Energy Systems; Three-Dimensional Space.*

INTRODUCTION

The concept of arrays of offshore renewables presents a complex and multidisciplinary challenge that requires careful consideration from academia and the private sector. The economic justification for large-scale deployment of offshore renewable energy technologies is at the heart of this discussion. Despite the inherent benefits of harnessing energy from offshore resources, such as wind and tidal currents, these ventures' initial and ongoing costs are considerably higher than on-land alternatives. Two primary strategies emerge to make offshore renewables economically viable: increasing energy density per unit area and reducing costs. However, achieving these objectives is far from straightforward. Simply lowering costs may not be sufficient, as offshore environments already host a variety of industries like fish farming, oil extraction, and marine transportation, each utilizing the available space and infrastructure. Therefore, a holistic approach is required, integrating renewable energy systems into existing offshore landscapes while maximizing efficiency and minimizing disruption to other activities.

The solution lies in developing offshore renewable energy arrays—sophisticated systems combining multiple renewable technologies in three-dimensional space. We can optimize energy production by integrating various renewable energy sources, such as wind, tidal, and wave power, within a shared offshore environment while minimizing the overall environmental footprint. Moreover, these arrays can leverage existing offshore infrastructure from other industries, reducing construction costs and easing the logistical burden of deploying new energy systems.

Developing offshore renewable energy arrays represents a significant scientific and engineering challenge. It necessitates hydrodynamics, aerodynamics, structural mechanics, and economics expertise to optimize design, performance, and cost-effectiveness. Furthermore, the multidisciplinary nature of this endeavor underscores the importance of collaboration between researchers, engineers, policymakers, and industry stakeholders. Looking ahead, the future of offshore renewable energy arrays holds immense promise. As technology advances and our understanding of complex offshore environments deepens, we can anticipate improved efficiency, reduced costs, and increased sustainability in energy production. However, challenges remain, including addressing environmental impacts, optimizing resource allocation, and navigating regulatory frameworks.

In conclusion, offshore renewable energy arrays are pivotal to realizing a sustainable and economically viable energy future. By leveraging interdisciplinary expertise and embracing innovative design approaches, we can unlock the full potential of offshore renewables, transforming our energy landscape while preserving our oceans and coastal ecosystems. In the present work, we review several literature contents to create a frame on arrays of offshore renewables. Then, the parameterization of an array for different disciplines is discussed. We conclude with our projections.

LITERATURE REVIEW

In this part, we first briefly mention renewables combined with offshore wind turbines. Then, issues about arrays are tried to be laid out by means of three articles and a lecture note.

Li (2012) analyse wave energy conversion methods, focusing on analytical, Boundary Integral Equation Method (BIEM), and Navier-Stokes Equation Method (NSEM) approaches. BIEM is highlighted for power generation, while NSEM is emphasized for survivability. NSEM provides a fully viscous solution for wave hydrodynamics by solving continuity and momentum equations. Linear Wave Theory is also discussed as a first-order approximation for the flow field, assuming small amplitude waves and linearized boundary conditions. Wave energy has gained significant attention recently, with various technologies proposed for harnessing ocean energy. These technologies include oscillating water columns, point absorbers, overtopping, and bottom-hinged systems. Among these, the point absorber technology is highlighted as a cost-efficient method for wave energy extraction. Specific systems discussed in the Li (2012) paper include the Tapchan shoreline system, Wave Dragon offshore floating system, Seawave Slot-Cone Generator integrated into a breakwater, Lilypad membrane device, and the buoy and submerged plate wave energy device. Each system utilizes different mechanisms to convert wave power into usable energy. Accordingly, these systems should be considered as potential candidates for offshore renewables arrays that contain a combination of renewables systems.

Zhang (2021) discusses the application of Smoothed Particle Hydrodynamics (SPH) modeling in accurately simulating free surface deformation in wedge water entry experiments and regular wave interactions with fixed and pitching devices. The study highlights the good agreement between SPH simulations and measured data, particularly in optimizing wave energy conversion performance with larger-scale devices in deep water. It also addresses challenges in wave energy conversion, such as reliability, cost, and efficiency, emphasizing the insights provided by SPH simulations for potential improvements in this field. The renewable energy system types mentioned in the work of Zhang (2021) are wave energy converters (WECs), overtopping systems, oscillating bodies, oscillating water columns, and membrane devices. Combining wave energy with offshore wind turbines has the potential to enhance energy production efficiency and reliability. Integrating these renewable energy sources can lead to a more stable and consistent power supply for offshore applications. Research indicates that the co-location of wave and wind energy systems could offer significant energy generation and cost-effectiveness benefits. The paper explores the comparison of wave power extraction between a compact array of small buoys and a large buoy. It delves into these array configurations' performance differences and efficiencies in harnessing wave energy. Zhang (2021) evaluates how the arrangement of multiple small buoys in an array compares to the energy extraction capabilities of a single large buoy. This analysis provides insights into the potential advantages and challenges of deploying arrays of wave energy converters for enhanced energy generation from ocean waves. The paper recommends further exploration and evaluation of the performance and efficiency of wave power extraction by compact arrays of small buoys compared to larger buoys. It suggests that studying different array configurations' dynamics and energy extraction capabilities can provide valuable insights for optimizing wave energy conversion systems. By focusing on array designs, researchers can potentially enhance wave energy converters' overall effectiveness and output in harnessing renewable energy from ocean waves.

Churchfield (2013) outlines the initial exploration into conducting large-eddy simulations of tidal turbine array flows. Initially, the authors executed a precursor simulation with horizontal periodicity to generate turbulent flow data. Subsequently, the authors utilized this data as inflow for a tidal turbine array featuring two rows and infinite width. The turbines were represented using rotating actuator lines, with the governing equations solved via the finite-volume method. Investigation into turbine wake patterns showed the authors that the vertical inflow shear, combined with wake rotation, induced lateral wake asymmetry. Diverse turbine configurations were simulated in the paper, focusing on assessing total power generation relative to isolated turbines. Notably, staggering consecutive rows of turbines in the simulations yielded optimal efficiency with minimal downstream spacing.

In contrast, counter-rotating downstream turbines in a non-staggered arrangement demonstrated modest benefits. Churchfield (2013) indicates some specific areas that are convenient for improvement. For instance, employing a larger precursor domain would better capture elongated turbulent structures, while incorporating salinity and temperature equations would address density stratification's impact on turbulence dynamics. Additionally, refinement of wall shear stress modeling and further exploration of array configurations are recommended for future investigations. The authors' preliminary investigation into applying Large-Eddy Simulation (LES) to tidal turbine arrays underscores this approach's potential to deliver valuable, time-dependent insights into wake behavior and power generation. Despite the computational expense associated with LES compared to Reynolds-Averaged Navier-Stokes (RANS) based methods, its capacity to furnish a comprehensive, temporally resolved solution incorporating large-scale eddies within the flow is a significant advantage. These simulations could serve as a basis for refining RANS turbulence models tailored for tidal turbine array assessments. This research underscores the importance of accurately representing tangential forces exerted by turbine models to reproduce wake asymmetry observed in practical turbine setups. The authors address the need for experimental data to assess further the numerical and computational tools they used. The significant influence of turbulent inflow simulation methods on predicted wake propagation and array power production is emphasized. The spatial domain utilized in the paper is insufficient to capture the largest-scale flow structures effectively. Consequently, a persistent low-speed structure within the studied domain led to cyclic variations, resulting in consistently lower power production from turbines on one side compared to the other. The authors set a larger computational domain size and experimental validation as future goals. The impact of salinity and temperature stratification on inflow dynamics and array performance is also a topic to study.

Gong (2018) discusses the efficiency and performance of tidal turbine arrays, focusing on the impact of blockage, turbine arrangement, and channel dynamics. The authors highlight the division of power per turbine into power acquisition and channel response components. The study emphasizes the importance of optimal turbine arrangement for maximizing power potential while considering the influence of channel dynamics. Additionally, it addresses the challenges in predicting power potential accurately due to the complexity of real tidal channels. The study emphasizes the significance of optimal turbine arrangement in maximizing the power per turbine in tidal arrays. By dividing the power per turbine into components related to power acquisition and channel response, the research sheds light on the critical factors influencing the performance and economics of tidal turbines. Understanding the impact of channel dynamics on turbine arrays is crucial for enhancing efficiency and power generation in tidal energy projects. The research underscores the importance of minimizing blockage in tidal turbine arrays to optimize power potential and force per turbine. By analyzing the effects of blockage on power coefficients and efficiency, the study highlights the benefits of an appropriate turbine arrangement in reducing blockage and maximizing power output. These findings provide valuable insights into improving the design and performance of tidal turbine arrays in real-world applications. Gong (2018) acknowledges the challenges in accurately predicting power potential in tidal channels due to their complex nature. Theoretical models are essential for simplifying predictions and understanding the efficiency of tidal turbine arrays. By exploring the trade-offs between power acquisition and channel response, the research advances the knowledge of tidal energy systems and optimizes their performance in practical settings. The paper suggests that optimizing turbine arrangement is crucial for maximizing tidal turbine arrays' power potential and efficiency. It recommends considering the impact of channel dynamics and blockage on power per turbine to enhance overall performance. The research highlights the importance of balancing power acquisition with channel response to achieve optimal results in tidal energy projects. By incorporating these recommendations into the design and operation of tidal turbine arrays, stakeholders can improve tidal energy generation's economic viability and sustainability. Combining tidal energy arrays with wave energy systems and offshore wind turbine systems has the potential to create hybrid renewable energy solutions that leverage the strengths of each technology. By integrating these systems, it is possible to enhance overall energy generation capacity, improve grid stability, and maximize energy output. The complementary nature of tidal, wave, and wind energy sources can lead to a more reliable and consistent renewable energy supply. Additionally, such hybrid systems can help optimize the use of marine resources and contribute to a more sustainable energy mix.

