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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 3rd EUROSA International Conference, held on 14-17 May 2025 in Vrnjačka Banja, Serbia.

The papers contained in this Proceedings represent current scientific and professional informations in the field of *Engineering and Occupational Safety Management, Environmental Engineering and Management; Fire Protection Engineerig and Management, Engineering and Management of Disaster and Emerency Protection, Good use of practice in protection* 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 2025 conference.

Vrnjačka Banja, May 2025

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ASSESSMENT OF SURFACE WATER POLLUTION BY HEAVY METALS IN SERBIA

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Abstract: The quality of surface waters in Serbia is systematically monitored by the Environmental Protection Agency as a competent authority. For the purposes of this publication, data on lead (Pb), copper (Cu), zinc (Zn), nickel (Ni), chromium (Cr) and cadmium (Cd) concentrations of the all monitored water bodies (2016-2022) were selected as indicators of the trends in surface water quality. Evaluation of the water quality was based on the limit values for priority and priority hazardous substances (Pb, Ni, Cd) in surface waters (Environmental Quality Standards - EQS) which are established by the "Official Gazette of RS", No. 24/2014 and "Official Gazette of RS", No. 50/2012 (for the Cu, Zn and Cr). Considering all metals, only a few percent of the values exceeded the MDK values, while over 90 % of the results indicate low pollution and good ecological status of the water bodies. The most polluted water samples were detected on the profiles Srpski Itebej (river Begej), Kraljevo and Raska (river Ibar) Novi Sad (channel DTD), Hetin (river Stari Begej), Jasa Tomic (river Tamis), Markovicevo (river Brzava), and Novi Becej (river Tisa). The highest levels of contamination were observed on the Vrbica profile (river Zlatica) in April 2019, with peak concentrations of Zn (9530 μg/L), Cu (3221 μg/L), and Cr (55.3 μg/L). In summary, elevated concentrations of heavy metals do exist but overall trends suggest relatively low pollution levels in the majority of monitored water bodies.

Keywords: *Heavy metals; Surface water pollution; Environmental Quality Standards; Serbia*

INTRODUCTION

Heavy metal pollution in the water resources has been a global ecological issue due to their high toxicity, persistence, tendency to accumulate and inability to degrade naturally. Sources of heavy metal pollution include natural processes, such as the breakdown of metal-containing rocks and volcanic eruptions, as well as human activities like urbanization, industrial development, agriculture and domestic activities through surface runoff, sewage, effluent discharge, mine drains, etc. These anthropogenic activities, disrupt existing biogeochemical cycles in both terrestrial and aquatic ecosystems and pose severe environmental hazards to the food chain due to their enduring presence in the environment. The accumulation of toxic heavy metals (metaloids) such as Cu, Ni, As, Pb, and Cd in organisms causes significant health risks across transferring between trophic levels and negatively impacting the health of living beings (Pujari & Kapoor, 2021).

Heavy metals are non-biodegradable and tend to accumulate and magnify within surface waters ecosystems posing serious health risks to consumers and to human health through the food chain. Their heightened toxicity leads to numerous negative impacts, such as the loss of microbial and aquatic ecosystems, chlorosis, inhibited germination and growth, reduced biomass production, impaired photosynthesis, decreased nutrient uptake, and the generation of free radicals that damage membranes and weaken cell structures in aquatic plants. In humans, heavy metal toxicity can result in neurological disorders, nervous system damage, multiple organ failures, Alzheimer's disease, cancer, and more. While the human body requires trace amounts of metals like Cu, Zn, and Fe for cellular and DNA-binding functions, elements such as Pb, Ni, Hg, As, Cr, and Cd can be dangerous due to their high atomic weights and densities, exceeding 5 g/cm^3 (Pandey & Kumari, 2023).

Increased Zn levels in water bodies is often consequence from the use of pesticides and fertilizers, along with waste from industries such as alloy production, dry batteries, printing, and mining. Cu is commonly used in electrical wiring, plumbing, alloy production, and heat exchangers, leading to higher environmental levels which affects water bodies. Cd is linked to industrial waste and solid waste (such as batteries, paints, and plastics) and is also released through the use of phosphate fertilizers. Its presence in the environment can vary, as it exists in different forms, including free ions and bound to organic material or sediments. Ni is used in alloys, batteries, and as a catalyst in chemical reactions (Stanojevic-Nikolic, 2024). Pb is one of the most toxic elements in surface waters and around 98% of Pb pollution is caused by anthropogenic activities. Dissolved Pb is potentially mobile, bio-accumulative and toxic and it has no biological function in living organism (Wei et al, 2023).

Heavy metals can accumulate in sediments, serving as persistent pollution reservoirs over time. Changes in environmental conditions, like variations in pH or redox potential, can cause these contaminants to be remobilized and reintroduced into the water column, presenting renewed threats (Sunjog et al, 2016). Therefore, there is an urgent need to investigate metal content in water and to implement relevant regulations.

Evaluating surface water quality is a crucial component of environmental monitoring and management overall. The Water Framework Directive (WFD) provides a strategic framework for future water policy initiatives within the European Union and candidate countries seeking EU membership (like Serbia). As the primary legislative tool in water management, the WFD has necessitated the adaptation of surface water monitoring programs which are one of the WFD's goals, with the primary aim to achieve good water quality (good ecological status) across all European waters.

Officially implemented on December 22nd, 2000, the WFD marked a new era in European water management by establishing a unique, coordinated framework for water protection throughout Europe. European waters are organized into large river basins managed collaboratively by the relevant member states. Effective cross-border river basin management requires strong cooperation and partnership among all member states. Consequently, the WFD seeks to harmonize water protection regulations. Continuous monitoring and reliable data are fundamental for identifying pollution sources, tracking changes over time and implementing effective remediation strategies for improving water status generally. In Serbia, the Environmental Protection Agency has been aligning its surface water status monitoring with WFD requirements since 2012.

For this research Pb, Ni, Cd, Zn, Cu and Cr concentrations were applied to assess whether the quality class of the observed water bodies meets the standards for good ecological status which provide conditions for the functioning of ecosystems, the life and protection of fish (cyprinids) and can be used for the following purposes: supplying drinking water with prior treatment of filtration and disinfection, bathing and recreation, irrigation, industrial use (process and cooling water).

MATERIALS AND METHODS

This article presents the surface water quality results derived from reports on the results of the quality assessment of surface and groundwater from 2016-2022 (Environmental Protection Agency, 2022). It includes organized data collected during the examination of biological quality elements used to evaluate ecological status and potential, along with physicochemical, chemical, and microbiological indicators of water quality in rivers, reservoirs, and groundwater across the Republic of Serbia. The assessment of surface water quality was conducted at 79 profiles across 47 watercourses, as well as at 6 profiles within the canal network and 2 reservoirs.

Typically, the water quality assessment is determined by comparing the measured results of various parameters against established water quality standards or guidelines. For this work, the results of the Cu, Zn, and Cr concentrations of surface water samples were compared with the threshold values (TV) of quality classes prescribed by the Regulation on Threshold Values for Pollutants in Surface and Ground Waters and Sediments and the deadlines for achieving them (Official Gazette of RS No. 50/2012). Threshold value is the EQS expressed as the concentration of an individual pollutant or a group of pollutants or pollution indicators in surface and groundwater which must not be exceeded in order to protect the environment and human health (Table 1). This regulation expresses limit values (TV) for Zn and Cu according to water hardness. After reviewing the results, it was determined that the water hardness in 95% of the samples ranged between 100 and 300 mg $CaCO_3$/L, and the limit values of 2000 µg/L for Zn and 112 µg/L for Cu were adopted.

The values of the priority and priority hazardous substances (Pb, Ni and Cd) were compared with the EQS values which are linked to the maximum allowed concentration (MDK) and to the values of average annual concentrations (PGK) of priority substances (Table 1). PGK is the average value of concentrations measured over the course of a year for individual pollutants or groups of pollutants in surface that must not be exceeded to prevent serious irreversible long-term consequences for ecosystems and the MDK is the maximum concentration of an individual pollutant or a group of pollutants in surface waters that must not be exceeded in order to prevent serious irreversible consequences for ecosystems. Both are prescribed by the Regulation on

Threshold Values of Priority and Priority Hazardous Substances Polluting Surface Waters and the Deadlines for Achieving Them (Official Gazette of RS No. 24/2014). Similar to Zn and Cu, the limit values for Cd are also dependent of the water hardness and the results are categorized into appropriate classes based on the water hardness values, and the corresponding criteria have been applied.

RESULTS AND DISCUSSION

The distribution of total metal concentrations is depicted in the box plots shown in Figure 1, while the descriptive statistics is presented in Table 1.

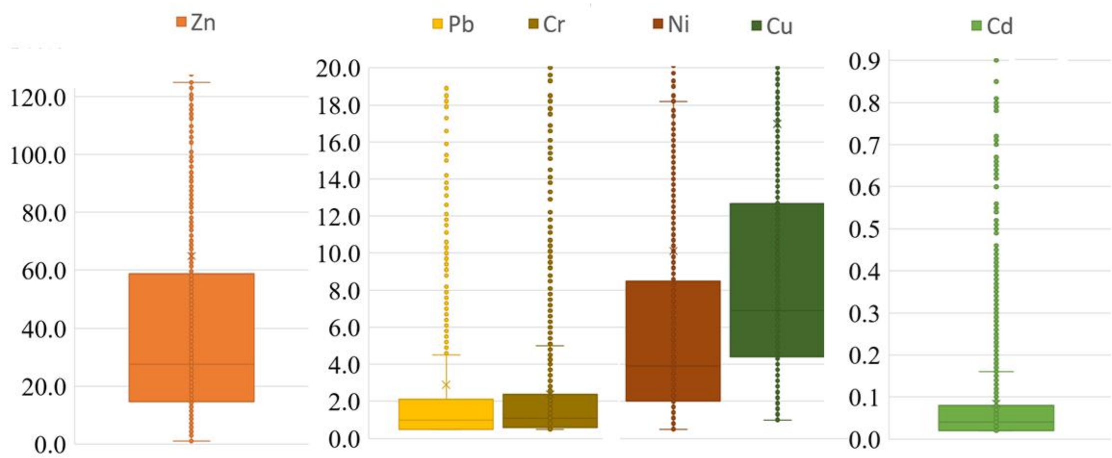

Figure 1. Box-plots (not all outliers and extreme values included) of the total metal concentrations detected in the surface waters from 2016-2022 in the Republic of Serbia.

Zn and Cu exhibited biggest values range followed by Ni. The profile with the highest Zn concentration was Vrbica, recording 9530 µg/L in 2019 (river Zlatica in the Tisa catchment area) (Table 1). However, this value was noted only once, and it may have resulted from localized one-time pollution since subsequent measurements were much lower. A similar trend was observed at the Markovicevo profile (river Brzava in the Danube-Tisa-Danube catchment area), which had a concentration of 2412 µg/L in 2022, and at Hetin (river Stari Begej in the Tisa catchment area), which measured 2305 µg/L in 2019.
For Cu, the profiles with the highest contamination were also Vrbica (3221 µg/L in 2019) (Table 1) and Markovicevo (842.1 µg/L in 2022), both identified only once. The highest total Ni concentrations were found at Novi Sad (555.1 µg/L in 2020 from the river Danube) and Markovicevo (428.5 µg/L in 2022) while the highest content of dissolved Ni was found in river Tamis on profile Jasa Tomic (225.2 µg/L in 2019). It was also evident that during 2019-2020 all dissolved Ni concentrations on this profile were among the highest of all measured at the same period in the country.

Very high Pb concentrations were recorded in the river Ibar of the Zapadna Morava catchment area, with profiles Kraljevo (169.1 µg/L in 2022) and Raska (236.3 µg/L in 2022) showing very high levels throughout the observed period due to long-term pollution and increased turbidity. Cr and Cd were detected in approximately 70 % of all water samples, with the highest concentrations found in Raska (Cr = 73.3 µg/L in 2016) and Badovinci (Cd = 3.14 µg/L from the river Drina) (Table 1).
Based on the total concentrations of the heavy metals analysed, the most contaminated profiles were Markovicevo, Hetin, Raska, Kraljevo, Jasa Tomic and Vrbica.

Table 1. Threshold values and summary statistics of the total and dissolved heavy metal concentrations in the surface waters in Serbia (2016-2022).

	Pb	Ni	Cd	Zn	Cu	Cr	Pb	Ni	(4) Cd	(5) Cd
	Total concentrations						Dissolved			
	µg/L									
Min	<0.5	<0.5	<0.02	<1	<1	<0.5	<0.5	<0.5	<0.02	
(1) Q_1	0.5	2.0	0.02	14.5	4.4	0.6	<0.5	1.2	<0.02	
Median	1.00	3.90	0.04	27.55	6.90	1.10	<0.5	2.2	<0.02	
(1) Q_3	2.1	8.5	0.08	58.8	12.67	2.37	<0.5	4.0	<0.02	
Max	236.3	555.1	3.14	9530	3221	73.3	9.4	225.2	2.2	
(1) IQR	1.6	6.5	0.06	44.3	8.27	1.77	<0.5	2.8	<0.02	
Range	235.8	554.6	3.12	9529	3220	73.5	9.15	224.9	<0.02	
Mean	2.90	10.11	0.08	65.01	16.97	2.38	0.55	4.56	0.03	
Count	2196						2348			
(2) PGK (2) MDK	*	*	*	*	*	*	1.2 14	4 34	0.25 1.5	0.15 0.9
(3) TV	*	*	*	2000	112	50	*	*	*	*

(1) Q1- value under which 25% of data points are found when they are arranged in increasing order. Q3- is the value under which 75% of data points are found when arranged in increasing order. Interquartile Range (IQR): the difference between Q3 and Q1,

(2) Regulation on Threshold Values of Priority and Priority Hazardous Substances Polluting Surface Waters and the Deadlines for Achieving Them (Official Gazette of RS No. 24/2014)

(3) Regulation on Threshold Values for Pollutants in Surface and Ground Waters and Sediments and the deadlines for achieving them (Official Gazette of RS No. 50/2012)

(4) Treshold values (PGK, MDK) for water hardness >200 mg $CaCO_3$/L

(5) Treshold values (PGK, MDK) for water hardness between 100 and 200 mg $CaCO_3$/L

As already mentioned, the total Cu, Zn, and Cr concentrations water samples, were compared with the TV of quality classes prescribed by the Regulation on Threshold Values for Pollutants in Surface and Ground Waters and Sediments and the deadlines for achieving them (Official Gazette of RS No. 50/2012) while the values of the Pb, Ni and Cd dissolved concentrations were compared with the MDK and PGK determined by the Regulation on Threshold Values of Priority and Priority Hazardous Substances Polluting Surface Waters and the Deadlines for Achieving Them (Official Gazette of RS No. 24/2014). Percentage of the total number of samples that meet the limit values regulated by the already mentioned guidelines are presented on the Figure 2.

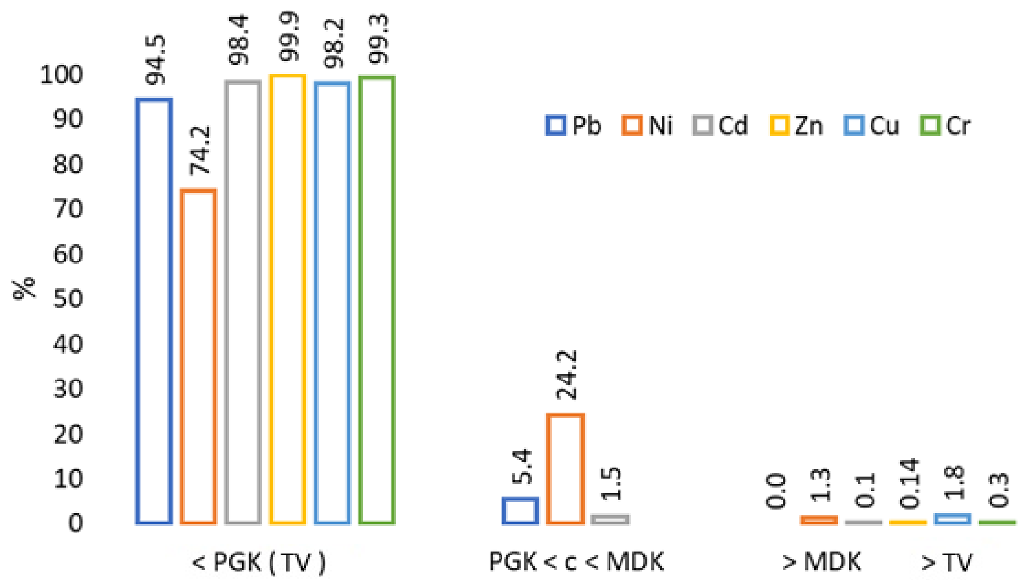

Figure 2. Percentage of the total number of samples that meet the limit values for good/moderate/poor/bad ecological status regulated by the Official Gazettes of RS No. 50/2012 (TV) and No. 24/2014 (PGK, MDK).

It illustrates that a very small percentage of all samples, in terms of total concentrations of Zn, Cu, Cr, and dissolved Pb, Ni, and Cd, exceeded the threshold values (TV) for Zn, Cu, and Cr or the maximum allowable concentrations (MDK) for Pb, Ni, and Cd, failing to meet the criteria for good ecological status. Ni was identified as the most problematic metal, with the highest number of samples (569 out of 2,348) exceeding the permissible concentration guideline (PGK), resulting in a classification of moderate to poor ecological status. Additionally, 1.3% of the samples were identified as water bodies with bad ecological status. As mentioned earlier, the Jasa Tomic profile accounted for 1.3% of these occurrences, being recorded four times during 2019-2020, which resulted in a bad ecological status indicating that the surface water cannot be used in any purpose. The same applies to the Hetin profile in 2019 (95.8 and 74.8 µg/L) and 2022 (108.7 and 94.5µg/L).
Compared to Ni, the highest percentage of samples that did not meet the criteria for good ecological status (1.8%), are those based on Cu content (40 samples). Among all profiles, the most problematic included Hetin 5 times, Jasa Tomic, Markovicevo, and Novi Becej 3 times

each, and Srpski Itebej 2 times.

CONCLUSIONS

Based on the concentrations of the observed heavy metals and relevant regulations, several profiles were identified as water bodies which didn't meet the criteria for good ecological status. The most problematic profile was Srpski Itebej (river Begej, Danube catchment), with 7 samples exceeding limits, followed by Novi Sad (Danube-Tisa-Danube canal Savino Selo), Hetin, Jasa Tomic, Markovicevo, and Novi Becej (river Tisa, Danube catchment), each with 6 problematic samples. The most polluted sample was recorded at the Vrbica profile in April 2019, showing the highest concentrations of Zn (9530 µg/L), Cu (3221 µg/L), and Cr (55.3 µg/L). It signifies a severely degraded aquatic ecosystem, with very low possibility of biodiversity and high levels of pollutants. This water body failed to achieve the minimum ecological quality standards. However, these elevated concentrations were observed only once and may result from recent contamination likely linked to anthropogenic activities.
This study highlights that although many monitored water bodies exhibited low heavy metal pollution levels, some water bodies particularly the Ibar, canal DTD, Velika Morava, Tamis and Tisa rivers demonstrated elevated concentrations that require special attention.
In summary, the continuous monitoring of surface water quality in Serbia ensures compliance with regulatory standards aimed safeguarding environmental and human health. While elevated concentrations of heavy metals do exist, overall trends suggest good ecological status in the majority of monitored water bodies.

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HEALTH PROFILE OF THE SELECTED PHARMACEUTICAL POLLUTANTS IN THE AQUATIC ENVIRONMENT

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Abstract: This article investigated whether pharmaceuticals such as Carbamazepine and 4-AAA (4-acetyl-amino-antipyrine) as water pollutants can cause health issues and toxicological risks. The OPERA models were used for detail characterization of pharmacokinetic profile and the SILIS-PTOXRA software was used to predict acute based toxicity on multiple linear regression models. The results indicate increased concentrations in the liver and organs of the fetus after consuming contaminated water. In addition, significant effects on aquatic organisms are also expected.

Keywords: *pharmaceutical pollutants; aquatic environment; health effect; ecopharmacovigilance*

INTRODUCTION

In recent years, pharmaceuticals, a significant group of emerging environmental contaminants, have garnered global attention. Their usage and consumption have been steadily increasing due to the development of new drugs, a growing population, and shifts in the age structure of the general population. For example, there are approximately 3,000 different pharmaceutically active compounds in the European Union (EU) that are approved for medical use and have been thoroughly examined for their safety and toxicology. However, the potential environmental impacts associated with their production and use are less understood and have recently attracted research interest (Petrović et al., 2014)

These pharmaceuticals are not managed properly and they can enter aquatic environments through discharging directly into drains. Their main route into the environment is through municipal wastewater, as only a small amount is metabolized after ingestion, while the majority is excreted unchanged or as metabolites that enter the sewage system. Consequently, the presence of pharmaceuticals in the environment raises numerous questions regarding their biological effects on flora, fauna, and humans. Overall, there is very limited knowledge about the long-term effects and behaviours of these pharmaceuticals.

The most frequently pharmaceuticals found in surface water are carbamazepine and metamizole metabolite 4-AAA (Radović et al., 2015). Metamizole is among the most popular analgesic and antipyretic drugs that have been used for more than 70 years and carbamazepine is widely used as antiepileptic and is antidepressant drug and is known as a very persistent substance (Moldovan, 2006).

The aim of this manuscript was to estimate the pharmacokinetic profile of detected compounds also including vulnerable populations such as pregnant women, after consuming a contaminated water as well as to estimate their aquatic toxicity potential.

MATERIALS AND METHODS

Radovic et al. (2015) developed the method for determination of 25 different organic contaminants and investigated the presence of pharmaceuticals in aquatic environment (ground water, surface water and sediment in Serbia). 4-AAA and Carbamazepine were measured and the maximum concentrations were obtained in rivers Tisa and Morava, the Danube tributaries, at about 1 km before the confluence (Table 1).

Table 1. The detected concentrations of selected pharmaceutical pollutants in surface water (rivers Tisa and Morava) (Radović et al., 2015)

Pharmaceuticals	Surface waters (ng/l)
4-acetyl-amino-antipyrine (AAA)	512
Carbamazepine	94

The OPERA models as a part of the CompTox Chemistry Dashboard project (Żandarek et al., 2024) were used for more detail characterization of pharmacokinetic profile of carbamazepine and 4-AAA. The CompTox Chemistry Dashboard is a web-based application and the data hub was developed by EPA's National Centre for Computational Toxicology. In OPERA simulations for detected compounds, we applied solve_pbtk and solve_fetal_pbtk modeling.
OPERA models were used to estimate the physiologically-based pharmacokinetic profile of detected compounds in aquatic environment. The first simulation for plasma (Css) and tissue (Cmax) concentration was done by using the solve_pbtk modeling. The solve_pbtk is a multiple-compartment PBPK model from EPA's httk R package (v. 2.2.2) that includes gut, artery, vein, lung, liver, kidney, and rest-of-body compartments. For the detected compounds, the following conditions of solve_pbtk modeling were applied: human (70 kg), exposure dose was estimated concentration per liter of water intake, exposure route oral, exposure interval hours (24 h), simulation length days 3. The second simulation for plasma (Css) and tissue (Cmax) concentration was done by using the solve_fetal_pbtk modeling type. The solve_fetal_pbtk is a multiple-compartment human PBPK model from EPA's httk R package (v 2.2.2) that includes maternal compartments, fetal compartments, and a placenta modeled as a joint organ shared by mother and fetus. The model is for simulating maternal and fetal chemical distribution for exposure via the oral or intravenous injection route starting at 91–280 days gestation. The solve_fetal_pbtk model is design only for human. For the cefepime-related compounds, the following conditions of solve_fetal_pbtk modeling were applied: human (70 kg), exposure dose was estimated concentration per liter of water intake, exposure route oral,

exposure interval hours (24 h), simulation length days 3, gestational day when exposure start (91).

Toxic Hazard and Risk Assessment, is a freely available software developed for the prediction (Żandarek et al., 2025) of toxicological endpoints. In our analysis, we used the SILIS-PTOXRA software to predict acute based toxicity on multiple linear regression models. The following ecotoxicological endpoints were observed:

• Acute Toxicity towards Zebrafish Embryo. Regression model to predict acute toxicity (pLC50) time toward zebrafish embryo.

• Acute Toxicity towards Freshwater Crustacean *Thamnocephalus platyurus*. Regression model to predict acute toxicity towards Freshwater Crustacean *Thamnocephalus platyurus* (*T. platyurus*).

RESULTS AND DISCUSSION

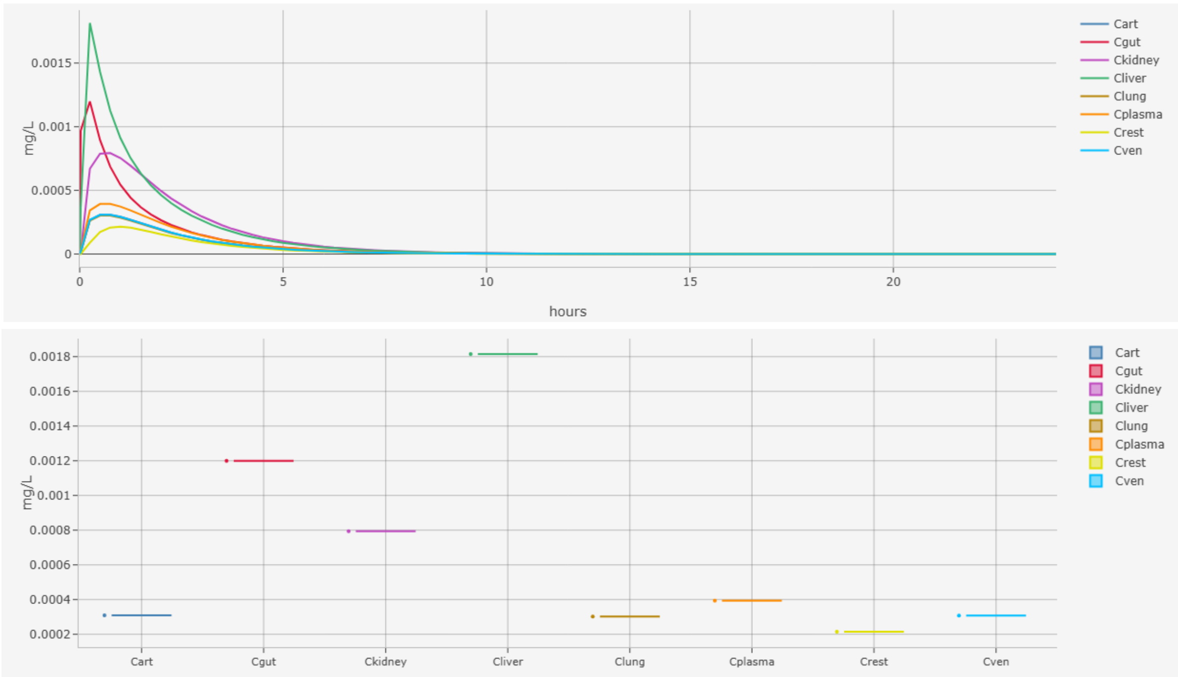
A graphical representation of the obtained results is given in Figures 1-2, showing the concentration profile curves (Css) for the display of the concentration profile graph (time series) for each compound, as well as the box plots of the Cmax values. The points in the box plot correspond to the compartment Cmax for selected compounds, and the boxes show the median Cmax and interquartile range for each compartment.

Box-plots of observed pharmaceuticals representing the predicted concentrations in human compartments are presented in the Figures 1a and 1b.

The solve_fetal_pbtk model predictions show that the maximal accumulation for 4-AAA is expected in liver (0.001815 mg/ml) and gastrointestinal system (0.001199 mg/l) (Figure 1a). This includes potential hepatotoxicity. In the case of carbamazepine (Figure 1b), the highest Cmax can also be expected in the liver (0.0003mg/l) and gastrointestinal system (0.0001mg/l).

Graphical illustration of detected compounds representing the predicted concentrations in human compartments for pregnant woman are presented in the Figures 2a and 2b. For 4-AAA, in a case of pregnant woman and woman in lactation (solve_fetal_pbtk model), higher concentrations can be expected in the kidneys (Cfkidney = 0.0009 mg/l; Ckidney = 0.0008 mg/l) and liver (Cfliver = 0.0009 mg/l).

There are especially higher concentrations on the fetus. In the case of administration of contaminated water during pregnancy, the distribution of carbamazepine in the liver (0.00018 mg/ml) and kidneys (0.00018 mg/ml) of the fetus can be expected (Figure 2b).



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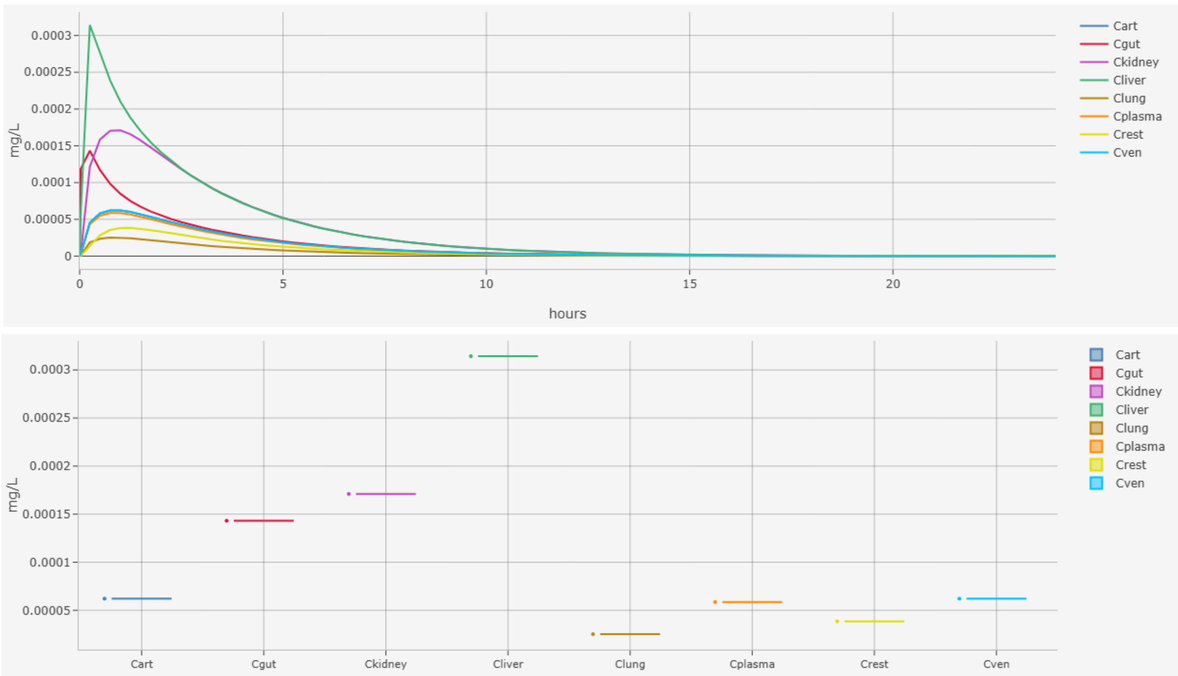
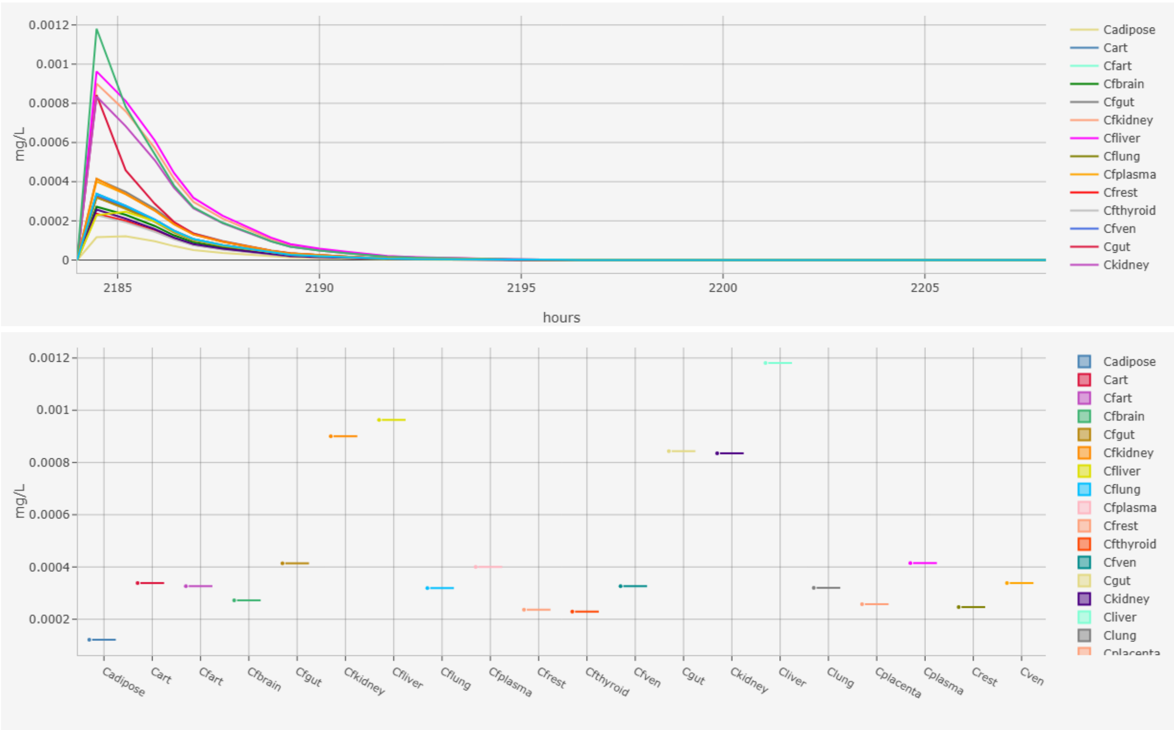