Sørensen (2024) discusses the development and visualization of wake structures in water tunnels, focusing on the vortex system formation, tip vortices destabilization, and turbulent mixing. The author highlights the unconditional instability of wakes behind wind turbines and the importance of vortex dynamics in blade loading. The document also delves into the relationship between vortex dynamics, meandering, and added turbulence intensity, emphasizing the need to validate further wake models for performance predictions in wind farms and turbine lifetime estimations. Turbine spacing, wake dynamics, and turbulence intensity are crucial in wind farm performance and aerodynamics. The distance between turbines influences wake development and the overall efficiency of the wind farm. Understanding the dynamics of vortices shed by turbines is essential for optimizing power production. Additionally, ambient turbulence levels impact the stability and loading on wind turbine blades, affecting the overall performance and lifespan of the turbines within the wind farm. Stability analysis, wake dynamics, and model validation are crucial for comprehending and enhancing wind farm performance. Stability analysis provides insights into the unconditional instability of wakes behind wind turbines, which is essential for predicting turbine behavior. Understanding wake dynamics aids in optimizing power production and turbine lifespan. Furthermore, validating models through simulations and visualizations ensures the accuracy and reliability of predictions, ultimately contributing to the efficient operation and optimization of wind farms.

DISCUSSION OF PARAMETERIZATION OF RENEWABLES ARRAYS

Figure 1 shows a structured and unstructured two-dimensional array diagram that indicates the nodes and connection lattices.

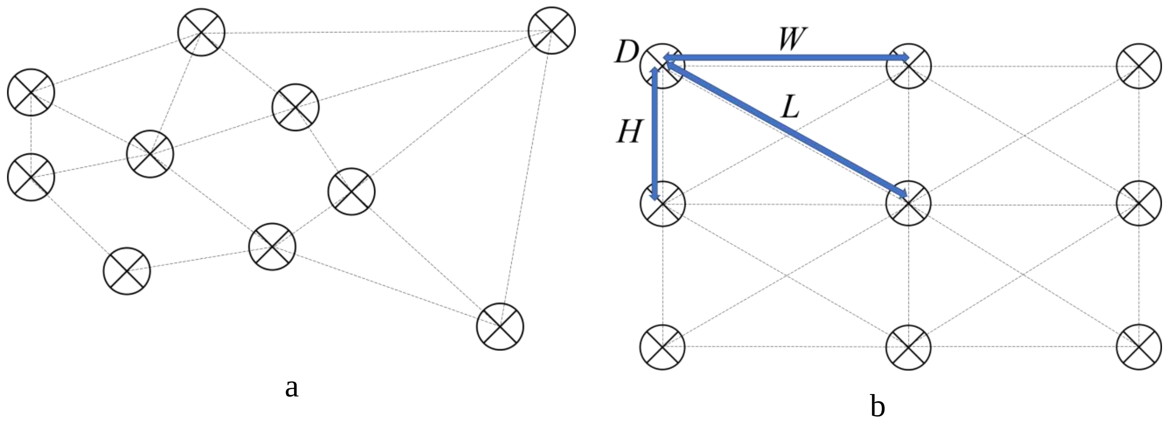

Figure 1. Diagram of structured and unstructured two-dimensional arrays. a- Unstructured array; b- Structured array.

Figure 1 shows that structured two dimensional arrays can be defined and examined by a few length properties. When those lengths are associated with performance and cost functions, as symbolized in equation (1), an optimization task can be conducted.

$$
\begin{aligned}
f_p &= f\left(D, H, L, W\right) \\
f_c &= g\left(D, H, L, W\right)
\end{aligned} \tag{1}
$$

On the other hand, considering the different elevations for wind, wave, surface, and tidal sources, a three-dimensional array and space could be imagined. Such a system adds dimension to (1) and combines different offshore renewables. A conceptual artificial intelligence-generated image is shown in Figure 2.

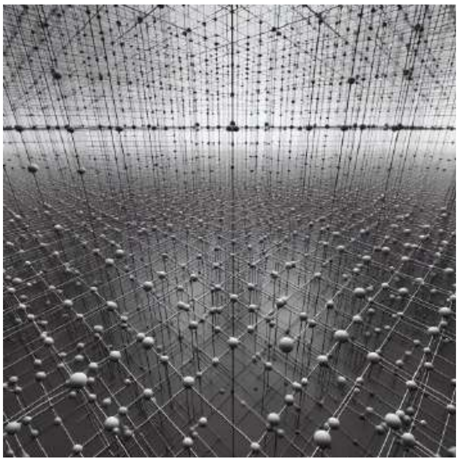

Figure 2. AI-generated three-dimensional array nodes and lattices.

Combining different renewables and three-dimensional array problems creates a multidisciplinary and complex problem. Therefore, creating digital twins of individual elements and creating simulations with numerous digital twins in three-dimensional arrays are paramount.

CONCLUSION

Arrays of offshore renewable energy systems, including wave energy systems, tidal turbines, and wind turbines, play a crucial role in the sustainable development of world energy resources. Arrays of offshore renewable energy systems harness natural resources like waves, tides, and wind in a concentrated area. By deploying multiple devices in an array, overall energy production can be more reliable and efficient. Redundancy in power generation ensures stability in supply, even when individual units are undergoing maintenance or repairs. Arrays allow for the scalability of renewable energy projects. Larger arrays can generate substantial power, making them viable alternatives to traditional fossil fuel-based energy sources. As technology advances, scalability becomes more feasible and cost-effective. Offshore environments often offer superior resource availability compared to onshore sites.

Offshore arrays can tap into stronger, more consistent wind patterns, powerful ocean currents, and energetic wave regimes, maximizing energy capture potential. Offshore renewable energy systems help reduce greenhouse gas emissions and dependency on finite fossil fuels. They contribute to cleaner air and water while preserving natural habitats on land. Combining various offshore renewable energy systems with marine industry structures introduces exciting possibilities. Integrating renewable energy systems with existing marine structures like fish farms, ships, or petroleum platforms can optimize the use of ocean space. This integration can lead to shared infrastructure, reducing costs and environmental impact. Marine industry structures can serve as platforms for deploying renewable energy devices, leveraging existing infrastructure and expertise. For example, using decommissioned oil rigs as support structures for wind turbines or integrating wave energy converters into floating docks. Combining energy systems with other marine industries allows for diversifying economic activities in coastal regions. It can foster job creation and economic growth while supporting the transition to a low-carbon economy. Continued innovation in offshore renewable energy technologies will reduce costs and improve efficiency. Advanced materials, improved design, and enhanced monitoring systems will make offshore arrays more reliable and economically viable. The trend toward combining multiple renewable energy systems with marine industry structures will accelerate. Integrated projects will become more common, benefiting from shared resources and reduced environmental impact. Offshore renewable energy arrays will proliferate worldwide, especially in regions with abundant marine resources. Governments and industries will increasingly invest in offshore energy projects to meet renewable energy targets and combat climate change. Future developments will prioritize environmental sustainability, minimizing ecological impacts, and optimizing coexistence with marine ecosystems.

In summary, arrays of offshore renewable energy systems are pivotal in advancing sustainable energy solutions. Combining these systems with marine industry structures opens up new opportunities for innovation and collaboration. Looking forward, the future holds great promise for expanding and integrating offshore renewable energy technologies into the global energy landscape. However, academia should conduct multidisciplinary studies to assess advanced renewables combinations and three-dimensional array designs. Especially, digital twins of potential elements of renewables combining efforts should be prepared for comprehensive simulations.

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OFFSHORE FLOATING WIND TURBINES AND A CONCEPTUAL DESIGN

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Abstract: Most of the major cities in the world are coastal cities. This is a natural outcome of the needs of human civilization. Some of the mentioned needs are transporting goods (shipping in literal means) and resources such as fish. On the other hand, wind and solar energy systems are usually built on arid land, away from settlements. Since there is an inverse relation between the size of a settlement and the aridness of a field, renewable energy systems, particularly wind and solar, are far from major settlements and industrial facilities. This creates and increases transfer/transmit and storage duties. Accordingly, additional costs arise. The additional costs and hardship undermine the transition to a carbon dioxide neutral circular sustainable life. Another thing about the location of renewables on land is that transmitting generated energy may not be possible at all. Consequently, offshore renewable energy systems are being studied and also applied. In the present work, we review the concurrent literature about offshore floating wind turbines, present an idea on them, and lay out basic equations for evaluating the idea based on economics and physics.

Keywords: *Economical Analysis; Investigation Parameters; Renewable Energy.*

INTRODUCTION

All sources should be tapped towards a carbon-neutral, sustainable, circular economy. Accordingly, floating systems are becoming of interest. Consequently, floating systems garner interest, benefiting from the technical experience of floating oil platforms. Nevertheless, it is not clear yet can the floating renewables can justify themselves in terms of economy and cost. Oil platforms have oil and this justifies their expensive constructions. On the other hand, the structures of renewables may be orders of magnitude smaller than the oil platforms. The aspect ratio differs from the oil platforms, particularly for the wind turbines. In conclusion, academia should study the topic and envision a general decision on whether real-world scale testing is logical in justifying the cost. In the present work, we review the concurrent literature about Offshore Floating Wind Turbines (OFWT), present an idea on them, and lay out basic equations for evaluating the idea based on economics and physics.