b)

Figure 1. Box-plots of detected compounds representing the predicted concentrations in human compartments: a) 4-AAA, b) Carbamazepine



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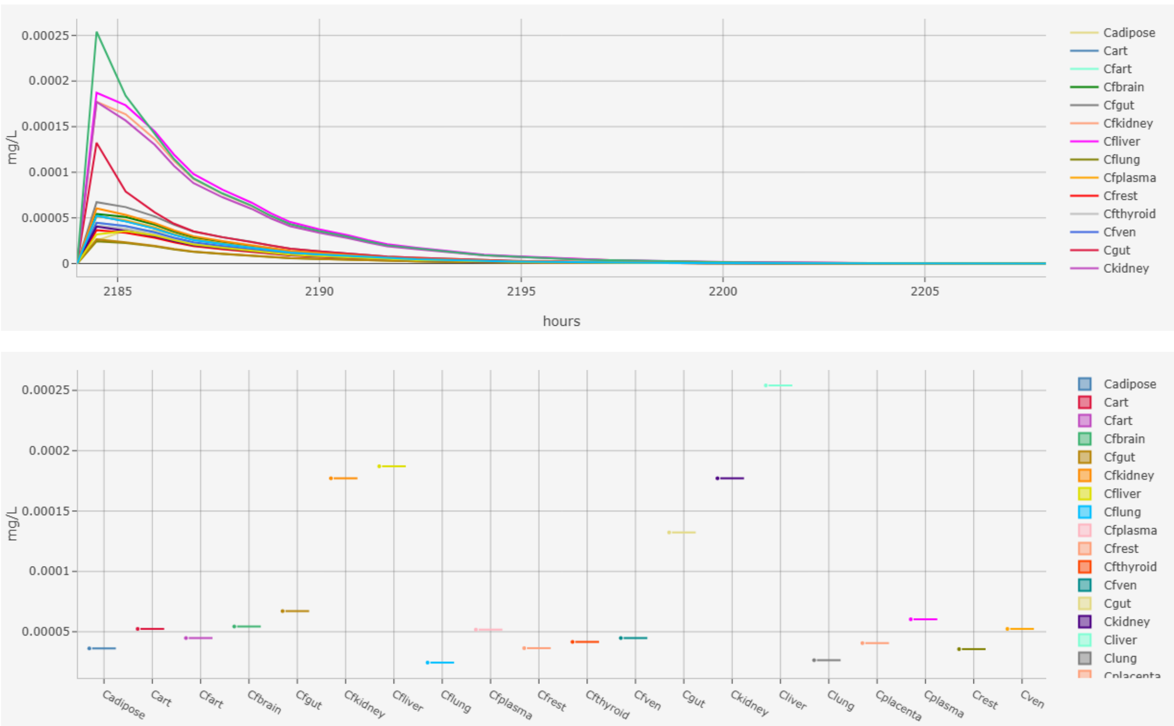

b)

Figure 2. Box-plots of detected compounds representing the predicted concentrations in human compartments for pregnant woman: a) 4-AAA, b) Carbamazepine

The predicted toxicology values (pLC_{50}) against *T. platyurus* and zebrafish are given in Table 2. A lower value of pLC_{50} corresponds to lower toxicity and vice versa. For the zebrafish model, the largest pLC_{50} is expected after 120 hours of exposure. In general, it can be seen that the predicted pLC_{50} values for *T. platyurus* are higher compared to zebrafish model.

Table 2. The predicted aquatic toxicity for *T. platyurus* and zebrafish models.

Molecules	pLC_{50}-*T.platyurus* (MLR)	pLC_{50}-048h-zebrafish_ (MLR)	pLC_{50}-096h-zebrafish_ (MLR)	pLC_{50}-120h-zebrafish_ (MLR)	pLC_{50}-132h-zebrafish_ (MLR)
4-AAA	1.754	0.707	-0.269	2.549	1.174
Carbamazepine	1.377	0.424	-0.534	2.115	1.548

CONCLUSIONS

The modern society is faced with the large use of drugs, their inadequate monitoring and increased presence in the environment. Pharmaceuticals as water pollutants can cause health issues and toxicological risks. The tested compounds (Carbamazepine, 4-AAA) may have increased concentrations in the liver and organs of the fetus after consuming contaminated water. In addition, significant effects on aquatic organisms are also expected. This study is the basis for further investigation of the expected health profile after administration of contaminated water with carbamazepine and 4-AAA substances.

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SLIPS, TRIPS, AND FALLS AS OCCUPATIONAL RISK FACTORS

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Abstract: Slips, trips, and falls represent one of the most common causes of occupational injuries, accounting for approximately one-third of all workplace accidents. The most frequent contributing factors include slippery floor surfaces due to spilled materials, reagents, or other liquids; wet footwear used by building occupants that introduces snow or mud; wet cleaning procedures; floor indentations; curbs near work equipment; stairs; various physical obstacles; and poor lighting conditions. Such events may result in injuries of varying severity and affecting different parts of the body-from tendon strains and contusions to bone fractures and, in extreme cases, fatalities. The aim of this paper is to analyze the methodology for testing the slip resistance of floor coverings in accordance with the BGR 181 and DIN 51130 standards, with the objective of implementing appropriate protective measures and reducing the level of occupational risk.

Keywords: *slipping; tripping; falling; resistance.*

INTRODUCTION

Slips, trips, and falls are among the leading causes of workplace injuries. According to statistical data from the Bureau of Labor Statistics (BLS, 2024), a total of 450,540 occupational injuries and 865 fatalities related to slips, trips, and falls occurred in the United States. Annually, approximately 65% of total working days lost in the U.S. are due to fall-related incidents involving employees, costing American society over 600 million dollars per year (NSW Government, 2022; EHS Software, 2024). Slips, trips, and falls are also the primary cause of occupational injuries across all industrial sectors in European Union countries (EU-OSHA, 2003). The most common contributing factors to slips, trips, and falls include: human error, wet and slippery surfaces, staircases, ladders, and inadequate lighting (ASSP, 2022). Specifically, the main causes of slipping in the workplace are associated with environmental conditions and floor surface characteristics: liquid or solid material spills, floor cleaning and washing, abrupt changes in flooring type, dust and sand on floors, inclinations, slopes and protrusions, poor lighting, rain, snow, ice, mud, etc. Falls generally occur when a person's center of gravity shifts, resulting in a loss of balance. Common causes of falls include obstructed vision, lack of attention to surroundings, and failure to use appropriate equipment and work tools (Yale University, 2024).

It is also important to consider both personal and organizational factors related to the type and condition of workers' footwear, as well as the existence and adherence to prescribed safety rules and procedures. Tripping occurs when a worker fails to notice an obstacle in their path, resulting in physical contact with the object, a loss of balance, and subsequently a fall. A trip may be triggered by changes in floor elevation of as little as 1 cm or more (Ontario Government, 2022). The most frequent causes of tripping in the workplace include: poor lighting, untidy work areas, uncovered cables, and uneven walking surfaces such as thresholds and stairs (CCOHS, 2024). Obstacles may be either permanent or temporary, and the most common include: damage and cracks in floors or floor coverings, changes in floor level, thresholds and stairways, technological openings in floors, power cables and other floor-level installations, temporarily placed objects and materials, open doors and drawers, scattered tools, and other items used during work processes. One of the most critical factors contributing to slips, trips, and falls is the type of flooring. Properly selected and correctly installed floor surfaces can provide adequate slip resistance, even in conditions where footwear with varying slip-resistant properties is worn and the floor surface is soiled or wet.

In this context, the present paper outlines the methodology for testing the slip resistance of floor coverings in accordance with the BGR 181 and DIN 51130 standard series.

Slip Resistance Testing According to BGR 181 and DIN 51130

The EU Construction Products Regulation requires that floor coverings must be safe for use, obligating manufacturers to provide a declaration of performance for the flooring within the technical documentation of the product. Exceptions to this rule include individually manufactured products or custom-made items (European Parliament, 2023). Flooring used in the workplace must demonstrate a minimum slip resistance. This resistance is typically expected to be 0.6 or higher in terms of the coefficient of friction (Ontario Government, 2023). Such criteria impose the need to meet specific requirements in various industrial systems where injury risks may be present.

The BGR 181 standard defines requirements for the slip resistance of floors in workrooms and workspaces where there is a risk of slipping. The slip-resistant properties of floor coverings are assessed through type testing in accordance with BGR 181 guidelines by walking on an inclined ramp. This method (DIN 51097 - testing of floor coverings for slip resistance under wet conditions), standardized through DIN 51130, involves the test subject walking forward and backward in an upright position on the floor sample. The test ramp is 600 mm wide and 2000 mm long, with an adjustable inclination along its longitudinal axis ranging from 0° to 45°. The angular velocity must not exceed 10° per second. The ramp may be raised either continuously or incrementally, with step adjustments of 0.5° controlled by the examiner. The ramp angle is displayed with a measurement accuracy of ±0.2° (Forbo, 2020).

Motor oil is applied to the floor surface, and the test subject wears standardized safety footwear with defined soles. The ramp angle is gradually increased until the subject begins to lose footing and is no longer willing to continue walking. The critical ramp angle at which slipping occurs is used as the indicator of slip resistance. According to the European standard EN 20345, specific requirements are defined for slip-resistant footwear based on the following test conditions:

1. Heel slip on a ceramic tile floor with a sodium lauryl sulfate solution - minimum friction 0.28,
2. Flat forward slip on the same ceramic tile surface - minimum friction 0.32,
3. Heel-forward slip on a steel floor with glycerin - minimum friction 0.13,
4. Flat forward slip on a steel floor with glycerin - minimum friction 0.18.

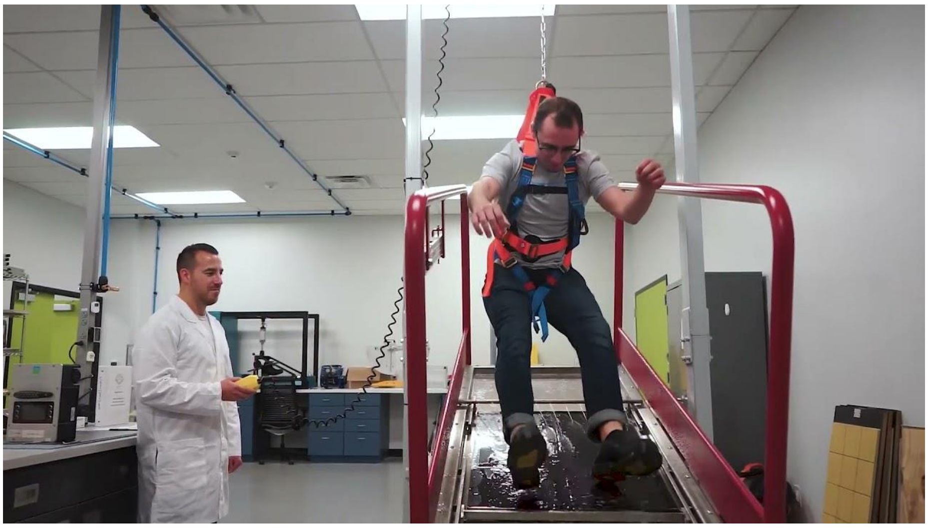

Figure 1. Slip Resistance Test

Floor coverings are classified into five slip resistance rating groups (R9 to R13), based on their performance. Floorings rated as R9 meet the minimum slip resistance requirements, while those rated as R13 offer the highest level of slip resistance.

Table 1. Slip Resistance Classes

Slip Resistance Class	Visual Representation	Lower Limit	Upper Limit
R9		6°	10°
R10		>10°	19°
R11		>19°	27°
R12		>27°	35°
R13		>35°	

Work areas and spaces where displacement is necessary require recessed zones below the walking surface to allow the drainage of substances that significantly increase the risk of slipping. These areas are marked with the letter "V" followed by a number indicating the minimum displacement volume.

Table 2. Floor Classification According to German Standard DGUV - I 8687

Classification	Minimum Slip Angle in ^{0}
A	12
B	18
C	24

Table 3. Slip Resistance Classes

Displacement Space Code	Minimum Displacement Volume Below the Walking Surface
V4	4 cm^3/dm^2
V6	6 cm^3/dm^2
V8	8 cm^3/dm^2
V10	10 cm^3/dm^2

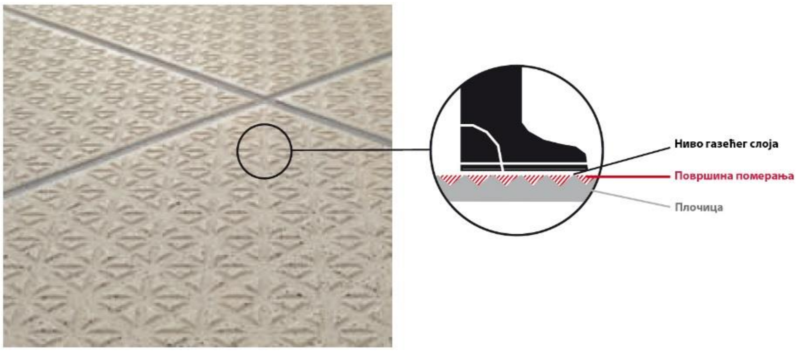

Figure 2. The displacement space is the cavity (marked in red) between the raised sections of the tile below the walking surface level

Areas prone to slip hazards (e.g., circulation zones in public buildings, retail and wholesale facilities, swimming pools, and sanitary spaces) require slip-resistant floor coverings. These typically consist of glazed or unglazed ceramic tiles with slightly rough, textured, or profiled surfaces. When small-format tiles are used, the high proportion of grout lines contributes positively to the overall slip resistance.

Slip-resistant coverings in publicly accessible areas are differentiated based on whether individuals walk barefoot or in footwear. Currently, there are no regulations in place for private use, such as residential bathrooms or kitchens.

Workrooms and Areas with Slip-Resistant Flooring in Accordance with BGR 181

Workrooms and areas are classified into five groups for assessment based on the degree and type of slip hazard. Floor coverings classified as R9 meet the lowest requirements, while the strictest requirements apply to those rated R13. Workrooms and areas that require displacement space below the walking surface-for the drainage of substances that significantly increase the risk of slipping-are designated with a “V” followed by a number indicating the minimum displacement volume.

In addition to general work areas, specific requirements are defined for 31 technological processes and spaces, including: 1 - margarine, edible fats, and oil production, 2 - dairy processing, 3 - chocolate and confectionery production, 4 - bread and pastry production, 5 - meat processing, 6 - fish processing, 7 - vegetable processing, 8 - food and beverage production, 9 - kitchens and dining halls, 10 - cold storage rooms, deep-freeze facilities, and depots, 11 - sales areas and retail stores, 12 - premises of public health institutions, 13 - laundries, 14 - animal feed production, 15 - leather goods and textile manufacturing, 16 - paint shops, 17 - ceramics industry, 18 - glass and stone processing, 19 - cement plants, 20 - storage areas, 21 - chemical and thermal treatment of iron, metals, and glass, 22 - metalworking workshops, 23 - vehicle maintenance workshops, 24 - aircraft maintenance facilities, 25 - sewer maintenance, 26 - fire stations, 27 - banks, 28 - parking areas, 29 - schools and kindergartens, 30 - off-road pathways, and 31 - designated parking surfaces.

Table 4. Workrooms and Areas with Slip-Resistant Flooring in Accordance with BGR 181

No.	Workrooms and Traffic Routes	Slip Resistance Class	Displacement Space Code
0	**General workrooms and areas**		
0.1 0.2	Entrance areas, indoor Entrance areas, outdoor	R9 R10 ili R11	V4
0.3 0.4	Stairways, indoor Stairways, outdoor	R11 ili R10	V4
0.5	Sanitary facilities (e.g., toilets, changing rooms, or restrooms) Break rooms (e.g., lounges, canteens) Medical rooms	R10 R9 R9	
1	**Production of margarine, edible fats, and oils**		
1.1	Fat melting	R13	V6
1,2	Edible oil refining	R13	V4
1.3	Margarine production and packaging	R12	
1.4	Edible fat production and packaging, edible oil bottling	R12	
2	**Milk treatment and processing, cheese production**		
2.1	Processing of fresh milk, including butter production	R12	
2.2	Cheese production, storage, and packaging	R11	
2.3	Ice cream production	R12	
. . .			
30	**Off-traffic roads**		
30.1	Roadways	R11 ili R10	V4
30.2	Loading ramps		
30.2.1	Covered	R11 ili R10	
30.2.2	Uncovered	R12	
30.3	Inclined ramps (e.g., wheelchair ramps, loading bridges)	R12	
30.4.1	Fueling area	R12	
30.4.2	Covered fueling area	R11	
31	**Parking areas**		
31.1	Garages, multi-story and underground, not exposed to weather conditions	R10	
31.2	Garages, multi-story and underground, exposed to weather conditions	R11 ili R10	V4
31.3	Outdoor parking areas	R11 ili R10	V4

Occupational Safety Measures for Preventing Slips, Trips, and Falls

Occupational safety and health standard 1910 (U.S. Department of Labor, 2022), which refers to walking-working surfaces, provides general requirements for surfaces such as aisles, storerooms, service areas, and work surfaces. This standard encompasses the following safety measures: maintaining floors in a clean, orderly, and dry condition; ensuring safe access and egress to walking surfaces; keeping working areas in good condition; and repairing hazardous floors as soon as possible. The European standard EN 13036-4:2011 classifies slip resistance levels for all types of floor surfaces. It is defined by the pendulum method, which assesses the surface properties of floors in both wet and dry conditions and estimates the potential level of injury risk. The Pendulum Test is a reliable method and provides a scale of values: 0–24: high slip potential, 25–35: moderate slip potential, over 35: low slip potential (Scandraft, 2023; OSHA, 2024). Key standards related to flooring within the European Union include: EN 14041 – Resilient, textile, and laminate floor coverings (essential characteristics), EN 14342 – Wooden floorings and parquet (conformity assessment and marking), EN 14411 – Ceramic tiles (definition, classification, characteristics, assessment and verification of constancy of performance, and marking). A significant number of potentially hazardous areas and situations related to slips, trips, and falls can be eliminated through relatively simple measures such as: proper design and organization of the work environment, workplace layout and hygiene maintenance, employee training, appropriate footwear, lighting, and noise protection, marking workplace obstacles with contrasting colors (Ontario Government, 2023).

Hazard avoidance should be addressed as early as the design phase of any new workplace. In existing workplaces, potential hazards should be identified and addressed with appropriate corrective actions, including: marking all floor level changes, delineating walkways with floor marking tape near revolving doors and staircases, using fall-prevention systems (SafetySign, 2024), installing anti-slip floor coverings at all critical points, ensuring adequate lighting, especially on stairs and in passageways, implementing drainage for wet floors and installing anti-slip walkways, organizing storage and material handling to prevent cluttering, organizing waste disposal during work processes, enforcing hygiene standards and proper tool and equipment storage, identifying slip, trip, and fall hazards, reducing worker exposure to such risks, ensuring effectiveness of noise control measures, and highlighting hazards using contrasting colors (Ontario Government, 2023), among others.

Figure 3. Anti-Slip Tape and Warning Marking

Self-adhesive anti-slip tape with an R13 slip resistance rating-the highest category according to DIN 51130-provides enhanced safety on stairs and platforms. Its coarse surface ensures secure footing, while the black and yellow color scheme enhances visibility in hazardous zones. The tape is durable, chemically resistant, adapts to surface structure, and is easy to apply. Each worker should: be trained to recognize and eliminate hazards that may lead to slipping or tripping; mark or report such hazards to the responsible person; follow procedures related to material storage and the disposal of waste generated during work processes; keep their workstation clean and orderly; minimize spillage, leakage, and floor contamination during work; immediately clean up any spilled liquids or scattered materials that could cause slips or falls for others; ensure the safety of colleagues while performing work tasks; wear appropriate and prescribed protective footwear; and verify that the workplace is adequately illuminated.

SRPS EN ISO 20346:2022 defines the basic and additional requirements for protective footwear intended for general use. These requirements include, for example, protection against mechanical hazards, slip resistance, thermal hazards, and ergonomic performance. This standard does not cover high-visibility properties due to their interaction with footwear and the characteristics of the working environment.

The Serbian standard relevant to slip protection for workers is SRPS EN ISO 13287:2009. Specific risks are addressed through complementary occupation-related standards (e.g., footwear for firefighters, electrical insulating footwear, chainsaw injury protection, chemical and molten metal splash protection, and protective footwear for motorcycle riders).

CONCLUSION

Research confirms that slipping, tripping, and falling are among the leading causes of occupational injuries, with significant consequences for employee safety and employer costs. These incidents are particularly prevalent in sectors characterized by high moisture levels, chemical exposure, uneven surfaces, and poorly maintained walking areas. The analysis of relevant standards, such as BGR 181 and DIN 51130, enables accurate risk assessment related to floor coverings and their classification according to slip resistance levels. The application of these standards not only provides a foundation for preventive measures but also promotes the integration of safety requirements in the design and equipping phases of workplace environments. In addition to technical specifications, the implementation of organizational and educational measures is essential, including regular employee training, selection of appropriate footwear, placement of visual warnings, and maintenance of optimal hygiene and lighting conditions. Introducing comprehensive protective measures that combine technical, organizational, and educational elements can significantly reduce the number of workplace injuries, near-miss incidents, and improve the overall level of occupational safety. This approach contributes not only to the protection of workers' health and lives but also to the long-term sustainability of business processes in accordance with modern occupational health and safety standards.

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PSYCHOLOGICAL DETERMINANTS OF SHIFT WORK TOLERANCE

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Abstract: Shift work is an essential component of modern industrial and service-based economies, but it is also associated with numerous health and psychosocial risks. While some individuals adapt well to non-standard work schedules, others experience significant difficulties. Based on empirical findings, this paper examines the main factors influencing shift work tolerance, such as age, sex, circadian preferences, personality characteristics, and prior exposure to shift work. It discusses the complex interplay between these factors, highlighting how younger age and evening-type orientation are generally associated with better short-term adjustment, whereas older workers may exhibit greater long-term health resilience. Personality traits such as extraversion, low neuroticism, and internal locus of control also contribute to improved tolerance. It emphasizes the importance of context—particularly occupational environment and shift design—in shaping outcomes. The paper concludes by proposing directions for future research and outlining practical implications for shift schedule optimization, personnel selection, and individualized intervention strategies aimed at promoting sustainable shift work practices.

Keywords: *Psychosocial risks; Work-related stress; Regulations; Guidelines; International labor organization.*

INTRODUCTION

In the contemporary global economy, shift work has become an indispensable element of many industries, facilitating uninterrupted operations in sectors such as healthcare, manufacturing, transportation, and emergency services. This trend toward a “24/7 society” is driven by economic globalization, technological advancement, and societal expectations for constant service availability. As a result, an increasing number of employees are engaged in non-standard work schedules—including evening, night, and rotating shifts—which, while essential for operational efficiency, present serious challenges for worker well-being.

Shift work, particularly night shifts, disrupts the body's natural circadian rhythm, undermines sleep quality, and interferes with social and family life. These disruptions have been linked to a host of negative outcomes, including heightened risks of cardiovascular and metabolic diseases, emotional distress, anxiety, chronic fatigue, and depressive symptoms. Socially, shift workers often report reduced family time, strained relationships, and feelings of isolation due to their irregular hours. Despite these well-documented risks, not all individuals respond to shift work in the same way. Substantial individual differences exist in the capacity to tolerate shift work, influenced by a combination of biological, psychological, and socio-environmental factors. Variables such as age, sex, chronotype, sleep habits, personality traits, familial responsibilities, and even genetic predispositions can significantly shape one's resilience or vulnerability to the adverse effects of shift work. For instance, individuals with flexible circadian habits and evening-type preferences generally adapt more successfully, while rigid sleep routines and morning chronotypes are associated with greater difficulties.

Understanding these individual differences is critical for improving shift schedule design, developing targeted interventions, and supporting workers' health and performance. Among the leading theoretical models developed to explain this phenomenon is the shift work tolerance

GENDER DIFFERENCES IN SHIFT WORK TOLERANCE

The connection between gender and tolerance to shift work has produced varied and often complex results. While several studies report no significant gender differences in aspects such as sleep quality, job attitudes, or satisfaction (Ritonja et al., 2019; Saksvik et al., 2011), the majority of available evidence leans toward greater tolerance among men.

In particular, women appear to be more vulnerable to sleep-related disturbances. Multiple studies report that female shift workers experience more frequent difficulties falling asleep, higher usage of sleep medications, and shorter sleep duration following night shifts compared to their male counterparts (Lecca et al., 2023; Tsou, 2022). One study, for example, found that women working night shifts for a year or more consistently reported less total sleep time than men, though the small sample size calls for cautious interpretation (Rotenberg et al., 2000).

Beyond sleep, men are more likely to adopt active, behavior-based coping strategies in response to shift work demands (Easton et al., 2024), which may buffer the adverse effects of irregular schedules. Additionally, longitudinal studies have shown more favourable outcomes among male shift workers in terms of reduced risk of disability pensions, lower mortality rates, better hormonal profiles, and lower rates of obesity, fatigue, and excessive sleepiness (Torquati et al., 2019).

However, this pattern is not without exceptions. A smaller number of studies found that female shift workers may actually face lower risks of certain chronic health conditions, such as cardiovascular disorders and hyperuricemia (Johnson et al., 2020), particularly when working in environments with lower exposure to physical and psychosocial stressors, such as noise and job insecurity (Torquati et al., 2019). These contextual differences in occupational environments may partly explain the lower disease risk reported among women, despite their higher vulnerability to sleep disruption.

CIRCADIAN TYPE AND SHIFT WORK TOLERANCE'

Chronotype—or an individual's circadian preference for morning or evening activity—has emerged as an important, though not entirely consistent, predictor of shift work tolerance. The majority of studies suggest that evening types are better suited to shift work, particularly night shifts. Individuals with low scores on morningness typically report lower sleepiness and drowsiness during night shifts (Ahn et al., 2024), greater sleep flexibility (Cyr et al., 2023), higher job satisfaction (Awan, 2013), and better self-rated adaptation and work performance (Burch et al., 2009). Conversely, morning types tend to struggle more with adjusting to shift work, often experiencing poorer sleep quality, reduced performance on night shifts, and heightened subjective fatigue. Interestingly, some studies have found that low morningness scores also predict lower job satisfaction and higher work-family conflict in rotating shift workers (Al-Hammouri & Rababah, 2023)., suggesting that eveningness may come at the cost of social and familial strain.

Despite the general trend favouring evening types, a few studies contradict these findings. For example, high morningness scores have been associated with greater long-term shift work tolerance (Saksvik et al., 2011), possibly due to better alignment with structured routines and social expectations. Morning types may also manage social variables more effectively, maintaining stability in mood, family arrangements, and overall satisfaction, despite struggling with sleep disruption. Moreover, evening types frequently report more difficulties with early morning shifts, which can limit their flexibility in certain work schedules (Saksvik et al., 2011).

PERSONALITY TRAITS AND SHIFT WORK TOLERANCE

Personality traits have been frequently examined as potential predictors of shift work tolerance, though the results are complex and sometimes contradictory. A predominant finding across multiple studies is that certain traits—including internal locus of control, extraversion, and high self-esteem—are positively associated with greater adaptability to shift work (Natvik et al, 2011; Storemark et al., 2013). These traits are typically linked to proactive coping strategies, higher resilience, and better regulation of stress in irregular schedules.

Conversely, high levels of neuroticism and related characteristics—such as trait anxiety, emotional repression, low positive affect, and a generally negative mood profile—have been repeatedly associated with lower shift work tolerance (Natvik et al, 2011). Individuals with such traits tend to report higher levels of fatigue, sleep disturbances, emotional instability, and job dissatisfaction when working non-standard hours.

Nevertheless, some researchers caution against overemphasizing the role of neuroticism, noting that highly neurotic individuals may report more negative experiences across various life domains, not just within the context of shift work (Hennig et al, 1998). In fact, there are broader concerns regarding the directionality of influence: it remains unclear whether personality traits predict poor adaptation to shift work, or whether prolonged exposure to shift work can induce changes in personality, such as increased irritability or emotional volatility (Saksvik et al., 2011). Despite these reservations, studies that have assessed the impact of neuroticism on shift work tolerance have generally applied multi-dimensional and well-constructed measures, including subjective well-being indices, physiological sleep and fatigue metrics, and even biological data such as salivary markers of circadian disruption (Costa, 2004). Still, the lack of longitudinal designs limits the ability to draw firm conclusions about causality. Moreover, some studies suffer from small sample sizes, such as the research by Hennig et al. (1998), which included only 88 participants.