In the quest for sustainable energy sources and the mitigation of climate change impacts, offshore floating wind turbines have emerged as a promising frontier in renewable energy technology. These innovative structures represent a shift from traditional fixed-bottom offshore wind farms, offering the potential to harness wind energy in deeper waters and closer to densely populated coastal regions. Offshore wind energy has gained traction globally due to its abundant resource and potential to generate large-scale electricity without consuming land resources or emitting greenhouse gases. However, conventional offshore wind farms are limited to relatively shallow waters where fixed foundations can be installed securely. This constraint restricts their deployment to some geographical regions and distances from shore. Floating wind turbines break through these limitations by employing buoyant platforms anchored to the seabed using mooring systems. This technology enables the deployment of wind turbines in deeper waters, where wind speeds are often higher and more consistent, unlocking vast untapped wind energy potential worldwide. One of the key advantages of offshore floating wind turbines is their proximity to major population centers and industrial hubs. By locating closer to shore in deeper waters, these turbines can deliver renewable electricity directly to coastal cities, reducing transmission losses and costs associated with long-distance power delivery. This proximity enhances grid stability and resilience while minimizing environmental impacts on land.

Furthermore, offshore floating wind turbines offer flexibility in deployment, allowing for the installation of larger and more efficient turbines in optimal wind conditions. This scalability can significantly reduce the levelized cost of electricity (LCOE) over time, making offshore wind energy more competitive with conventional fossil fuel-based power generation. Advancements in materials science, engineering, and offshore oil and gas industry experience have accelerated the development of offshore floating wind technology. Lessons learned from floating oil platforms, including design principles, structural integrity, and mooring systems, have been adapted and applied to floating wind turbine projects, contributing to their technical feasibility and economic viability. Despite these advancements, challenges remain in adopting offshore floating wind turbines. Cost competitiveness, environmental impact assessments, regulatory approvals, and infrastructure limitations are among the critical factors that must be addressed to realize the full potential of this technology. Offshore floating wind turbines represent a transformative opportunity to expand renewable energy capacity and accelerate the transition to a low-carbon economy. As technology evolves and costs decline, offshore wind energy, particularly floating turbines, holds immense promise for meeting global energy demands while reducing reliance on fossil fuels and mitigating climate change impacts. Continued research, innovation, and collaboration across industries and governments will be essential to realize the full potential of offshore floating wind turbines and pave the way towards a cleaner, greener future. In Figure 1, an offshore floating wind turbine concept is being visualized by a Creative Commons licensed graphic.

Figure 1. A Creative Commons licensed conceptualization for offshore floating wind turbine (Pegalajar-Jarudado, 2024).

Despite their potential, OFWTs face several technical challenges that must be addressed to ensure their viability and efficiency. One of the primary challenges is the design and construction of the floating platforms, which must withstand harsh marine conditions, including waves, currents, and storms. The platforms must also maintain the stability and alignment of the turbines to optimize energy generation. To tackle these challenges, researchers explore various floating platform designs, such as spar buoys, tension-leg platforms, and semi-submersibles. Each design offers unique advantages and trade-offs regarding stability, cost, and environmental impact. For instance, spar buoys are relatively simple and inexpensive but may be less stable in rough seas, while tension-leg platforms provide excellent stability but are more complex and costlier to construct. Another significant challenge is the mooring and anchoring systems, which must secure the floating platforms to the seabed while allowing some movement to accommodate waves and current actions. The design of these systems must consider factors such as water depth, seabed conditions, and environmental impacts. Research is ongoing to develop advanced mooring and anchoring solutions that balance cost, performance, and environmental sustainability. Lastly, the electrical infrastructure required to transmit power from OFWTs to the grid presents challenges. Underwater cables must be designed to withstand the harsh marine environment and minimize energy losses over long distances.

Several single-turbine prototypes have been installed since 2007, marking the early phase of commercial floating wind turbines. As of 2023, four operational floating wind farms boast a combined capacity of 193 MW. Notably, the Hywind Tampen floating offshore wind farm, the world's largest, began operating off the coast of Norway in August 2023. Comprising eleven turbines, it is expected to supply about 35% of the electricity needed for five nearby oil and gas platforms (Anonymous, 2024).

In the next section, six important sources in terms of offshore floating wind turbines are reviewed. Under the third title, we present a "mobile" floating wind turbine concept and discuss its implications. The last title concludes with a general frame evaluation of offshore floating wind turbines.

LITERATURE REVIEW

Wu (2019) reports a comprehensive literature review based on 168 literature papers on offshore wind turbines. The authors deal with both the bottom-fixed and the floating types. Cycling loads and pile sizes are emphasized, while the authors stressed a need for a legal code just for offshore wind turbines. Structure-foundation-soil triple system is introduced, and numerical simulations are sought. The numerical simulations should exceed the concurrent abilities. The physics desired to be incorporated are interface conditions between foundation and soil, properties of soil, loads from wind, current, wave, ice, and soil constitutive models deemed necessary. Wu (2019) mentions the lack of experimental data that can validate the numerical simulations sufficiently. They call campaigns for experimentation and monitoring from the fields. Anchors are addressed for research related to geotechnical engineering considering deep water applications. Mooring systems are also essential and their hydrodynamics pose another problem to be solved. Wu (2019) claims that offshore wind energy will be one order of magnitude higher than onshore wind energy between 2030 and 2050. However, offshore wind turbines are currently 50% more expensive than onshore ones. Wu (2019) also states that the main cost-creating factor differs for bottom-fixed and floating wind turbines, while the latter is due to the substructure and foundations. The typical support structures for different water depths are gravity, monopile, monopile with guy wires, tripod, jacked/lattice structure, tension legs with suction buckets (ballast stabilized), and buoy with suction anchor. The floating ones have fewer options, i.e., semi-submersible platforms with mooring lines, spar with mooring lines, and tension leg platforms. Since the foundation plays a major role in the cost, it should be emphasized. On the other hand, floating systems raise another point for engineering study. Anchor design must be studied since the mooring lines are essential for floating wind turbines. The types seen in the literature are gravity, piles, drag embedded, vertically loaded, suction caissons, suction embedded plate, torpedo, and deep penetrating. The authors review the modeling of the foundation and soil elaborately and list and review different modeling approaches.

The operation and maintenance of offshore wind turbines are reviewed by Ren (2021). The authors review 234 scientific articles. Rather than a single offshore wind turbine, the main focus shifted to offshore wind farms and their levelized cost in terms of energy. Of course, the levelized cost concept necessitates operational and maintenance costs to be known for a lifetime of the mentioned offshore wind turbine farm elements. The authors claim that the maintenance strategy strongly affects overall efficiency, profit margin, lifetime of the system, sustainability, and safety. Another exciting and less apparent side of the topic is the environmental impact of operation activities, specifically maintenance operations. Ren (2021) also emphasizes the operation and maintenance issue of offshore wind farms as a major part of the total energy generation cost compared to the onshore counterparts. The authors mention weather uncertainty as one of the important challenges for planning maintenance schedules. An interesting and less apparent problem with maintenance is the qualified personnel with offshore wind farm experience. The authors indicate the necessity of remotely controlled robotic systems that could replace humans in the operational field. Proactive and preventive maintenance and operation are deemed necessary to enable levelized costs to be acceptable. A crucial part of proactive/preventive operation and maintenance is the team's route planning, which relies on forecasting the systems and the weather. Lifting the special equipment during installations and/or maintenance is explicitly mentioned as challenging due to irregular wave phenomena. Numerical simulations for predicting numerous operational scenarios generally benefit from rigid-body assumptions. Lumped-mass connections simulate flexible structures. Remote or digital twin monitoring is crucial to reduce the elevated cost of wind farms. Another unintuitive recommendation of the article is that the authors recommend operation and maintenance-friendly turbine design even though it means less energy generation capacity or efficiency. Last but not least, larger and special equipment such as vessels and cranes are reminded, and outsourcing is pointed as another aspect.

Floating wind turbine aerodynamics is tackled by Micallef (2021) by the review of 151 scholarly articles. Six degrees of freedom is stressed out since floating wind turbines are affected aerodynamically and hydrodynamically. The scientific works are summarized as they handle the analyses using two approaches, i.e., coupled or uncoupled hydrodynamics and aerodynamics. Again, most of the works are stated to focus on single floating turbines while farms of them are seldomly investigated. Surge and pitch motions of the platform are the focus most of the time. In the case of multiple turbines, Micallef (2021) detects that the pitching rotor shifts turbulent kinetic energy upward. Also, generally, wake recovery is found to be realized in shorter distances both for laminar and turbulent inflow, in contrast to the findings of the earlier works with simpler models. The authors list pre-commercial floating offshore projects between 2018 and 2022. Four floating platforms are mentioned for the wind turbines, among which barge type is the only type not mentioned in the present proceeding paper. The figures from reviewed articles show the aerodynamical differences due to floating and waves. The rotor's four aerodynamic loading states are a windmill, turbulent wake, vortex ring, and propeller. Last but not least, the authors claim to highlight research gaps for floating wind turbines in terms of aerodynamics.

Gao (2022) addresses the hydrodynamics problem of offshore wind turbines by reviewing 165 literature papers. The authors emphasize that offshore wind turbines are generally a topic of oceanic countries. Among related phenomena such as hydrodynamics, aerodynamics, structural dynamics, elasticity, and other operational theories, hydrodynamics is the key topic for realizing offshore wind turbines at scale. On the other hand, for several reasons, vertical axis wind turbines are not as competitive as horizontal-axis wind turbines. Accordingly, most future work is anticipated on horizontal wind turbines for offshore systems, including floating ones.