IMPLICATIONS AND DIRECTIONS FOR FUTURE RESEARCH

Understanding individual differences in shift work tolerance has practical implications across several domains, particularly in personnel selection, vocational guidance, and the development of targeted interventions to support workers' adaptation to non-standard schedules. Tailoring interventions based on individual traits may significantly enhance their effectiveness, especially when implementing circadian-based strategies such as bright light exposure or melatonin supplementation (Lowden et al., 2019). However, studies suggest that these interventions may not be equally effective for all individuals—chronotype, age, and personality traits appear to moderate their impact (Moreno et al., 2022). For instance, younger shift workers tend to prefer moderately paced forward rotations and faster backward rotations, whereas older workers show improved outcomes—in terms of sleep quality, general well-being, and health—when working under rapid forward-rotating schedules (Ritonja et al., 2019). These findings highlight the importance of age-specific shift schedule design and the need for adaptive models that reflect the dynamic nature of individual circadian capacity.

Future research should strive to distinguish between general vulnerability traits (e.g., neuroticism as a predictor of poor sleep quality across contexts) and specific interactions between such traits and shift work environments. For example, rather than solely assessing whether individuals high in neuroticism struggle with sleep, it is more useful to determine whether shift work exacerbates these vulnerabilities relative to day work.

While creating personalized guidelines based on personality traits like morningness or neuroticism is complex—since individuals typically score high or low across multiple dimensions—there remains value in developing general recommendations for those with known susceptibilities.

A methodological concern for future research involves the frequent comparison of current shift workers to day workers or former shift workers, which may skew results due to the "healthy shift worker effect" (Knutsson, 2004). Individuals who remain in shift work are often those who are already more resilient, thus potentially underestimating the real impact of shift schedules. Addressing this issue requires the inclusion of appropriate control groups consisting of health-matched individuals, along with clear operational definitions and detailed reporting of the type and structure of shift systems being studied.

In conclusion, advancing our understanding of shift work tolerance demands not only better conceptual clarity and methodological rigor, but also an emphasis on interactional models—where the effects of shift work are seen as a product of both individual predispositions and specific organizational practices.

CONCLUSION

Shift work, as a defining feature of modern labour systems, poses substantial challenges to workers' health, performance, and overall well-being. However, as the literature consistently shows, not all individuals respond to shift work in the same way. This review has demonstrated that younger individuals tend to perform better in cognitively demanding tasks and show more flexibility in sleep–wake patterns, while older workers may benefit from experience-based coping strategies and, in some cases, exhibit greater health resilience. Gender differences are evident, with male shift workers generally reporting fewer sleep disturbances and more active coping strategies, though women may experience lower long-term health risks in safer occupational contexts.

Chronotype emerged as a particularly relevant predictor: evening types generally adapt better to night shifts in terms of sleep and performance, whereas morning types may cope better with social and emotional demands. Similarly, personality traits, such as extraversion, internal locus of control, and low neuroticism, appear to facilitate better shift work tolerance, although these effects are often moderated by environmental conditions and personal circumstances.

Despite the widespread use of the term, shift work tolerance remains inconsistently defined and operationalized across studies. This inconsistency has led to variability in findings and underscores the need for standardized measurement tools that distinguish between short-term adaptability and long-term resilience. Future research should also address context-specific factors, such as type of occupation, shift system design, and work demands.

From a practical standpoint, these findings have direct implications for occupational health policy, shift schedule design, and individualized interventions. Efforts to improve shift work tolerance should consider chronobiological principles, age-specific needs, and personality-informed strategies, while also being mindful of broader organizational and environmental influences. Ultimately, enhancing shift work adaptation is not a one-size-fits-all endeavour. By applying models and integrating individual differences into workplace design and support mechanisms, it is possible to reduce health risks, improve performance, and promote sustainable working conditions for those engaged in non-standard work hours.

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REAL-TIME MONITORING OF INDOOR AIR QUALITY: EMERGING SENSOR TECHNOLOGIES AND APPLICATIONS

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Abstract: Indoor air pollution remains a significant global health issue, driven by emissions from cooking activities, cleaning agents, construction materials, and the infiltration of outdoor pollutants. Traditional monitoring approaches, relying on periodic sampling, often overlook the dynamic fluctuations in indoor pollutant levels. Real-time sensor technologies present a transformative approach by offering continuous, high-resolution monitoring that captures temporal, spatial, and source-specific variations in indoor air quality (IAQ). This paper explores recent developments and future prospects in the application of real-time sensors for indoor pollution assessment. Focus is placed on critical pollutants, including particulate matter (PM), volatile organic compounds (VOCs), carbon dioxide (CO_2), nitrogen dioxide (NO_2), and formaldehyde, all of which are associated with adverse health effects. Real-time monitoring enables detailed characterization of pollutant behavior, identification of peak exposure periods, source attribution, and a better understanding of indoor-outdoor pollutant dynamics. Advances in sensor design have further enabled the integration of predictive modeling, supporting proactive indoor air management strategies. Applications extend to smart buildings, wearable monitoring systems, and public health initiatives. Current research is aimed at enhancing sensor precision, lowering costs, and broadening the range of detectable pollutants, ultimately contributing to improved indoor air quality management and risk mitigation.

Keywords: *Indoor air quality, Real-time sensors, Sensor technology, Environmental health*

INTRODUCTION

Indoor air pollution has emerged as a significant public health concern globally, with diverse sources contributing to the presence of pollutants that can have detrimental effects on human health and well-being [1]. Pollutants such as particulate matter (PM), volatile organic compounds (VOCs), nitrogen dioxide (NO_2), carbon dioxide (CO_2), and formaldehyde are commonly found indoors and originate from sources including cooking activities, cleaning products, tobacco smoke, building materials, and outdoor air infiltration [2]. The continuous exposure to indoor air pollutants has been linked to a range of adverse health outcomes, including respiratory diseases, cardiovascular disorders, allergies, and even certain cancers [3, 4].

Traditional methods of assessing indoor air quality (IAQ) have relied primarily on periodic sampling and laboratory analysis, providing snapshots of pollutant concentrations that often fail to capture the dynamic nature of indoor air pollution [1]. Real-time sensor technology represents a revolutionary approach to IAQ monitoring, offering continuous and high-resolution data that can capture fluctuations in pollutant levels over time, space, and in relation to specific sources [5, 6]. Real-time sensors provide a more comprehensive understanding of indoor air pollution dynamics, enabling researchers and policymakers to identify peak exposure periods, assess the contributions of different pollution sources, and evaluate the effectiveness of mitigation strategies [7].

The deployment of real-time sensors in indoor environments has facilitated significant advances in characterizing indoor air pollution. These sensors can detect a wide range of pollutants with high sensitivity and specificity, including ultrafine particles, volatile organic compounds emitted during cooking or cleaning, and gases such as carbon monoxide (CO) from incomplete combustion [2]. The ability of real-time sensors to continuously monitor pollutant levels allows for the identification of pollution "hot spots" within indoor spaces, highlighting areas where pollutant concentrations may exceed recommended exposure limits.

One of the key advantages of real-time sensor technology is its ability to provide insights into the relationship between indoor and outdoor air quality [5, 7]. Sensors can quantify the infiltration of outdoor pollutants into indoor environments and assess the impact of indoor activities on pollutant levels. Understanding this indoor-outdoor relationship is essential for developing effective strategies to mitigate indoor air pollution and protect human health [3].

In recent years, there has been a growing interest in leveraging real-time sensor data for predictive modeling and forecasting of indoor air pollution [5, 8]. By analyzing historical sensor data and incorporating factors such as occupancy patterns, outdoor air quality, and weather conditions, researchers can develop models to predict future pollutant levels [1, 6]. These predictive models have the potential to support proactive interventions and enable the implementation of real-time feedback systems to inform building occupants about IAQ conditions and potential health risks [3].

This review aims to provide a comprehensive overview of the current state of real-time sensor technology for indoor air pollution monitoring. We will explore the methodologies employed to characterize indoor air pollution dynamics, discuss the applications of real-time sensors in various indoor environments, and highlight ongoing developments in sensor technology that are shaping the future of IAQ monitoring and management. Additionally, we will examine the implications of real-time sensor data for public health, building design, and policy development aimed at improving indoor air quality and reducing the burden of indoor air pollution-related diseases.

Targeted indoor air pollutants

Indoor air quality monitoring targets several key pollutants that originate from various indoor sources and can significantly impact human health [3]. Common indoor air pollutants include gaseous compounds such as volatile organic compounds (VOCs), nitrogen dioxide (NO_2), carbon dioxide (CO_2), and formaldehyde, as well as particulate matter (PM) comprising dust, soot, and allergens. These pollutants are emitted from household products, building materials, combustion processes, and outdoor sources infiltrating indoor environments (Figure 1 and Shema1) [1, 9, 10].

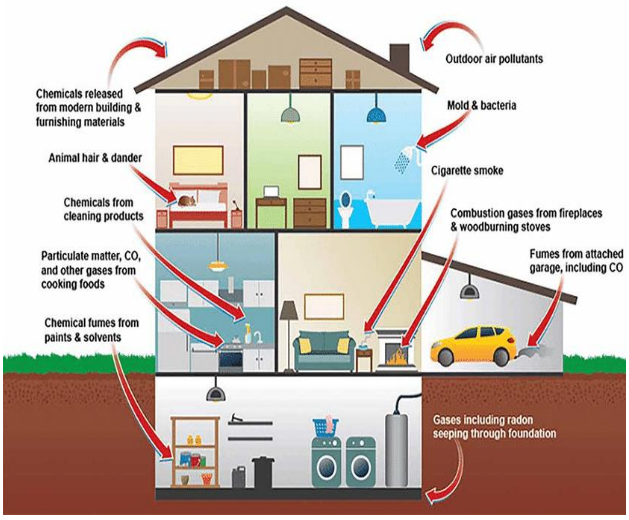
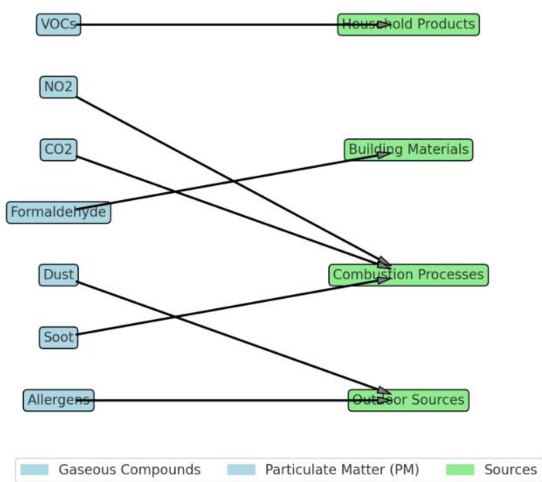


Fig. 1. Indoor house air pollutants



Shema 1. Targeted indoor air pollutants and their sources

Detection of gaseous air pollutants

Volatile Organic Compounds (VOCs). VOCs are a group of organic chemicals that evaporate easily at room temperature, leading to their widespread presence in indoor environments. These compounds originate from a variety of sources, including household products like paints, cleaning supplies, adhesives, and air fresheners. VOCs can also be emitted from building materials and furnishings, such as carpets and composite wood products. The health effects of VOC exposure range from short-term irritation of the eyes, nose, and throat to long-term effects like liver and kidney damage and central nervous system issues. Some VOCs, such as benzene and formaldehyde, are known carcinogens. Reducing VOC emissions involves using low-VOC or VOC-free products and ensuring proper ventilation.

Nitrogen Dioxide (NO_2). Nitrogen Dioxide (NO_2) is a reactive gas that forms primarily from combustion processes. Common indoor sources of NO_2 include gas stoves, heaters, and tobacco smoke. Exposure to NO_2 can irritate the respiratory system, reduce lung function, and increase the risk of respiratory infections, particularly in children and individuals with asthma. Long-term exposure to elevated levels of NO_2 can contribute to the development of chronic respiratory diseases. Mitigating NO_2 levels indoors involves ensuring proper ventilation, using exhaust fans, and regularly maintaining gas appliances to prevent leaks and incomplete combustion.

Carbon Dioxide (CO_2). Carbon Dioxide (CO_2) is a colorless, odorless gas that is a natural component of the earth's atmosphere. Indoors, CO_2 levels can rise due to human activities such as breathing and combustion from stoves and heaters. While CO_2 is not harmful at typical indoor concentrations, elevated levels can indicate poor ventilation and lead to discomfort, headaches, and impaired cognitive function. Maintaining adequate ventilation is crucial for controlling CO_2 levels indoors. This can be achieved through mechanical ventilation systems, opening windows, and using air purifiers.

Formaldehyde. Formaldehyde is a VOC that is widely used in building materials and household products. It is commonly found in pressed-wood products, glues, adhesives, and coatings. Formaldehyde is a potent irritant and a known human carcinogen. Short-term exposure can cause irritation of the eyes, nose, and throat, while long-term exposure has been linked to respiratory problems and an increased risk of cancer. To reduce indoor formaldehyde levels, it is essential to use products that are low in formaldehyde emissions, ensure good ventilation, and control humidity levels, as higher humidity can increase formaldehyde emissions from materials.

Maintaining indoor air quality by monitoring and controlling the levels of these gaseous compounds is essential for protecting human health. Proper ventilation, using low-emission products, and regular maintenance of combustion appliances are key strategies in minimizing the risks associated with mentioned chemical species.

Real-time sensors play a crucial role in monitoring gaseous pollutants indoors. These sensors continuously measure pollutant concentrations, providing insights into exposure patterns and identifying sources of indoor air pollution. For VOCs, sensors can detect specific compounds emitted from various sources like cleaning products and building materials. Nitrogen dioxide (NO_2) sensors are sensitive to combustion byproducts, aiding in identifying sources like gas stoves and heating systems. Carbon dioxide (CO_2) sensors assess ventilation efficiency and occupancy levels. Formaldehyde sensors detect this carcinogenic compound emitted by building materials and furniture.

Detection of particulate air pollutants

Particulate matter (PM) is a mixture of solid particles and liquid droplets found in the air. It includes a variety of components such as dust, soot, and allergens. These particles can vary in size, with some being large enough to see with the naked eye while others are so small that they can only be detected with an electron microscope. Understanding the sources and health impacts of these particulates is essential for maintaining good indoor air quality. Particulate matter is often categorized by size: PM10, PM2.5, and PM1.

PM10, PM2.5, and PM1. PM10: Particles with diameters that are 10 micrometers and smaller.

These can be inhaled and accumulate in the respiratory system.

PM2.5: Fine particles with diameters that are 2.5 micrometers and smaller. These can penetrate deeper into the lungs and even enter the bloodstream.

PM1: Ultrafine particles with diameters that are 1 micrometer and smaller. These particles can reach the deepest parts of the lungs and have significant health impacts.

Dust. Dust is one of the most common types of particulate matter found indoors. It comprises tiny particles from various sources, including soil, pollen, dead skin cells, textile fibers, and outdoor air that enters the home. Household activities like cleaning, cooking, and even moving around can stir up dust, making it airborne. While generally considered a nuisance, dust can pose health risks, particularly for individuals with respiratory conditions such as asthma and allergies. Inhaling dust particles, especially PM10 and PM2.5, can lead to symptoms like sneezing, coughing, and eye irritation. To manage dust levels, regular cleaning with a vacuum equipped with a HEPA filter, dusting with damp cloths, and using air purifiers can be effective strategies.

Soot. Soot, also known as black carbon, is a fine particulate matter that results from the incomplete combustion of fossil fuels, wood, and other organic materials. Indoor sources of soot include fireplaces, wood stoves, candles, and tobacco smoke. Soot particles, particularly PM2.5 and PM1, are extremely small, allowing them to penetrate deep into the lungs and even enter the bloodstream. Exposure to soot can cause a range of health problems, from respiratory issues like bronchitis and aggravated asthma to cardiovascular diseases and increased cancer risk. Reducing indoor soot levels involves using cleaner-burning fuels, ensuring proper ventilation, and avoiding the use of open flames and tobacco products indoors.