According to the review by Gao (2022), Denmark appears as a major player with its companies, pioneer field applications, and research bodies. Then, we can mention the Netherlands. Of course, there are numerous countries now racing on the subject. China has become a major player. The two ways of affecting the OFWT wakes by the waves are explained as the wave interaction with the tower and the altered wake propagation due to the waves. Hydrodynamics, aerodynamics, and their interaction with the floating wind turbine that has several different dynamics including yaw, pitch, roll, heave, sway, surge, and many more makes the topic very complicated. Therefore, some researchers are trying to combine computational aerodynamics with scaled experimental wave and hydrodynamic investigations. Last but not least, freak wave formation is thought to be probable due to spatial variation of the kurtosis coefficient, which is reported by the reviewed papers.

Zhang (2022) reviews 74 papers to address interactions between floating wind turbines. They also try to analyze such couples' performance and cost indications systematically. The authors used unsteady Reynolds averaged Navier Stokes finite volume-based computational simulations to test several scenarios of two floating wind turbines and evaluate the results in terms of levelized cost of energy. Of course, the positions of the turbines, together with aerodynamics and hydrodynamics, affect the power output and torque due to the six degrees of freedom response. This decides whether the operation or the initial investment is the major factor in the levelized cost. Zhang (2022) claims that side by side layout is better than tandem. They suggest 1.56 times the turbine diameter for the distance between the side-by-side turbines, while 9.25 times the turbine diameter is recommended for a tandem arrangement.

OFFSHORE FLOATING WIND TURBINE CONCEPT AND DISCUSSION

Figure 2 shows the schematic diagram of the proposed offshore floating wind turbine concept.

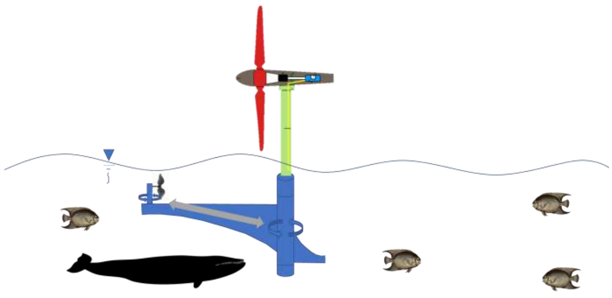

Figure 2. An offshore floating wind turbine concept with no mooring lines and bottom connection.

The proposition in Figure 2 is for deep sea where accomplishing a connection with the ocean bottom is problematic. The concept has a telescopic boom extension on the spar to create a gravitational balance to the force due to the wind. The propeller on the extension is for avoiding drift and/or relocation of the turbine. Considering concurrent technology, the system needs a sophisticated and automated control system, which seems doable. However, there is a grid connection problem for this concept. Most probably, the concept would necessitate energy storage solutions. After a complete system solution that can be analyzed for competitiveness and applicability, an initial economic and performance analysis should be conducted, represented with the following expressions.

$$C = \sum n_i R_i \tag{1}$$

$$B = (I) - (E) \tag{2}$$

$$I = U \frac{(\sum n_i P_i) - (\sum n_i A_i)}{M_i} \tag{3}$$

$$P = f(L, \alpha, \eta, u, \rho) \tag{4}$$

The initial investment cost is as in (1). There, *i* is an integer indicating a renewable energy system used in the design as a combined element, *n* is the number of a type of element, and *R* is the purchase price in USD. The purchase means the total amount, including everything needed to establish, install, and prepare the system for operation. The operational income and expense balance per unit of time can be approximated via (2) and (3). In eq. 2 and 3, *I* is income in USD per time, *E* is expense per time due to methanol transport by ships, *P* is the generated electrical power of an element, *A* is the power consumptions of elements such as actuators and control computers, *M* is the methanol conversion number of an element for unit time, and *U* is the unit price of the methanol. The basic payback period and more advanced economic calculations can be done based on the relation between *C* and *B*. The parametric analyses on the design should be prepared for calculating *Pi* and *Ai*. Some examples may be as in (4). Figures of the design should show parameters in (4).

CONCLUSION

In conclusion, offshore floating wind turbines represent a transformative opportunity to expand renewable energy capacity and accelerate the transition to a low-carbon economy. Offshore floating wind turbines represent a promising frontier in pursuing clean and sustainable energy. They represent a bold leap toward a greener future. While technical challenges remain, ongoing research and development efforts pave the way for the successful deployment and integration of OFWTs into the global energy mix. As technology evolves and costs decline, offshore wind energy, particularly floating turbines, holds immense promise for meeting global energy demands sustainably while reducing reliance on fossil fuels and mitigating climate change impacts. Continued research, innovation, and collaboration across industries and governments will be essential to realize the full potential of offshore floating wind turbines and pave the way towards a cleaner, greener future. By harnessing the immense potential of wind energy at sea, OFWTs have the potential to play a significant role in the transition towards a carbon-neutral future. As we navigate the complexities of deep waters, we must continue to innovate, collaborate, and push the boundaries of what is possible. These majestic giants, swaying gracefully on the open sea, hold the promise of a cleaner, more sustainable world—one gust at a time. The new propositions should solve the cost-effectiveness issue in terms of initial investment and operation realization costs. The initial investment cost of the propositions includes the grid connections under salt water and/or energy storage and transportation means. The same means should also be considered for operational costs. At this point, digital twins of proposed designs by numerical simulations would play crucial roles since there are immense probabilities.

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AN OVERVIEW OF INJURIES IN REPUBLIC OF SERBIA AND THE REPUBLIC OF SRPSKA (B&H): A BRIEF SUMMARY

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Abstract: This paper presents a brief analysis of workplace injuries in Serbia and Republic of Srpska (B&H), building upon prior research conducted on the occupational safety and health frameworks in these two regions. The study identifies existing issues within the systems and offers recommendations for improvement, underscoring the necessity for additional research to delve deeper into the complexities of these issues. Through recommended future comprehensive examination of injury data and related factors, the paper aims to contribute to the enhancement of occupational safety and health practices in Serbia and Republic of Srpska (B&H).

Keywords: *statistics, injuries, occupational safety and health*

INTRODUCTION

Fagan and Hodgson (2017) pointed to an increase in the rate of underreported and inadequately documented injuries worldwide. Fontaneda et al. (2019) examined the relationship between variables (worker age, type of job, workplace location, company size, day of the week, etc.) and the duration of sick leave following a workplace injury. Studies conducted by Bellamy (2015) and Marshall et al. (2018) suggest a correlation between severe injuries and serious fatal accidents, where knowledge of the former could prevent those ultimately resulting in death.

Occupational accidents have a direct impact on shaping social reality, representing a significant public health concern as they incapacitate and sometimes fatally injure individuals, particularly those in their youth and working age. While the social impacts and human suffering stemming from work-related accidents are immeasurable, their financial repercussions pose significant challenges across all levels of society, affecting social security programs and corporate productivity. According to the International Labour Organization (ILO), approximately 4% of the world's gross domestic product (GDP) is lost annually due to accidents, occupational diseases, health expenditures, pensions, absenteeism, and rehabilitation. The ILO defines a death as work-related if it occurs within one year of the accident. The precise number of deaths resulting from occupational accidents and diseases worldwide is not readily available due to the lack of reliable data sources in most countries. Nevertheless, the ILO estimates a decrease from 358 thousand fatal accidents annually in 2003 to 321 thousand in 2008, followed by an increase to 350 thousand. (Melchior C. and Zanini R.R, 2019)

The Framework Directive 89/391/EEC on measures to promote improvements in the safety and health of workers at work introduced the requirement for employers to maintain a record of occupational accidents where a worker is unable to work for more than three days. Additionally, in accordance with national laws and/or practices, employers are obligated to compile reports on occupational accidents experienced by their employees. Based on this directive, the European Statistics on Accidents at Work (ESAW) project was initiated in 1990 to standardize data collection on accidents at work, specifically for incidents resulting in more than three days of absence from work. According to the ESAW methodology, an 'accident at work' is defined as a distinct event occurring during work that results in physical or mental harm. The term 'in the course of work' refers to being engaged in an occupational activity or during the time spent at work.

The aim of this study is to conduct a comparative analysis of accident statistics in two countries, Serbia and the Republic of Srpska, utilizing reports on work injuries following the ESAW methodology in Serbia, and reports from authorities in the Republic of Srpska. The objective is to gain a better understanding of the situation and identify directions for further improvement. This research serves as an addition to a previous paper analysing the occupational safety and health (OSH) state in these two countries. (Vranjes and Zoraja, 2023)

MATERIAL AND METHODS

We carried out the literature mapping of the reports and research studies about work-related injuries in 2018, 2019 and 2020 year. We used the following keywords and combinations to select the papers and reports: mortality, fatality, workers, occupational mortality, fatal occupational accidents, occupational activity, occupational fatalities, fatal injuries, occupational, accident, safety, injury, health administration, and occupational health services. The selected studies were classified according to the year of publication, the period of data analysed in the study, the type of study performed, the journal in which the research was published, the title of the work, the economic sector studied, the number of work-related deaths, as well as the region and country where the data was collected.

Serbia

Statistical Office of the Republic of Serbia (RZS): The official statistical body of Serbia provides detailed data on various aspects of society, including work injuries. Relevant information can be found in their annual reports or publications.

Republic Health Insurance Fund (RFZO): RFZO maintains records of medical cases, including work injuries. Annual reports on the execution of the Mandatory Social Insurance Policy may contain data on the number and types of work injuries in Serbia.

Legislation of the Republic of Serbia: Texts of relevant laws, such as the Law on Occupational Safety and Health, can be found on the official website of the National Assembly of the Republic of Serbia or on specialized portals for legal regulations.

Ministry of Labour, Employment, Veteran and Social Affairs: The ministry responsible for labor issues in Serbia can provide information on initiatives and programs aimed at improving occupational safety. In Serbia, work injuries are depicted based on the Reports of the Administration for Occupational Safety and Health for the years 2018, 2019, and 2020. These years were chosen for potential comparison with the Republic of Srpska. It's important to note that the ESAW methodology has been applied only since 2019. Other segments of the analysis are selected where common data is available (such as industry, gender, age, company size, etc.).

Republic of Srpska

The reporting system for work injuries in the Republic of Srpska, whether it concerns minor, severe, or fatal injuries, occupational diseases, or work-related illnesses, is outdated, very sluggish, and lacks coherence among the institutions responsible for collecting, monitoring, and analyzing injuries. As a result, we cannot obtain an adequate analysis, nor realistically assess how much the work process is affected by workplace injuries, or how much the budget of the Republic of Srpska is burdened by the treatment of injured workers or those suffering from occupational diseases or work-related illnesses. (Republic of Srpska, Ministry of Labor and Veterans' and Disabled Protection, 2021). The analysis presented below is the result of the author's efforts and data collection.

DISCUSSION AND RESULTS

The occupational safety and health systems result in the injuries shown in Tables 1 and 2.

Serbia

Statistics according to ESAW methodology consist of more data, but for purpose of this paper and possibilities of comparing, only this groups of data are selected.

Table 1. Analysis of Injuries in the Republic Serbia for the Period 2018-2020. (Directorate for Occupational Safety and Health, 2019, 2020, 2021)

Injuries	Subcategory	2018	2019	2020
Economic Activity	Agriculture, forestry, and fishing	47	23	42
	Mining	52	43	41
	Manufacturing industry	216	357	217

Injuries	Subcategory	2018	2019	2020
	Electricity, gas, steam, and air conditioning supply	62	68	99
	Water supply, sewage management, waste removal, and similar activities	47	65	31
	Construction	70	76	106
	Wholesale and retail trade, repair of motor vehicles and motorcycles	69	81	120
	Transportation and storage	65	89	94
	Accommodation and food service activities	7	9	6
	Information and communication	9	22	33
	Financial and insurance activities	9	33	20
	Real estate activities		5	1
	Professional, scientific, innovative, and technical activities	19	14	8
	Administrative and support service activities	27	61	20
	Public administration and defense, compulsory social security	14	60	61
	Education	28	70	47
	Healthcare and social assistance	59	131	162
	Arts, entertainment, and recreation	-	19	8
	Other service activities	-	9	100
	No data	10	12	21
Educational Attainment	First level (Level 1) – Primary education and upbringing, adult basic education	-	147	188
	Second level (Level 2) – Vocational training lasting one year, education for work lasting two years, non-formal adult education lasting	-	46	81

Injuries	Subcategory	2018	2019	2020
	Third level (Level 3) – Secondary vocational education lasting three years, non-formal adult education	-	325	345
	Fourth level (Level 4) – Secondary gymnasium education lasting four years	-	425	417
	Fifth level (Level 5) – Craftsmanship, specialist education lasting one or two years, and non-formal adult education lasting at least six months	-	29	51
	Sixth level (Level 6) – Basic academic studies of at least 180	-	50	35
	Seventh level (Level 7) – Integrated academic studies ranging from 300 to 360 ECTS, master's academic studies of at least 60 ECTS	-	122	91
	Eighth level (Level 8) – Doctoral studies of 180 ECTS, without data	-	2	9
	Top of Form	-	101	20
Severity of Injury and Recovery Method	Fatal injuries at work	7	14	11
	Serious injuries at work	788	1232	1226
	Serious injuries (upon arrival, departure from work)	522	597	435
	Minor injuries	9804	11462	8623
Number of employees at the employer	1 - 9 employees	25	31	52
	10 - 49 employees	85	128	135
	50 - 249 employees	69	348	314
	250 - 499 employees	221	159	152
	500 or more employees	388	565	558

Injuries	Subcategory	2018	2019	2020
	Number of employees unknown	7	15	26
Age of the Injured	less than 18	1	0	1
	18-25	33	108	85
	26-35	68	231	235
	36-45	356	293	269
	46-55		352	371
	56-65	329	243	266
	over 65		3	7
	no data	8	17	3
Gender of the Injured	Male	589	801	790
	Female	206	446	447
	No data available	-	0	0

Analyses show that the most common causes of work injuries in Serbia are falls, injuries due to impact or collision, and injuries resulting from handling tools and machinery. This data is available in the annual reports of the Republic Health Insurance Fund of Serbia.

Republic of Srpska

Key conclusions drawn from the presented analysis in Table 2. include:

- The highest number of injuries is present in high-risk production sectors, such as industry and mining, and construction, while in service sectors, it's in the healthcare sector.
- There is a trend of 75% of injuries occurring among semi-skilled, skilled, and workers with vocational education.
- A concerning fact is that 75% to 80% of injuries result from human factors: negligence, haste, failure to follow work processes, failure to use personal protective equipment, etc.
- Although 70% to 75% of injuries did not require hospitalization, there are no relevant data on the economic effects of treating these injuries.
- Regarding the timing of injuries (month, day), it's slightly higher in the warmer part of the year due to the higher intensity of work in high-risk sectors, with a weekly peak at the beginning and middle of the workweek.

- The majority of injured workers are aged between 30 and 60, i.e., workers who are the main drivers of work processes.
- Approximately 40% of injured workers have work experience of up to 10 years.
- Regarding gender, the percentage of injured males is double that of females, reflecting both a higher proportion of male employees and a higher percentage of males in high-risk sectors.

Table 2. Analysis of Minor Injuries in the Republic of Srpska by Economic Activities and Etiological Parameters for the Period 2018-2020. (Republic of Srpska, Ministry of Labor and Veterans' and Disabled Protection, 2021)

Category of Minor Injuries	**Subcategory**	**2018**	**2019**	**2020**
Economic Activity	Industry and Mining	443	440	302
	Agriculture, Mining, Water Management	111	90	106
	Construction	39	39	55
	Transport and Communications, Railways, Telecommunications and Postal Services	120	108	84
	Trade, Hospitality, Tourism	84	108	121
	Craft and Personal Services	13	65	26
	Communal Activities	8	48	44
	Financial and Business Services; Funds and Business Organizations	27	32	10
	Education, Science, Culture, Information and Social Services	38	77	64
	Health Services	285	257	205
	Production of Electricity and Electric Distribution	130	136	126
	Public Administration, Police, Army	176	192	202
	No data available	0	21	2
Educational Attainment	Unskilled Worker	139	163	103
	Semi-skilled, Skilled, Vocational	1123	1245	1047

Category of Minor Injuries	Subcategory	2018	2019	2020
	Secondary School, Higher Vocational School			
	Higher Vocational, University	212	205	169
	No data available	0	0	28
Nature of Injury	Dependent on the Injured Person	1086	1304	1091
	With/without influence	177	173	160
	Independent of the Injured Person	124	79	84
	No data available	87	57	12
Severity of Injury and Recovery Method	Minor Injury - Home Recovery - No Disability	1096	1181	955
	Complicated and Multiple Injuries - Longer Hospitalization - Possible Disability	355	422	352
	No data available	23	10	40
Time of Occurrence (Month)	January	148	222	170
	February	100	107	145
	March	140	105	97
	April	73	93	79
	May	120	150	70
	June	120	138	110
	July	137	136	156
	August	110	132	99
	September	169	143	113
	October	139	160	127
	November	4	131	91
	December	4	93	90

Category of Minor Injuries	**Subcategory**	**2018**	**2019**	**2020**
	No data available	210	3	0
Time of Occurrence (Day)	Monday	294	315	252
	Tuesday	262	317	267
	Wednesday	233	272	224
	Thursday	268	264	213
	Friday	241	257	219
	Saturday	119	127	107
	Sunday	53	61	60
	No data available	4	0	5
Age of the Injured	Up to 30	276	340	265
	30 to 40	344	367	326
	40 to 50	387	395	344
	50 to 65	462	509	412
	Over 65	0	1	0
	No data available	5	1	0
Length of Work Experience of the Injured	Up to 10	525	660	511
	10 to 20	356	369	352
	20 to 30	312	281	258
	30 to 40	228	237	168
	Over 40	19	20	17
	No data available	34	46	41
Gender of the Injured	Male	977	1054	899
	Female	496	559	448
	No data available	1	0	0

Conclusions on the analysis of the state of occupational safety and health in the Republic of Srpska:

- The lack of a unified database on work-related injuries and a unified analysis of their sources and causes hampers the development of occupational safety and health measures.
- Further development and improvement of legislative regulations (alignment with European standards, issuance of regulations for high-risk activities: construction, forestry, etc.).
- Strengthening the capacity of institutions in the occupational safety and health system, especially in the field of labor inspection, to improve the implementation of occupational safety and health measures.
- Intensifying and improving the quality of cooperation within relevant institutions of the occupational safety and health system, with a focus on improving the role of occupational health services in monitoring the health status of employees.
- Organized education of employers and persons responsible for occupational safety and health at the employer's site in the field of prevention and improvement of occupational safety and health measures.
- Improvement of the procedure for reporting and recognizing occupational diseases, and organization of informational and media campaigns on the importance and characteristics of occupational diseases.
- Organization of regular consultations with representative representatives of employers and trade unions to determine priorities in addressing issues related to occupational safety and health (e.g., in woodworking industry, construction, mining, among employers using chemical substances in the production process, etc.).
- Organization of public thematic gatherings with social partners, employers, professional associations, and scientific institutions.
- Special emphasis and promotion of occupational safety and health for sensitive categories of workers (young and older workers, pregnant women, disabled workers, and people with disabilities or work limitations).
- Raising awareness of the importance of occupational safety and health through media campaigns to develop and promote a culture of prevention and the application of examples of good practice in the field of occupational safety and health.
- Development of lifelong and continuous learning models and the improvement of knowledge about occupational safety and health from an early age (preschool and school education, formal and non-formal education, etc.). (Republic of Srpska, Ministry of Labor and Veterans' and Disabled Protection, 2021)

Although the welfare implications behind these figures are immeasurable, good occupational safety and health practice helps businesses become more productive, competitive, and sustainable. Estimates show that for every euro invested in OSH, the return for the employer is approximately twice as high. The ILO established OSH as the primary international labour standard, and the Labor Law considers OSH as one of the basic legal principles within labour relations. According to the ILO, OSH generally aims to:

- Improvement and sustainability of the highest level of physical, mental and social well-being for workers of all occupations;
- Protection of health and workers in relation to working conditions;
- Protection of employees at work from risks arising from factors harmful to health;
- Designation of employees and protection of their integrity in the working environment, adaptation to their physical and psychological capabilities;
- Work should be adapted to people.