Allergens. Allergens are particles that can trigger allergic reactions and asthma attacks. Common indoor allergens include dust mites, pet dander, mold spores, and pollen. Dust mites thrive in warm, humid environments and are often found in bedding, upholstered furniture, and carpets. Pet dander consists of tiny flakes of skin shed by cats, dogs, and other animals. Mold spores are released into the air from damp, moldy areas such as bathrooms, basements, and kitchens. Allergens can cause symptoms such as sneezing, runny or stuffy nose, itchy eyes, and shortness of breath. Managing indoor allergens requires a multifaceted approach, including controlling humidity levels, using allergen-proof mattress and pillow covers, washing bedding regularly in hot water, and using air purifiers with HEPA filters.

Particulate matter such as dust, soot, and allergens can significantly impact indoor air quality and human health. Regular cleaning, proper ventilation, and the use of air purifiers are essential measures for reducing the presence of these particulates in indoor environments. By addressing the sources and taking preventive actions, individuals can create a healthier living space and minimize the adverse health effects associated with particulate matter.

Particulate matter sensors monitor suspended particles in indoor air. They detect fine and ultrafine particles that can penetrate deep into the respiratory system, causing health issues [3]. PM sensors aid in assessing exposure levels and identifying sources like cooking activities, smoking, and dust from carpets or furniture [2]. Advanced sensor technologies improve the accuracy and sensitivity of particulate matter detection, enabling better characterization of indoor air quality and supporting targeted interventions to reduce pollutant concentrations.

CHARACTERIZING INDOOR AIR POLLUTION USING REAL-TIME DATA

Real-time data from indoor air quality (IAQ) monitoring systems provide valuable insights into the dynamic characteristics of indoor air pollution, enabling a comprehensive understanding of pollutant distribution, sources, and health implications.

Temporal, Spatial, and Vertical Variation

Real-time sensors capture temporal variations in indoor pollutant concentrations over time, revealing peak exposure periods and fluctuations influenced by occupancy patterns and activities. Spatial variation refers to differences in pollutant levels across different locations within a building, influenced by room size, ventilation, and proximity to pollution sources. Vertical variation involves changes in pollutant concentrations at different heights within indoor spaces, such as ground level versus elevated areas. Real-time data allow for the characterization of these variations, aiding in targeted interventions to mitigate exposure risks [1, 9].

Source Contribution

Real-time sensor data enable the apportionment of pollutant contributions from various indoor sources. By analyzing pollutant profiles and source signatures, researchers can identify and quantify the impact of specific activities such as cooking, cleaning, smoking, and use of building materials on indoor air quality [2]. Source attribution helps prioritize interventions to reduce pollutant emissions and improve IAQ.

Indoor and Outdoor Relationship

Understanding the relationship between indoor and outdoor air quality is essential for effective IAQ management. Real-time sensors quantify the infiltration of outdoor pollutants into indoor environments and assess the indoor generation of outdoor pollutants (e.g., through combustion processes). This relationship informs ventilation strategies and pollution control measures aimed at minimizing indoor exposure to outdoor pollutants.

Indoor Air Pollution Forecasting

Real-time sensor data support the development of predictive models for indoor air pollution forecasting. By analyzing historical data and incorporating factors such as occupancy, outdoor air quality, and weather conditions, researchers can anticipate future pollutant levels. Indoor air pollution forecasting facilitates proactive interventions, enabling timely implementation of mitigation strategies to minimize health risks associated with indoor air pollution [2, 8].

Health Effect Assessments

Continuous monitoring with real-time sensors allows for better assessments of the health impacts associated with indoor air pollutants. By correlating pollutant exposure levels with health outcomes, researchers can identify potential risks and inform public health policies. Real-time data support epidemiological studies linking indoor air pollution to respiratory diseases, cardiovascular disorders, allergies, and other adverse health effects [3,4].

FURTHER DEVELOPMENT OF REAL-TIME SENSORS FOR INDOOR AIR POLLUTION

Advancements in sensor technology are driving the evolution of real-time sensors for indoor air pollution monitoring, with a focus on enhancing detection capabilities, improving accuracy, and expanding the range of detectable pollutants.

New sensor designs aim to improve sensitivity and selectivity for targeted indoor air pollutants. Miniaturization of sensor components allows for integration into compact devices, facilitating widespread deployment in indoor environments.

Wireless connectivity enables remote monitoring and data transmission, enhancing accessibility and scalability of sensor networks. Real-time data analytics play a crucial role in processing large datasets generated by sensor arrays, enabling rapid interpretation of pollutant trends and identification of pollution sources [1].

Emerging technologies such as machine learning and artificial intelligence contribute to sensor development by optimizing sensor performance, improving calibration methods, and enhancing data processing algorithms. These technologies enable adaptive sensor networks capable of self-calibration and real-time adjustment to changing environmental conditions.

Future directions in sensor development focus on multi-pollutant detection capabilities, robustness in complex indoor environments, and cost-effective mass production to facilitate widespread adoption. Collaborative efforts between academia, industry, and government agencies drive innovation in sensor technology, fostering the integration of real-time IAQ monitoring into smart building systems and public health initiatives [3].

CONCLUSION

The utilization of real-time sensors for indoor air pollution monitoring represents a significant advancement in environmental science and public health. These sensors enable continuous and high-resolution data collection, providing insights into the dynamic characteristics of indoor air quality. Through the characterization of temporal, spatial, and source-related variations in pollutant concentrations, real-time sensors facilitate targeted interventions to mitigate exposure risks and improve IAQ management.

Further development of real-time sensor technology is essential to enhance detection capabilities, increase accuracy, and expand the range of detectable pollutants. Advancements in wireless connectivity, data analytics, and machine learning contribute to the scalability and accessibility of sensor networks, supporting their integration into smart building systems and public health initiatives.

Overall, real-time sensors offer a transformative approach to understanding and managing indoor air pollution, with implications for policy development, building design, and public awareness. Continued research and collaboration in sensor development are crucial for advancing IAQ monitoring and protecting human health from the adverse effects of indoor air pollution.

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RESTORATION OF SODA PANS: A SUSTAINABLE APPROACH TO BIODIVERSITY CONSERVATION

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Abstract: Soda pans, rare and biodiversity rich alkaline wetlands, are among the most ecologically unique and vulnerable inland water bodies in Europe. Found predominantly in the Carpathian Basin, these habitats support specialized biological communities and provide critical ecosystem services, including biodiversity conservation and climate regulation. They are increasingly threatened by climate change and anthropogenic disruptions to natural hydrological regimes, particularly in Central Europe. This study evaluates restoration results across three reconstructed soda pans in Hungary, situated along the Hanság Main Canal, and compares them with three natural soda pans in Austria. In Hungary, water supply has been regulated through engineered sluices, leading to initial ecological improvements. Long term outcomes have varied, highlighting the complexity of balancing hydrological management with ecological integrity. The comparative analysis highlights the importance of maintaining natural salinity regimes and precipitation based hydrological inputs to sustain the unique biogeochemical and biological characteristics of soda pans. Furthermore, this paper emphasizes the necessity for adaptive water management strategies, particularly as many of these habitats are protected under international frameworks such as Natura 2000 and the Ramsar Convention.

Keywords: *Ecosystem; Water; Wetland*

INTRODUCTION

Changes in water levels occur naturally in many regions of the world, and numerous organisms have evolved to adapt to these variations. Due to disruptions in hydrological regimes, there has already been a noticeable decline in the number of soda pans, with some even disappearing across the globe (Alcocer and Escobar, 1990). Climate change in Central Europe, characterized by windier winters, calmer summers, rising summer temperatures, and decreasing annual precipitation, can lead to a range of biotic and abiotic changes in lake ecosystems (Dokulil, 2013).

Soda pans primarily rely on precipitation to meet their ecological water needs, which supplies sufficient water for the plants and animals living there. This helps sustain the ecosystem services wetlands provide, including climate regulation and biodiversity support (Cao et al, 2020). In recognition of ecological importance and vulnerability, many soda pans in the European Union have been designated as protected habitats under the Natura 2000 network (Boros et al, 2014,

European Commission). Several of these sites have also been recognized under the Ramsar Convention for their critical role in supporting migratory bird populations, and many are situated within national parks (Gavrilovic et al, 2018, Ramsar Convention Secretariat).
These vulnerable protected habitats represent some of the rarest and most distinctive types of inland saline water bodies, notable for their high alkalinity (pH > 9) and elevated concentrations of sodium carbonate (Boros et al, 2013). Extreme chemical conditions support unique biogeochemical processes and host highly specialized biological communities that are diverse from those in other saline aquatic systems (Boros et al, 2017). The unique chemical composition of soda lakes is shaped by geological, climatic, and hydrological factors, resulting in distinct ionic profiles that influence the biological communities (Bui, 2017, Lameck et al, 2025, Melese and Jebessa Debella, 2023). The average salinity of the soda pans fell within the hyposaline range (4 g L^{-1}). However, the minimum and maximum salinity values covered both the sub-hypersaline (0.5–3 g L^{-1}) and hypersaline (>50 g L^{-1}) categories (Boros et al, 2014). The dominant ions typically include sodium (Na^+), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and varying amounts of sulphate, chloride, potassium, calcium, and magnesium. Based on ionic dominance, soda systems have been classified into two primary types: "soda" and "soda-saline" (Boros and Kolpakova, 2018). In the "soda" type, Na^+ and HCO_3^- + CO_3^{2-} both exceed 25% of the total ionic content. The "soda-saline" type is similarly sodium-dominated, but although HCO_3^- and CO_3^{2-} exceed 25%, they are not the primary anions.
Understanding the diversity and vulnerability of these ecosystems is essential for developing effective conservation strategies, particularly in the face of accelerating climate changes. The Carpathian Basin holds the highest concentration of soda lakes and pans in Europe, with around 80 known sites distributed across Austria, Hungary, and Serbia. In Hungary, all soda pans receive national protection, and similar protective measures exist in parts of Serbia.

RESTAURATION OF SODA PANS IN HUNGARY

Shallow soda pans have seen a dramatic global decline, highlighting the urgent need for intensified conservation efforts. Since there are no known examples of comprehensive ecological restoration of permanent or semi-static soda lakes, the preservation and restoration of soda pans in Central Europe is of global significance.
Soda pan restoration and reconstruction projects, especially in Hungary, often focus on revitalization of alkaline wetland ecosystems, which are rare and important habitats for biodiversity. These projects aim to restore the unique hydrology and saline conditions of the soda pans, which are critical for specific plant and animal species, including migratory birds.
This paperwork examines the implementation of restoration efforts, detailing the methods used to rehabilitate the soda pans and their ecosystems. These examples offer valuable insights into the techniques and results of restoration initiatives in soda pan ecosystems. Two studies dealing with the effects of reconstruction and restoration of salt ponds were analysed (Lengyel et al, 2016; Boda et al, 2021). First study (Lengyel et al, 2016) focuses on three restored soda pans

in Hungary. Soda pan 1 is situated directly on the left side of the Hanság Main Canal. The open water surface is 64 ha, the average water depth is 23 cm (Boros et al, 2013). Sluices built on the Canal ensure the water supply from Lake Ferto to increase the water level and surface area of the pan. Soda pan 2 is located directly on the right bank of the Hanság Main Canal.

The open water surface of this turbid pan is 31 ha, and the average water depth is 8 cm (Boros et al, 2013). The management of this pan is similar to that applied for the soda pan 1. Soda pan 3 which can be found on the right side of one of the numerous drainage canals in the area. The open water surface of this turbid pan is 1 ha, and the average water depth is 25 cm (Boros et al, 2013).

All three analysed soda pans that were reconstructed were compared with the reference three natural soda pans in Austria. All pans are from subsaline to hyposaline, "soda" type (Na–HCO_3) with sulphate as the second most important anion. Their open water surface varied between 5 and 36 ha and the average water depth changed between 6 and 41 cm (Boros et al, 2013).

Despite initial promising outcomes, the current ecological status of soda pans 1 and 2 is now considered moderate. However, their natural physical, chemical, and biological characteristics remain suboptimal, largely due to the significant manipulation of water levels (Lengyel et al, 2016). Soda pan 3, despite initial promising outcomes, deviated significantly from its natural state, as its conductivity remained consistently low and biodiversity was high, dominated by freshwater species. This was primarily due to the absence of a natural hydrological regime (Lengyel et al, 2016). However, these lakes have significant conservation value, since they provide habitats for several vulnerable species.

The good ecological status of the soda pans should be completely restored. The absolute success of their reconstruction could be predicted after the restoration of natural hydrological and disturbance regimes.

Second study analysed restoration of soda pan (salt marsh) which is located near Balmazújváros, in the Hungarian Great Plain, in the middle of Hajdú-Bihar County. In 2012, two hectares of soda pan bed were restored to provide sufficient water supply and maintain the ecologically suitable hydrological regime of the pan. A restoration treatment (including streambed modification and installation of sluices for water retention purposes) was performed only along the section of Magdolna-ér (hereafter supply stream) that runs across the soda pan.

This study attracts further attention to the importance of the side effects and unwanted consequences of conservational treatments in aquatic ecosystems. After the streambed restoration, 1.5 livestock unit/ha have started to graze continuously on the soda pan (including Magdolna-ér). The area was utilized by ecologically sustainable high level grazing and the main goal of the soda pan restoration was achieved. However, due to treatments a single stress appeared on the site S (water retention along unchanged stream section), and a complex stress (water retention and grazing along modified stream section) appeared on the site C of the supply stream.

Both studies suggest that the restoration and reconstruction of soda pans are achievable, but they emphasize the importance of carefully managing several key factors. Specifically, attention must be given to the physical and chemical properties of the water, such as salinity, conductivity, and nutrient levels, to ensure they align with natural soda pan conditions. Additionally, it is crucial to monitor and support the local flora and fauna, ensuring the re-establishment of species that thrive in soda pan environments. The water inputs that feed the soda pan also require close management, as they play a critical role in maintaining the hydrological balance necessary for a healthy ecosystem.

The variation observed at the functional and phylogenetic levels might stem from the fact that each is influenced by distinct environmental factors. Properly addressing these elements can improve the chances of successful restoration efforts.

In the case of the Rusanda salt pan in the Republic of Serbia, one potential future solution for maintaining water levels during dry periods is the use of treated wastewater from the nearby spa. After appropriate treatment, this water could be redirected indirectly into the lake to help counteract the negative impacts of external water inputs, while avoiding the ecological disruptions that occurred in Hungary when natural water sources were used to replenish salt pans. To ensure the protection of the ecosystem, it would be essential to monitor the quality of the treated spa water, along with ongoing assessments of the lake's physical and chemical characteristics, as well as well as the flora and fauna, to ensure the health of the ecosystem.

CONCLUSIONS

The restoration and reconstruction of soda pan ecosystems, particularly in Hungary, have demonstrated both the potential and challenges associated with rehabilitating these unique and ecologically valuable habitats. The two studies analysed in this paper highlight significant insights into the methods and results obtained from efforts to restore soda pans.

The restoration of soda pans in Hungary, especially those located near the Hanság Main Canal, provides a valuable case study for understanding the complexities of restoring natural hydrological regimes and saline conditions. Despite initial improvements, the ecological status of the restored soda pans has been suboptimal, with issues such as altered water levels and the persistence of freshwater species. These findings highlight the need for a more holistic approach to restoration, ensuring that both physical and biological characteristics align with the natural soda pan environment. A key takeaway from the first study is the critical importance of reconstructing natural water dynamics, such as appropriate water depth, salinity, and hydrological regimes, to ensure the long term success of restoration projects.

The second study examining the restoration of a soda pan near Balmazújváros highlights the importance of careful management in ecological restoration efforts. While the use of streambed modifications and sluices achieved the goal of maintaining suitable hydrological conditions, the study also emphasizes the unintended consequences that can arise from such interventions, including the potential for grazing pressures and other environmental stresses. The presence of both single and complex stresses at different sites of the restoration area emphasizes the need for monitoring and adaptive management strategies that account for both expected and unforeseen impacts on the ecosystem.