CONCLUSION

In the Republic Serbia and Republic of Srpska, there is no comprehensive database of workplace injuries. The lack of accurate data on workplace injuries affects professionals in occupational safety and health, scientists, all employees, trade unions, employers, doctors, insurance companies, as well as government institutions such as the Ministry. Decision-makers rely on data on workplace injuries to enact effective regulations in the field of occupational safety and health. Scientists use data to understand the causes and assess the necessary interventions for preventing and controlling injuries.

Workplace injuries incur costs for companies, employees, and society, making the minimization of workplace injuries not only a necessity but also an imperative. Due to the concerning situation regarding the number of workplace injuries, the Government of the Republic of Serbia decided to declare 2019 as the Year of Occupational Safety and Health to draw special attention to the importance of this field. Identifying the factors influencing the rate of injuries and the direct causes of injuries is the first step in determining the direction of preventive action.

However, we highlight the importance of renewed attention to workers exposed to high-risk and dangerous environments such as heavy machinery. The results obtained from this study allow for deeper analysis of the relationship between the number of injuries, mortality rate and other parameters of each economic sector. Some proposed measures to address issues related to injuries include:

Investment in training and education of workers (primarily younger categories of workers) and employers.

Stricter enforcement of compliance with and implementation of occupational safety and health measures (internal and external inspection controls in business entities).

Development of prevention strategies.

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NEW APPROACH TO THE METHODOLOGICAL PROCEDURE FOR PROFESSIONAL RISK ASSESSMENT

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Abstract: The lack of precisely defined procedures for assessing professional risk leads to the use of various methodologies with different methodological approaches to selecting and evaluating risk assessment indicators in practice. Consequently, ambiguous results and different risk assessments are obtained for job positions where identical tasks are performed and where employees are exposed to the same hazards and risks. This results in difficulty in controlling the validity of the obtained assessment. The subject of this study is the definition of an innovative methodological approach aimed at standardizing the criteria for assessing professional risk with a special focus on assessing the condition of the workplace environment.

Keywords: *methodology; assessment; occupational risk; condition of the workplace environment.*

INTRODUCTION

Risk assessment is the systematic identification and evaluation of hazards and harmful factors in the technological process that can lead to work-related injuries, occupational diseases, and work-related illnesses. Its aim is to determine ways to prevent, eliminate, or reduce the level of risk (Krstić, 2010). The Directive of the European Economic Community (EEC) stipulates that each country may adapt the methodology for risk assessment to its national legislation, i.e., to the laws and sub-legislative regulations applicable in its territory. Accordingly, by adopting the Law on Occupational Safety and Health and the Regulation on the Method and Procedure for Risk Assessment in the Workplace and Work Environment, a procedure for risk assessment without precisely defined methodology was adopted. However, in some European countries, there are specific regulations on the method and methodology for risk assessment. In Slovenia, the procedures and content of risk assessment are defined by the Regulation on the method of preparing the risk assessment statement. The regulation does not specify the methodology and methods for risk assessment, but it is a requirement that the methodology must be verified by the Ministry of Labour. This means that the employer, legal entity, or natural person engaged in the process can choose the methodology and submit a verification request to the competent Ministry. In Croatia, the methodology is defined by the Regulation on the preparation of hazard assessments, according to which risk levels are assessed as low, medium, and high. In Bosnia and Herzegovina, risk assessment is carried out in accordance with the Rules on risk assessment, which determine the risk level from insignificant to very high using the matrix method. In Montenegro, the procedure for risk assessment is regulated by the Regulation on the method and procedure for risk assessment in the workplace, but without a defined methodology. A similar situation exists in North Macedonia, where the risk assessment process is defined by the Regulation on the preparation of safety statements, its content, and the data on which the risk assessment should be based. However, such a risk assessment approach allows for significant subjectivity without considering all factors that influence the level of risk, especially the elements of the condition of the workplace environment. Namely, the Regulation on preventive measures for safe and healthy work at the workplace prescribes minimum requirements that the employer must meet to ensure the implementation of preventive measures for safe and healthy work at the workplace in terms of the organization of the work environment. Accordingly, the methodology applied in risk assessment must consider these elements when determining the level of risk.

The aim of this paper is to establish a methodology that would entail a unified methodological procedure for determining indicators and criteria for assessing professional risk. This approach would define procedures in the risk assessment process, select individuals for conducting the assessment, methods for evaluating indicators, and their processing in professional risk assessment. This would enable easy insight into the state of occupational safety and health and a simple review of the obtained results, thereby facilitating oversight in the implementation of protective measures. Consequently, it is necessary to adopt mandatory revisions of the Risk Assessment Act within a defined timeframe.

METHODOLOGICAL PROCEDURE

Risk Assessment Procedure is initiated by the employer through the adoption of a Decision to initiate the risk assessment process. Through this decision, the employer designates one or more persons responsible for conducting the assessment.

The competent person compiles a Risk Assessment Implementation Plan approved by the employer, which includes:

- legal basis for risk assessment;
- organization and coordination of implementation to the risk assessment procedure;
- list of legal and natural persons competent for risk assessment;
- risk assessment methods;
- phases and deadlines for risk assessment;
- method of collecting documentation required for risk assessment;
- informing the risk assessors;

- coordination among risk assessors;
- method of gathering information for risk assessment from employees;
- consultations with employee representatives;
- other actions necessary for the implementation of the risk assessment procedure.

Methodological procedure for risk assessment comprises a general and specific part. The general part includes: employer data, legal basis, methodology, description of the technological process, analysis of occupational diseases and injuries, and work organization recording. The specific part contains: hazard and risk identification, risk assessment, determination of measures to reduce the level of risk, conclusion, modifications, and amendments to the Risk Assessment Act.

When assessing risk, according to the Labour Law and company regulations, to standardize risk, it is necessary to consider the organization of work at the workplace (professional qualifications, work experience, age, health conditions, general characteristics of the work process, time spent at the workplace, organization of working hours and breaks), employee training and medical examinations, physical and psychophysiological demands.

Based on the identified hazards and risks in the workplace and work environment, the employer is obliged to determine the organization for implementing measures to eliminate risks and ensure the safe and healthy work of employees through a risk assessment document. The implementation of measures specified in the risk assessment document represents rights, obligations, and responsibilities for both responsible persons and employees. As the fundamental document in the field of occupational health and safety, the risk assessment document allows the employer to assess the overall working conditions at each workplace, determine measures and priorities to improve working conditions, and eliminate or minimize risks. This written document serves as the basis for creating appropriate instructions, guidelines, permits, and similar documents to ensure that employees perform their work safely.

Grouping hazards and harmful factors

When determining data on hazards and/or harmful factors in the workplace and work environment, it starts with reviewing the existing occupational safety and health conditions:

- expert findings on inspections of equipment, electrical and lightning installations;
- expert findings on inspections of working environment conditions;
- reports on previous and periodic medical examinations of employees;
- records of work-related injuries, occupational diseases, and illnesses;
- records of hazardous materials used during work;
- records of inspections and testing of personal protective equipment;

- inspection findings from conducted supervision;
- safety instructions and others.

After that, the identification of hazards and/or harmful factors takes place, as a crucial phase of risk assessment, determining their presence and impact on the health of employees. Specifically, it's necessary to recognize the hazard and/or harmful factor and establish whether it falls within "permissible values," meaning those values under which changes in normal system conditions and human organism do not exceed natural fluctuations and do not lead to undesired consequences. Identification and determination of hazards and/or harmful factors in the workplace and work environment are based on data collected from the employer's documentation, measurements and tests, observation and monitoring of the technological process, interviews with employees, and gathering information from other sources. For this purpose, surveys can be useful, where the assessor, in addition to identified hazards and harmful factors, records significant data for assessment, such as: locations of hazard and harm sources, exposure time, work activities, their duration and nature, etc. Based on the collected data, hazards and harmful factors are grouped, providing the basis for risk ranking.

Given that the Regulation on the Procedure and Method of Risk Assessment in the Workplace and Work Environment, as well as the Regulation on Records in the Field of Occupational Health and Safety, did not include re-grouping of hazards and harmful factors, there is a need, in line with improving the methodological approach, for a revision of hazards and harmful factors. Table 1 will facilitate this process.

Table 1. Hazards and Harmful Factors in the Workplace and Work Environment

Codes	**Hazards and Harmful Factors in the Workplace**	**Codes**	**Hazards and Harmful Factors in the Workplace**
I Mechanical hazards		**II Hazards associated with job characteristics**	
I01	Mechanical hazards that occur when using hand tools	II01	Work at height
I02	Mechanical hazards arising from the use of mechanical tools	II02	Work at depth
I03	Mechanical hazards arising from the use of production machinery	II03	Work in high or low-pressure atmospheres
I04	Mechanical hazards arising from the use of internal transportation equipment	II04	Work in cramped, confined, or hazardous spaces
I05	Mechanical hazards arising from the use of external transportation	II05	Work near water or below the water surface

	equipment		
I06	Mechanical hazards arising from handling objects	II06	Physical instability of the workplace
I07	Other mechanical hazards	II07	Slipping and tripping
III Dangers associated with the use of electrical energy		**IV Thermal hazards**	
II01	The danger of direct contact with live parts of electrical installations and equipment	IV01	Working with hot objects or materials
III02	The danger of indirect contact	IV02	Working with cold objects or materials
III03	The danger of thermal effects produced by electrical equipment and installations (overheating, fire, explosion, electric arc or sparking, etc.)		
III04	The danger of harmful effects of electrostatic discharge		
III05	Hazards due to lightning strikes and consequences of atmospheric discharges		
V Hazards of fire and explosions		**VI Harmful effects arising from the use of hazardous substances**	
V01	Hazards of fire	VI01	Explosive materials
V02	Hazards of explosions	VI02	Flammable materials
		VI03	Toxic substances
		VI04	Infectious materials
		VI05	Corrosive materials
		VI06	Radioactive materials
		VI07	Other hazardous substances
VII Chemical hazards, dust, and fumes		**VIII Biological hazards**	
VII01	Chemical hazards	VIII01	Bacteria
VII02	Dust	VIII02	Fungi
VII03	Fumes	VIII03	Parasites
		VIII04	Viruses

		VIII05	Other biological hazards
IX Physical hazards (noise)		**X Physical hazards (vibrations)**	
IX01	Noise	X01	Whole-body vibrations
		X02	Hand-arm vibrations
XI Physical hazards (electromagnetic radiation)		**XII Physical hazards (adverse effects of lighting)**	
XI01	Ionizing radiation	XII01	Inadequate lighting
XI02	Non-ionizing radiation	XII02	Excessive lighting
XIII Physical hazards (adverse effects of microclimate)		**XIV Adverse climatic influences**	
XIII01	High or low temperature	XIV01	Work outdoors
XIII02	High or low humidity		
XIII03	High air flow velocity		

XV Harmful effects resulting from physical strain		**XVI Harmful effects resulting from psychophysiological strain**	
XV01	Non-physiological body posture - prolonged standing	XVI01	Psychomotor strain
XV02	Non-physiological body posture - prolonged sitting	XVI02	Psychosensory strain
XV03	Non-physiological body posture - squatting and kneeling	XVI03	Monotony
XV04	Non-physiological body posture - twisting and bending (forward, backward, sideways)	XVI04	Emotional strain
XV05	Efforts or physical strains - manual handling of loads	XVI05	Intellectual (mental) strain
XV06	Efforts or physical strains - pushing and pulling loads	XVI06	Harassment (mobbing, bullying)
XV07	Efforts or physical strains - climbing and descending	XVI07	Burnout
XV08	Efforts or physical strains - prolonged increased physical activities - heavy physical work	XVI08	Responsibility for human lives and property
XV09	Efforts or physical strains - fast-paced	XVI09	Responsibility for vehicle

	work		operation
		XVI10	Inadequate ergonomic design of the workplace
XVII Hazards related to work organization		**XVIII Other hazards and/or harmful effects**	
XVII01	Shift work	XVIII 01	Harm caused by third parties (violence towards counter staff, security personnel, etc.)
XVII02	Night work	XVIII 02	Working with customers and money
XVII03	Overtime work	XVIII 03	Working with animals
XVII04	Field work	XVIII 04	Working with firearms
XVII05	Time-normed work	XVIII 05	Other hazards and/or harmful effects
XVII06	On-call duty for interventions		

This kind of systematization enables a more precise identification and classification of hazards and risks, reducing the possibility of accidental omissions in risk assessment. Additionally, it allows for clearer definition of different types of hazards and risks, thereby improving risk assessment and management. In this way, thermal hazards are considered as a separate category, facilitating better understanding and treatment of thermal risk factors.

METHODS OF PROFESSIONAL RISK ASSESSMENT

After identifying and analyzing hazards and/or harmful effects, it is necessary to assess their intensity. There are several methods described in the literature for risk assessment, often tailored to specific types of technical systems or particular types of harmful events.

The latest experiences and recommendations from developed EU countries suggest that quantitative risk assessment should be introduced wherever possible and given much greater significance and application. There are a number of new models and recommendations that indicate how quantitative risk assessment can be relatively efficiently and simply carried out in the field of occupational health and safety. Effective risk assessment, in addition to the expert knowledge of the assessors, also depends on the alignment of the chosen method with the technology and work processes within the company.

Assessors should choose method which must be:

- recognized within professional teams and suitable for the group of specifical problems;
- based on uniform criteria;
- verifiable and easy to usefor the employer and employees;
- adapted to the Rulebook on the method and procedure for risk assessment in the workplace and in the working environment.

Given that the Rulebook does not define the method by which risk assessment will be carried out, modified methods based on recognized methods are most commonly used, such as:

- AUVA (*Allgemeine Unfallversicherungsanstalt*);
- BG (*Die gewerblichen Berufsgenossenschaften*);
- WKO (*Wirtschaftska-mmern Osterreichs*);
- Kinny;
- SME (*Small and Medium-sized Enterprises*) and others.

The significance of the modified AUVA and BG methodology lies in the systematic approach to assessing the state of the workplace environment as the primary element in determining the level of risk, which is fully compatible with the Regulation on preventive measures for safe and healthy work at the workplace, table 2.

Table 2. Elements for assessing the state of the work environment

Serial number	Elements for assessing the state of the work environment
1.	Working space and work surfaces
2.	Tools and equipment for work
3.	Raw materials, primary, auxiliary, and waste materials
4.	Hazards of electrical energy
5.	Hazardous substances
6.	Chemical hazards
7.	Biological hazards
8.	Noise
9.	Vibrations
10.	Electromagnetic radiation
11.	Lighting

12.	Thermal comfort
13.	Atmospheric and climatic influences
14.	Fire and explosion protection
15.	Passageways, access, and evacuation routes
16.	Organizational measures for safety and health at work
17.	Personal protective equipment
18.	Competence for safe work
19.	Provision of safety and health markings at work
20.	Provision of first aid
21.	Smoking, alcohol, and substance abuse prohibition
22.	Condition of sanitary facilities and rest areas, provision of first aid, and occasional heating of employees
23.	Inspection findings from conducted supervision
24.	Occupational injuries, occupational diseases, and work-related illnesses

Elements for assessing and evaluating risk according to this method are probably the probability of occurrence of hazards or harmful effects and the severity of potential consequences. Accordingly, the level of risk is defined as the product of the rank of the probability of an unwanted event and the rank of the potential severity of injury. The probability of occurrence of hazards or harmful effects depends on workers' exposure to hazards and harmful effects and on the state of the work environment (existing occupational safety and health conditions). Based on the level of compliance with occupational safety and health requirements, a quantitative assessment of the state of the work environment is determined. The risk level of the workplace is determined by the highest risk rank of individual hazards or harmful effects. Workplaces with risk ranks I and II are considered to have acceptable risk. Workplaces with increased risk are those with risk ranks III, IV, and V.

According to the Law on Occupational Safety and Health, a workplace with increased risk is defined as a workplace at height, a workplace in depth, a workplace in vehicle operation and internal transport (forklifts, cranes, conveyors, construction and agricultural machinery, etc.), and other workplaces identified in the employer's risk assessment document where, despite fully implemented measures in accordance with this law, there are circumstances that may endanger the safety and health of employees. Choosing an inadequate risk assessment method may lead to failure to recognize workplaces with increased risk that are legally defined.

The Rulebook on workplaces or jobs where the insurance period is calculated with increased duration is the basis for defining workplaces with increased risk. This regulation identifies workplaces or jobs where work is particularly difficult, dangerous, and harmful to health, despite all general and special protective measures prescribed by regulations in accordance with technological processes. These include mining, geological and mining exploration, ferrous metallurgy, non-ferrous metallurgy, foundries, forges, refractory material production, oil refining and liquid petroleum gas production, forestry and wood industry, chemical industry, production of explosives and explosive materials, river shipbuilding and ship repair, glass production, transportation, construction and maintenance of overhead and underground power lines, construction, printing industry, leather processing industry, textile industry, rubber industry, pharmaceutical industry, electricity production, battery production, meat industry, cable industry, work at low temperatures, underwater work, viscous product and cellulose production, chlorine and caustic soda production, municipal services, health institutions, wagon production, installation of technological equipment in thermal power plants and chemical industry, artistic activities, nuclear plants, and laboratories).

The Rulebook defines the procedure and methodology for preparing expert documentation to determine workplaces where the insurance period is calculated with increased duration. It is important to note that for healthcare institutions, there is a Special Collective Agreement for Healthcare Institutions, whose founders are the Republic of Serbia, autonomous provinces, and local self-governments. According to this agreement, the working time of employees is reduced proportionally to the harmful effects of working conditions on their health and work capacity, in accordance with the risk assessment and expert analysis conducted by the occupational health service. In addition to the jobs listed in the regulation related to increased insurance period, this regulation also adjusts the working hours for positions in pathology departments, forensic medicine, administering cytostatic therapy, operating and delivery rooms, hemodialysis units, intensive care units, and others.