Furthermore, these studies emphasize the significance of water quality in the success of soda pan restoration. The management of water inputs, particularly with regard to salinity, conductivity, and nutrient levels, is crucial for maintaining a healthy ecosystem. The potential future use of treated spa wastewater in the Rusanda salt pan (Republic of Serbia) offers an innovative solution to maintain water levels during dry periods, but it also underscores the need for careful monitoring of the water's quality and its impact on the ecosystem.

This study concludes that restoration efforts of three reconstructed soda pans in Hungary initially improved ecological conditions, long term outcomes have been diverse. These findings underscore the ecological importance and restoration challenges of soda pans, reinforcing the urgent need for improved water management approaches to preserve these fragile ecosystems and the vital services they provide.

Restoration efforts presented in this study align with SDG 6 (Clean Water and Sanitation) by promoting the sustainable management of water resources, conserving biodiversity, and ensuring the availability of freshwater ecosystems. The presented projects also contribute to SDG 13 (Climate Action) by addressing the impacts of climate change on vulnerable ecosystems, and SDG 15 (Life on Land) by restoring critical habitats and protecting biodiversity. Proper management of these ecosystems demonstrates how sustainable practices can help mitigate environmental degradation while promoting ecological resilience and biodiversity.

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DATE PIT-DERIVED BIOCHAR AS A COST-EFFECTIVE SOLUTION FOR SUSTAINABLE WATER TREATMENT

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Abstract: This study investigates the development of biochar from date pits, a lignocellulosic agricultural waste, for removing the emerging micropollutant isoproturon from water. Effects of various parameters on pesticide removal from water were examined. Three kinetic models were applied to analyse the experimental data: the pseudo-first-order model, the pseudo-second-order model, and the intraparticle diffusion model. The pseudo-second-order model provided the best correlation, suggesting that chemisorption may play a significant role in the adsorption process. The intraparticle diffusion model indicated the presence of multiple stages in the adsorption pathway, including external surface adsorption and gradual intraparticle diffusion. The results showed that date pits-based biochar is a promising, low cost, and environmentally friendly biosorbent, supporting multiply Sustainable Development Goals by providing an affordable solution for micropollutant removal from water and promoting the circular use of agricultural waste.

Keywords: *Isoproturon; Pesticide; SDG; Wastewater*

INTRODUCTION

The increasing detection of micropollutants in aquatic environments poses a serious challenge to water quality and ecosystem health (Tarigan et al, 2025). Pesticides are commonly used micropollutants in agricultural, domestic, and industrial applications which have been frequently identified in both surface and groundwater, as well as in effluents from wastewater treatment plants (WWTPs). These substances are often persistent under conventional activated sludge treatment conditions, either due to their resistance to biodegradation or the limited hydraulic retention times in such systems (Saleh et al, 2020). Therefore, several pesticides, including herbicides from the phenylurea family such as chlorotoluron, diuron, and isoproturon, have become environmental contaminants of concern (Mohanty et al, 2024).

Isoproturon, a persistent pesticide, is introduced into water systems through agricultural runoff, making its removal crucial for sustainable water management. This is moderately hydrophobic, water-soluble herbicide, with low soil adsorption, making it prone to leaching and runoff. Its presence has been reported in water environment, raising concerns over its ecological toxicity (Liu, 2001). Environmentally relevant concentrations of isoproturon have been associated with adverse effects on aquatic organisms, prompting regulatory bodies, such as the European

Union, to include it in the list of 45 priority substances under Directive 2013/39/EU within the Water Framework Directive 2000/60/EC (European Commission, 2013; European Parliament and Council, 2000). Therefore, it is important to focus on effective water treatment technologies and priority substances pollution reduction. To address this issue, adsorption has emerged as a promising and widely accepted water treatment technology due to its operational simplicity, absence of chemical reagents, and broad range of applicable adsorbents (Ogbeh et al, 2025). Activated carbon is traditionally the most used adsorbent, valued for its high surface area, porous structure, and rich surface functional groups (Babel and Kurniawan, 2003). However, the high production cost of activated carbon motivates the search for sustainable and low-cost alternatives (Hgeig et al, 2019). Biochar derived from agricultural waste presents an environmentally friendly and cost-effective solution, contributing directly to the United Nations Sustainable Development Goal (SDG) 6: Clean Water and Sanitation, which emphasizes pollution reduction and the implementation of effective water treatment strategies.

The use of date pit-derived biochar offers a new approach for removing priority pollutants such as isoproturon from aqueous media. This study evaluates the impact of key operational parameters on the adsorption performance including adsorbent dose, pH, initial pesticide concentration, contact time, and temperature, aiming to establish an efficient method for pesticide removal from contaminated water sources.

MATERIAL AND METHODS

Date pit-derived biochar was prepared to investigate the isoproturon removal from water under different operational parameters. Date pits were purified with boiled water, dried at 60°C for 24 hours, and then carbonized at 550°C for 30 minutes. After grinding into powder, they were washed with boiled water and dried at 110°C overnight. The resulting product was impregnated with a 30% phosphoric acid solution at a 3:1 (w/w) ratio. The study examined the effects of various parameters on pesticide removal, such as adsorbent dose, pH, initial pesticide concentration, contact time, and temperature.

The efficiency of isoproturon removal was evaluated using high-performance liquid chromatography coupled with a diode array detector (HPLC-DAD). Chromatographic separation was performed on an Eclipse XDB-C18 column (3.0 × 150 mm, particle size 3.5 μm). The column was maintained at 30 °C, with a constant flow rate of 0.4 mL min^{-1}. The injection volume was 10 μL. The mobile phase consisted of water (A) and acetonitrile (B). A binary gradient elution program was employed: starting with 25% B at 0 min, increasing linearly to 50% B at 5 min, and returning to the initial condition of 25% B at 7 min. Detection was carried out at a wavelength of 215 nm.

To investigate the adsorption behaviour of pesticides onto date pit-derived biochar, three kinetic models were employed to analyse the experimental data: the pseudo-first-order model, the pseudo-second-order model, and the intraparticle diffusion model.

The pseudo-first-order kinetic model is described by the following equation:

$$log(q_e - q_t) = log\, q_e - \left(\frac{k_1}{2,303}\right) t \quad (1)$$

This model involves the equilibrium rate constant k_1 (min^{-1}), which reflects the rate of adsorption. The value of k_1 can be obtained by plotting log ($q_e - q_t$) versus time (t), where q_e is the amount of adsorbate at equilibrium and q_t is the amount at time t. The amount of adsorbate at equilibrium qe (mg g^{-1}) is calculated by equation:

$$q_e = \frac{(C_0 - C_e)}{m_{ads}} \cdot V \quad (2)$$

where C_0 and C_f are the initial and final isoproturon concentrations, respectively (expressed in mg L^{-1}), V is the solution volume (mL) and m is the adsorbent dosage (g) . The pseudo-second-order kinetic model is expressed by the equation:

$$\frac{t}{q_t} = \frac{1}{k_2^2 \cdot q_e} + \frac{1}{q_e} t \quad (3)$$

where K_2 (g mg $^{-1}$ min^{-1}) is the pseudo-second order rate constant. It can be determined by plotting t/q_t versus t. This model assumes that the adsorption process may involve chemisorption as the rate-limiting step.

The Weber–Morris intraparticle diffusion model is represented by the following equation:

$$q_t = k_{md} \cdot t^{\frac{1}{2}} + C_i \quad (4)$$

In this model, K_i (mg g^{-1} $min^{-1/2}$) is the intraparticle diffusion rate constant, which is derived from the plot of q_t versus $t^{1/2}$. The constant C_i (mg g^{-1}) indicates the thickness of the boundary layer: a larger C_i suggests a more significant boundary layer effect, implying that surface diffusion might also influence the adsorption process (Pap et al, 2016).

RESULTS AND DISCUSSION

Physical characterization methods highlighted the potential of the biochar for efficient pesticide adsorption. The study also examined the effects of various parameters on pesticide removal, such as adsorbent dose, pH, initial pesticide concentration, contact time, and temperature. Solution pH is a key factor in the adsorption process, influencing both efficiency and the interaction between the pesticide and the adsorbent. The effect of pH on isoproturon removal was evaluated over a pH range of 3.0 to 10.0, using a 5 mg L^{-1} solution in contact with date pit-derived biochar for 60 minutes at room temperature. Optimal removal was observed at pH 7.00. The removal efficiency increased from 54.00% to 88.25% as the date pit-derived biochar dose rose from 1.00 to 4.00 g L^{-1}.
To investigate the adsorption behavior of pesticides onto biochar derived from date pits, three

kinetic models were applied to analyze the experimental data: the pseudo-first-order model, the pseudo-second-order model, and the intraparticle diffusion model (Figure 1). Batch adsorption experiments were conducted under varying contact times to evaluate the kinetics of the process. The fitting of the experimental data to these models helped identify the predominant adsorption mechanism. The pseudo-second-order model provided the best correlation, suggesting that chemisorption may play a significant role in the adsorption process. Additionally, the intraparticle diffusion model indicated the presence of multiple stages in the adsorption pathway, including external surface adsorption and gradual intraparticle diffusion.

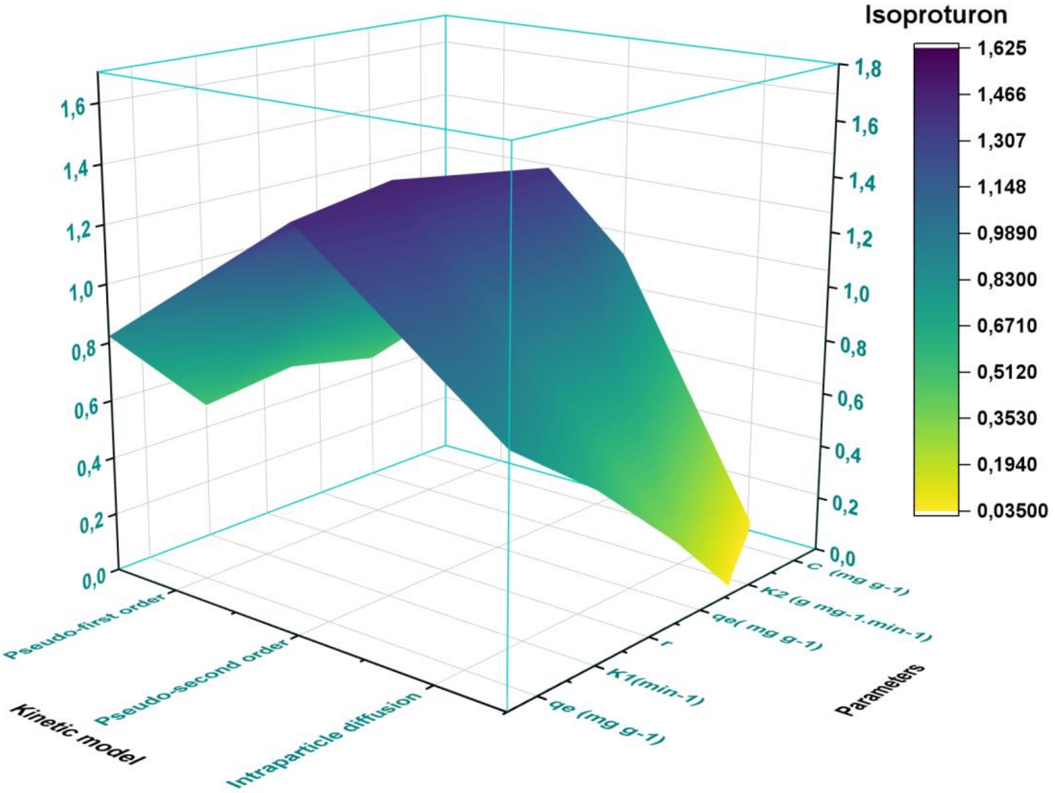

Figure 1. Kinetic models for isoproturon removal by date pits derived biochar from water

The regeneration study demonstrated that biochar prepared from date pits maintained good performance over multiple cycles, retaining over 69% efficiency for isoproturon after three adsorption-desorption cycles.
Economic evaluation showed that the date pit-based biochar is a cost-effective alternative to conventional treatment systems using commercial adsorbents. This aligns with SDG 6 by offering an affordable water treatment solution, especially for resource-limited areas, while contributing to waste minimization and promoting concept of circular economy (10Rs principle). Following these principles, an evaluation of every manufacturing phase of date pit biochar would yield feasible solutions to currently existing limitations with its long term sustainability (Kurniawan et al, 2023).

A SWOT analysis assessed the potential of date pit-based biochar for large-scale implementation. Strengths include low cost, high removal efficiency, and the abundant availability of date pits. Optimizing the landfilled amount of raw date pits as food waste contributes substantially to the 10Rs principles and SDGs accomplishment. Opportunities lie in its economical, environmentally friendly nature and potential for modification to enhance adsorption properties. However, challenges such as phosphoric acid consumption, limited regeneration capacity, and the production of potentially toxic sludges require attention. Furthermore, additional research is required on its performance in real world industrial systems where critical operational and configurational parameters must be thoroughly evaluated.

An innovative approach for the regeneration process needs to be taken into consideration for further investigations. A new environmentally responsible and sustainable methodology needs to be developed to enhance the performance of date pit biochar, maintain it stable throughout multiple reused cycles, and foster the use of green solvents (Alsawy et al, 2022).

The commercial feasibility of incorporating engineered biochar in large scale plants demands a proactive relationship and networking among water related stakeholders, scientific institutions, and other facilities to provide comprehensive data on the economic, social, and environmental benefits. This approach enables the adequate dissemination of knowledge between all involved parties to overcome the gaps of implementation and upgrading the sustainability of adsorption technologies.

An analytical and strategic assessment is necessary to look at and evaluate the significance of all external priority barriers to the application of the analysed affordable biochar in engineering practices (Do Thi et al, 2023). Other possible limitations should be taken into account as well to the technical assessment of the viability of the date pits based adsorption strategy. The application of different management tools such as PESTLE analysis could be observed as a screening approach which evaluates possible shortcomings of the proposed new wastewater treatment method and mitigating promptly prior implementation in large-scale wastewater practice. External factors are divided into Political, Economic, Social, Technological, Legal and Environmental dimensions. The aforementioned factors constitute a positive and mutual correlation.

CONCLUSIONS

This study concludes that date pits-based biochar is a promising, low cost, and environmentally friendly biosorbent, supporting multiply SDGs by providing an affordable solution for micropollutant removal from water and promoting the circular use of agricultural waste. According to these tools of assessment, the implementation of biochar based technologies may contribute to the simultaneous fulfilment of up to 11 goals of the 2030 Agenda. The future of biochar from lignocellulosic agricultural waste as a sustainable water treatment solution depends on optimizing its regeneration process, conducting real world testing, and performing the life cycle assessments to evaluate its overall environmental footprint. The main outcome of this study is to emphasize the extensive research necessary to provide valuable information on the sustainability of adsorption based wastewater assessment (legal, treatment, environmental, and techno-economical). Establishing a sustainable management framework and overcoming spotted drawbacks to the use of a novel, economically viable biochar in engineering practice is therefore possible.

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CHALLENGES OF THE LEGAL REGULATION OF CONTINUOUS PROFESSIONAL DEVELOPMENT OF OCCUPATIONAL HEALTH AND SAFETY EXPERTS

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Abstract: Contemporary trends in the field of occupational safety and health, including technological advancements, changes in work organization, and the emergence of new risks, necessitate the continuous professional development of experts engaged in occupational safety and health activities. Given that the concept of continuous professional development in this field has only recently been recognized within the national legislative framework, the aim of this paper is to highlight two key aspects: the opportunities and benefits that continuous professional development offers to occupational safety and health professionals, as well as the challenges related to the legal regulation and practical implementation of this concept. Through the method of analyzing relevant scientific literature and applicable legal provisions, the paper arrives at a series of conclusions that may assist the legislator in further regulating this issue and contribute to the effective implementation of the concept in practice.