Considering that every element of the work environment, under certain conditions, entails risk, there is potentially a large number of risk factors in the work environment system. The risk of the work environment system should be analyzed by observing the elements of the technological system. In the functioning of technological systems, workers are exposed to various influences and actions resulting from technological processes and operations within them. Also, since it is practically impossible to eliminate the occurrence of hazards and/or harmful effects, or to build fail-safe and perfectly ergonomic work equipment, it is necessary to choose an organization of the technological process that takes into account the conditions of the work environment, initial risk factors, and includes measures, procedures, and means for timely elimination and/or reduction of unwanted events.

CONCLUSION

Starting from the subject matter, which aims to standardize assessment criteria, and with the application of a new methodological approach, conditions for more efficient and effective management of occupational risk are achieved. This leads to a higher-quality internal and external supervision of the occupational safety and health system, all with the aim of reducing workplace injuries, occupational diseases, and work-related illnesses. Therefore, it is also concluded that in addition to the innovative concept of assessing occupational risk, which involves a unique methodological approach that considers the state of the work environment, it is necessary to introduce mandatory monitoring or revision of the Risk Assessment Act as a preventive measure to reduce workplace injuries and improve the OH&S system.

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ASSESSMENT OF PROFESSIONAL RISK OF RADIOLOGICAL TECHNICIAN

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Abstract: This paper presents the professional risk assessment of a radiological technician working at the Health Center in Vranje. The risk assessment method employed was a modified AUVA (Allgemeine Unfallversicherungsanstalt - Austrian Pulp and Paper Industry Method) and BG (Die gewerblichen Berufsgenossenschaften - German Trade Associations Method) methodology. According to this methodology, the analyzed workplace is identified as having an elevated risk.

Key words: *radiological technician, AUVA and BG methodology, professional risk assessment*.

INTRODUCTION

The aim of professional risk assessment is to identify critical points, procedures, conditions, and processes where worker safety and health might be compromised in the workplace and working environment, and to undertake appropriate measures to eliminate or reduce them to an acceptable level (Krstić et al., 2011). The risk assessment process is carried out for three reasons: moral principle - it is in human nature to act preventively and avoid potential undesirable events; legal obligation - legal acts mandate the implementation of risk assessments; good governance - maintaining a low incidence of undesirable events results in higher productivity and a better working atmosphere (Đapan, 2014). Organizations must identify all sources of risk, their areas of impact, resultant events, as well as causes and potential consequences. This is a critical step because risks not identified at this stage will not be included in further analysis (SRPS ISO 31000:2019). Risk assessments are conducted for each recognized hazard or detriment by comparing with permissible values in relevant safety and health regulations, technical regulations, standards, and recommendations (Krstić et al., 2013). If, after applied protective measures, the workplace still presents a risk, the Risk Assessment Act declares it a workplace with increased risk, for which risk assessors must provide a justification or basis for its classification (Jocić, 2008). The Regulation on workplaces or jobs where the insurance tenure is calculated with increased duration forms the basis for defining workplaces with increased risk. This regulation determines workplaces or jobs where work is particularly hard, dangerous, and harmful to health despite all applied general and specific protective measures according to technological processes (healthcare facilities). It is important to note that for healthcare institutions, the Special Collective Agreement for Health Institutions, founded by the Republic of Serbia, autonomous province, and local government unit, applies. This agreement adjusts the working hours of employees proportionately to the harmful effects of working conditions on health and working ability according to the risk assessment and professional analysis of occupational medicine services. Besides the jobs listed in the regulation related to increased insurance tenure, this regulation also adjusts the working hours for workplaces where there is exposure to open sources of ionizing radiation, work in angiography rooms, etc. Accordingly, a professional risk assessment for the position of a radiological technician was performed (Figure 1).

Figure 1. *Radiological Technician*

Radiological technician tasks are performed in the Radiological Diagnostics Service and include the following activities:

- Planning and requisitioning all materials needed for the operation of the service.
- Preparing monthly, periodic, and annual reports on the service's operation.
- Responsible for the proper use of equipment and is required to promptly report malfunctions.
- Independently performs patient imaging using X-ray machines.
- Independently performs imaging using fluorographs.
- Prepares all cassettes and other materials needed for imaging.
- Performs technical tasks in the darkroom needed for quality film imaging.
- Processes all exposed films.
- Maintains a service log and submits invoices and reports on time.
- Assists severely ill patients with dressing and undressing.
- Performs contrast methods and irrigraphy.
- Ensures cleanliness of X-ray machines and participates in their cleaning.
- In the absence of a medical technician-administrative worker, performs all their duties.
- Performs other tasks within the domain of a radiology technician's work.

METHODOLOGICAL PROCEDURE FOR RISK ASSESSMENT

The elements for risk assessment and evaluation using the AUVA/BG method are the likelihood of occurrence of a hazard or detriment and the severity of possible consequences. Accordingly, the risk level (NR) is defined as the product of the probability of occurrence rank (RV) and the severity rank (RP):

$$NR = RV \times RP \tag{1}$$

The probability of occurrence of a hazard or detriment depends on the exposure of the employee to hazards and detriments and the state of the working environment (existing state of safety and health at work). The rank of probability of occurrence of a hazard and/or detriment is determined as the product of the rank of exposure and the rank of the state of the working environment. The rank of severity of possible consequences is ranged from very light injury to light injury, moderate severe injury, severe injury, and fatal injury. The risk rank for each identified or possible hazard and/or detriment in the workplace and working environment is determined. When establishing data on hazards and detriments in the workplace and working environment, grouping of hazards and detriments was used according to the Regulation on the method and procedure for risk assessment at the workplace and in the working environment.

The risk rank of the workplace is determined by the highest risk rank of individual hazards or detriments. Workplaces with risk ranks I and II are considered to have an acceptable risk. Workplaces with increased risk are those with risk ranks III, IV, and V. Based on the assessed risks in the workplace and working environment, methods and measures for their elimination, reduction, or prevention are determined, as well as special health requirements that employees at workplaces with increased risk must meet, as well as employees who handle specific work equipment.

IDENTIFICATION OF HAZARDS AND DETRIMENTS AND RISK ASSESSMENT

Mechanical hazards arising from the use of work equipment include:

- Mechanical sources of hazard - Using standard medical, sanitary, and office supplies;

Hazards related to the characteristics of the workplace include:

- Possibility of slipping or tripping (wet or slippery surfaces) - Working in the radiological diagnostics service, going to other services, etc.

Hazards arising from the use of electrical energy:

- Working with electrical medical and office devices.

Biological detriments

- Bacteria, fungi, parasites, viruses, etc.

Physical detriments (radiation)

- Ionizing and ultrasonic radiation.

Detriments arising from psychophysiological efforts

- Non-physiological body position - prolonged sitting.

Detriments arising from psychological efforts

- Psychological burdens - stress - psychological burden caused by working conditions;
- Conflict situations, etc.

Detriments related to work organization

- Shift work;
- Night work;
- On-call readiness for interventions.

Other detriments

- Participation in traffic - commuting to work and during work hours performing work activities.

Based on the conducted procedure of recording work organization, applied safety and health measures, identification of hazards and detriments in the workplace and working environment, and ranking of risks, it has been assessed that the analyzed workplace has an increased risk. The increased risk is assessed based on the detriments of ionizing and ultrasonic radiation (26).

Table 1. Identification of Hazards and Harmfulness in the Workplace and Risk Ranking

Code	**Danger and/or Hazard**	**Posible consequences**	RI	RO	RV	RP	NR	Risk Rang
Physical Hazards (Radiation)								
26	**Ionizing and Ultrasonic Radiation** Jobs of a Radiology Technician	Damage to the Eye Lens, Skin, and Other Organs	3	1	2	5	10	III

Based on the risk assessment, the following characteristic protective measures are defined:

- Conducting health examinations;
- Using personal protection equipment when working with sources of ionizing and ultrasonic radiation.

Initial examinations are mandatory upon employment because workers must meet special health conditions in accordance with the requirements and conditions for the workplace regulated by the Regulation on the conditions for the sale and use of radioactive materials, X-ray apparatuses, and other devices that produce ionizing radiation. Periodic examinations are mandatory every 12 months.

Special health abilities that radiological technicians must have include:

- Unaided visual acuity of at least 0.8 in both eyes or if one eye is 1.0, the other can be 0.6; normal width of the visual field, spatial perception, normal motility and phorias, and fusions within normal limits;
- Good condition of hearing and balance senses;
- Good concentration, quick and adequate response in all situations, positive personality traits;

Absence of severe diseases of the heart and blood vessels, respiratory, digestive, and endocrine systems, absence of severe psychological, psychiatric, and neurological conditions and diseases, and diseases of the locomotor system.

Healthcare for workers should be continuous. In this regard, preventive examinations (systematic, targeted screenings, etc.), continuous monitoring of the psychophysical abilities of employees, and special training programs to increase psychophysical endurance and tolerance to stress (through various programs of recreation, training, etc.) are advised.

CONCLUSION

By assessing the occupational risk using the modified AUVA/BG method, it has been determined that the position of a radiology technician carries increased risk. Based on the identified hazards and harmful effects, measures for occupational safety, medical examinations, and personal protective equipment have been defined. By evaluating the risks, specific protective measures have been prescribed to minimize the risk to the lowest possible level. Reducing the risk also decreases the number of work-related injuries and the number of workdays an employee is absent, while achieving the employee's psychological well-being through the safe and secure execution of work tasks and the preservation of physical health.

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