Keywords: *Occupational Safety and Health; Regulations; Continuous Professional Development.*

INTRIDUCTION

Occupational safety and health is a complex scientific and professional field dedicated to the analysis of work processes and working conditions, their impact on workers' health, psychological and physical well-being, the identification of risks and possibilities for their management, the development of measures and solutions for risk minimization, as well as the evaluation of the effectiveness of protective measures (Saari, 1995). It also serves as a foundational element of the labor law concepts of decent and dignified work (Ristanović, 2011; Perić, 2011).

Starting from the fact that, along with technical, technological, organizational, and other measures and solutions, knowledge forms the fundamental basis for risk management and occupational safety (Taradi, 2015), experts working in this field differ in terms of educational profiles and the tasks they perform (engineers, chemists, doctors, managers, etc.) (Garrigou, Peissel, 2008). In some countries, the tasks and roles performed by experts from various fields are defined by law, along with the required academic qualifications for each profile (Booth et al., 1991). This is the case in the Republic of Serbia, where the Law on Occupational Safety and Health (2023) precisely defines which profiles of experts are authorized to perform occupational safety tasks in specific industries.

In addition to prescribing which expert profiles are authorized to perform occupational safety tasks, the national legislator has also introduced a legal obligation for the continuous professional development of these experts. This marks the first formal recognition of such a requirement in Serbia, yet it represents a logical step, considering that continuous professional development in the field of occupational safety and health is one of the key factors in ensuring high-quality worker protection and in preventing occupational injuries and diseases. Furthermore, it is evident that contemporary trends in the world of work—including technological advancements, organizational changes, and the emergence of new risks—demand the ongoing updating of knowledge and skills among professionals engaged in occupational safety and health.

The aim of this paper is to examine the existing legal framework regulating the continuous professional development of occupational safety and health experts, to identify the main challenges in its implementation, and to propose concrete recommendations for improving both legislation and practice. Particular attention will be devoted to the potential legal challenges related to the regulation of specific aspects of continuous professional development—an issue of particular importance given that a dedicated bylaw governing this area has not yet been adopted.

CURRENT LEGAL FRAMEWORK FOR THE CONTINUOUS PROFESSIONAL DEVELOPMENT OF OCCUPATIONAL SAFETY AND HEALTH EXPERTS

The issue of the acquired education of a professional engaged in occupational safety and health serves as the fundamental basis for all subsequent discussions regarding continuous professional development. Without this foundation, continuous development lacks meaning. Accordingly, the legislator has precisely defined the qualifications required for professionals to perform occupational safety and health duties across various sectors (Ilić Petković, 2020).

In sectors such as construction, agriculture, and mining, the employer is obligated to appoint an occupational safety and health advisor. This individual must hold a minimum of 240 ECTS credits obtained through academic or professional studies within the educational-scientific fields of technical-technological sciences or natural-mathematical sciences, specifically in disciplines such as biological sciences, environmental protection sciences, physical sciences, physical-chemical sciences, and chemical sciences. In the field of healthcare and social protection, the employer may appoint an occupational safety and health advisor who has acquired at least 240 ECTS credits through academic or professional studies in the field of medical sciences. For all other sectors not explicitly listed, the employer may appoint an occupational safety and health associate. This position requires a minimum of 180 ECTS credits obtained through academic or professional studies in the fields of technical-technological sciences, natural-mathematical sciences, medical sciences, or social-humanistic sciences (Articles 48–49 of the Law on Occupational Safety and Health).

As can be observed, both the advisor and associate in the field of occupational safety and health are professionals with higher education qualifications. Occupational safety and health is an area

addressed by numerous higher education institutions in Serbia, where a variety of study programs are implemented (Nikolić, Ilić Petković, Galjak, Vukić, 2018). More precisely, in the Republic of Serbia, twenty study programs across all levels of academic and professional studies are currently offered in this field (National Entity for Accreditation and Quality Assurance in Higher Education, 2024). The attainment of higher education serves as the foundational basis for further knowledge development.
The continuous professional development of knowledge is regulated by Article 53 of the Law on Occupational Safety and Health. Employers are obliged to ensure the continuous professional development of employees designated to perform occupational safety and health tasks. Continuous professional development is a legal obligation for the following roles:

- occupational safety and health advisor,
- occupational safety and health associate,
- occupational safety and health coordinator in the project design phase,
- occupational safety and health coordinator in the construction phase,
- responsible person for the inspection and testing of work equipment, including electrical and lightning protection installations,
- responsible person for testing workplace environmental conditions, including chemical and physical hazards (excluding ionizing radiation), microclimate, and lighting, and
- responsible person for testing biological hazards in the workplace environment.

Continuous professional development is a prerequisite for the renewal of licenses held by these professionals. Employers are obligated to grant paid leave to the designated individuals for the purpose of continuous professional development necessary for license renewal. The content, manner, procedure, and duration of continuous professional development, as well as other matters related to it, are regulated by the Minister responsible for labor affairs. This implies that a bylaw is expected to be adopted to provide detailed regulation of all issues relevant to continuous professional development.
In this regard, the Occupational Safety and Health Act also stipulates that the manner of issuance, renewal, and revocation of licenses shall be regulated by the Minister responsible for labor affairs (Article 73). This matter is governed by the Rulebook on the Manner of Issuance, Renewal, or Revocation of Licenses for Performing Occupational Safety and Health Activities (2024). This Rulebook prescribes the issuance of licenses to legal entities, entrepreneurs, and individuals. An occupational safety and health advisor, as an individual, may renew their license if, among other requirements, they provide proof of completed continuous professional development (Article 4 of the Rulebook).
Similarly, the coordinator in the project design phase and the coordinator in the construction phase may renew their licenses if they meet this requirement among others (Article 5 of the Rulebook). The same applies to the responsible person for inspection and testing of work equipment and electrical and lightning protection installations, the responsible person for testing workplace environmental conditions (chemical and physical hazards excluding ionizing radiation), microclimate and lighting, and the responsible person for testing biological hazards

in the workplace (Article 6 of the Rulebook). These professionals may renew their licenses if, during the validity period of the license, they acquire the required number of credits through the process of continuous professional development (Article 16 of the Rulebook). Licenses are valid for a period of five years (Article 73, Paragraph 1 of the Occupational Safety and Health Act).

However, the current Rulebook does not specify the methods, procedures, evaluation criteria, or other important aspects of acquiring credits through continuous professional development. As such, further regulation of this matter is anticipated. It should be noticed that there is Rulebook on the Training Program and Other Issues Related to the Professional Development of Occupational Safety and Health Personnel (2017) which is currently in force (2017). This document only generally addresses certain issues, such as the forms of professional development, the structure of the training program, and the issuance of certificates upon completion of training. Many critical questions remain unresolved, including: who is authorized to conduct training—only legal entities (and which ones), or both legal and natural persons; how training formats are evaluated, i.e., how credits are assigned and accumulated; and the exact number of credits required for license renewal, among others.

REGULATORY CHALLENGES AND POTENTIAL REMEDIES

Since the concept of continuous professional development in the field of occupational safety and health is relatively new in the Serbian legal framework, it is realistic to expect that, in practice, various questions and uncertainties will arise—questions to which legal scholarship should offer appropriate answers.

One of the first issues that can be raised is: who is authorized to conduct continuous professional development? More specifically, can both legal and natural persons carry out these activities, or is this reserved only for legal entities—and if so, which ones, and under what conditions?

In this context, reference may be made to the Law on Adult Education (2013), which in Article 7 defines adult education activities, among others, as those aimed at improving knowledge, skills, and competencies for personal and professional development. According to Article 16 of the same Law, an organizer of adult education activities may be a primary or secondary school, other educational institution, public agency, public enterprise, employment service organization, employment agency, business entity, entity for professional rehabilitation, entrepreneur, trade union organization, association, professional society, adult education organizations (e.g., people's universities, workers' or open universities), centers and organizations for professional development, foreign language learning, ICT, training and human resource development, driver training, chambers of commerce, career guidance and counselling centres, employers' associations, cultural-educational centers, cultural institutions, as well as other entities registered for educational activities in accordance with the regulations governing the classification of activities.

In order for a legal entity to be recognized as an organizer of adult education, it must meet a series of conditions prescribed by this Law and must obtain authorization from the competent ministry. Furthermore, the Law on the National Qualifications Framework of the Republic of Serbia (2018) prescribes who may acquire the status of a publicly recognized provider of adult education activities, and under what conditions. These conditions are detailed in the Rulebook on Detailed Conditions Regarding the Program, Staff, Premises, Equipment, and Teaching Materials for Acquiring the Status of a Publicly Recognized Adult Education Activity Provider (2015).

It is also possible to elaborate on which types of professional development are the most appropriate—such as seminars, conferences, study visits, expert meetings, and similar formats. In this context, it is important to consider the broad opportunities offered by modern technologies. Certain forms of professional development should be made available online, as online occupational safety and health training is one of the most effective preventive interventions (Barati et al., 2023).

Furthermore, it is necessary to clearly define the rights and obligations of both employers and employees with respect to continuous professional development. The Occupational Safety and Health Act stipulates that the employer is required to grant paid leave to the employee for the days spent in professional development. However, this raises practical questions—for example, how much time an employee may spend in training during the five-year license renewal period. Is the employer obliged to grant paid leave only for the minimum number of training days required to accumulate the credits necessary for license renewal, or must paid leave be granted for every instance of professional development regardless of its direct relevance to license renewal?

Another unresolved issue concerns the financing of professional development. If an employee chooses to participate in a paid training program (e.g., a seminar that requires a registration fee), it is unclear who should bear the cost—the employer or the employee. At first glance, it might appear that the cost should be borne by the person who is undergoing the training and who requires the license. However, from a broader perspective, the employer has a significant interest in supporting the continuous development of their employees' skills and competencies, as this aligns with modern human resource management practices (Da Silva et al, 2022).

This raises the dilemma of whether the state should regulate such matters through binding legislation, or whether it should leave them to be defined autonomously by the parties to the employment relationship. The concern is that if left unregulated, these issues may often be resolved to the detriment of the employee.

Another question that arises is whether certain accommodations or additional benefits should be provided by the employer regarding paid leave and financing of professional development for certain "vulnerable" categories of employees working in occupational safety and health, such as single parents. Furthermore, could institutions organizing professional development programs offer some form of scholarships or discounts on training fees, and on what principles would such benefits be based? This would align with the principles of Goal 4 of the Sustainable Development Agenda (2015), which emphasizes ensuring equal access to education for all, including vulnerable groups.

Finally, another issue concerns whether an employer can mandate their employee to attend professional development programs. Can the employee refuse to participate in such programs, and if so, what consequences would follow? In this regard, reference can be made to the Occupational Safety and Health Act, which stipulates that the safety and health advisor or associate is obligated to continuously enhance their knowledge in the field of occupational safety and health (Article 50).

CONCLUSION

As the United Nations defines Goal 4 of the Sustainable Development Agenda (2015)—"Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"—it indicates that the approach taken in our legislation toward continuous professional development in the field of occupational safety and health is indeed the right path. This is especially true considering that the goal of every organization should be to ensure a safe, healthy, and sustainable work environment (Milea et al, 2025). Organizations must continually adapt to existing and potential risks in the working environment and must view safety within the broader context of organizational or corporate sustainability. It is essential to create a climate where managers at all levels understand the necessity and importance of continuous training within the organization (Nikolić et al, 2020).

In the Republic of Serbia, the normative regulation of continuous professional development for experts in the field of occupational safety and health is established through the Occupational Safety and Health Act, as well as various subordinate regulations. However, this paper highlights only certain issues that evidently require further and more precise regulation.

What should be the subject of scientific and professional public interest in the future are issues such as the quality control of training programs, the topics and areas covered within the continuous professional development programs, the assessment of professional competence, the motivation of both experts and employers for active participation in the development process, and so on. For a broader and deeper discussion, the following questions remain open: What kind of experts in occupational safety and health does our society require? What knowledge, skills, and competencies should they possess? How can employers be empowered to recognize the need to invest in their experts, and how can they be motivated to financially support the career development of their personnel? What is the role and place of the occupational safety expert within the organization? How can employees be motivated to comply with the instructions of the occupational safety expert at their workplace, etc?

Based on all of the above, it can be concluded that there is a foundation in the Republic of Serbia for the proper legal regulation of continuous professional development in the field of occupational safety and health, and that, at this stage, further and more detailed regulation of this issue is required.

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BETWEEN SILICA DUST AND DISEASE: HEALTH CONSEQUENCES AND AWARENESS AMONG CONSTRUCTION WORKERS

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Abstract: Construction sites represent a working environment that, in addition to the already polluted air from the environment, emits large amounts and emissions of polluting substances into the air and negatively affects employees' health. The most common problem is dust, which occurs during operations such as grinding, digging, demolition, surface treatment of concrete, cutting wood, sawing various beams and cutting tiles, and similar operations. All mentioned operations manipulate materials that contain silicon dioxide, which is why silica dust can be detected in the air during work and cause various respiratory diseases, as well as other autoimmune diseases, infections, and cancer diseases. This research aims to represent dust as one of the chemical hazards that affect the health of workers with a focus on silicate dust, its origin, the health consequences, preventive measures, and a survey about the awareness of construction workers about silicate dust. A survey conducted among 30 construction workers exposed to silica dust showed that the majority of workers do not recognize silicosis as a consequence of exposure and that although they have received training, some workers point out that they are not informed about the hazards, and that more effective training of workers is needed. Also, the survey confirmed a gap between the available protection and the actual application on the construction site itself, i.e. that 70% of workers use protective masks only occasionally.

Keywords: *silica; dust; construction; survey*

INTRODUCTION

Air pollution is an everyday problem that negatively affects people's lives and health. Different chemical substances found in the air can affect people's health in other ways, whether it is a simple irritation or a serious illness.

The construction industry is one of the primary sources of air pollution. Inhalation of dust from the construction site poses a health hazard to workers working on the construction of the facility, which can directly or indirectly affect the intense pace of the construction industry (Cheriyan & Choi, 2020). The dust that is created on construction sites is mostly of natural origin, but it is still dangerous for the respiratory system. The most common types of dust that pollute the air on construction sites are silicate dust, wood dust (generated during the processing of wood materials), and low-toxicity dust generated from materials such as gypsum, limestone, marble and dolomite (Mučenski, 2018).

The exposure of construction workers to silica dust exceeds 3 million in the European Union, 1.7 million in the United States of America, and 350,000 in Canada (Sauvé et al., 2013). The continents that record the largest cases of this disease are the regions in Asia, Africa, and South America (Hoy et al., 2022). According to a 2016 global survey, an estimated 10,400 deaths and 210,000 years of life are lost each year due to silicosis. Hoy & Chambers (2020) pointed out that all reports indicate a younger age at diagnosis, faster disease development, a high rate of disease progression, and as a result - death or the need for lung transplantation. Various studies indicate that the occurrence of silicosis is directly related to the availability and proper use of personal protective equipment (PPE). Pérez-Alonso et al. (2014) indicate that in most cases PPE is not provided by companies in Spain, or if PPE is provided, workers do not know how to use it properly. Consequently, silicosis was diagnosed in 84% of workers who indicated that they wore some type of PPE. In Australia (Hoy et al., 2018), a low percentage of workers with access to PPE was recorded. It is concluded that there is a significantly higher risk of silicosis among workers who did not use PPE properly, and the lack of education, training, and information can increase the risk of developing the disease eight times (Requena-Mullor et al., 2021).

In a study of 86 construction workers exposed to silica dust, low exposure to silica dust (0.0125 mg/m3) was observed among workers in underground excavation and tunneling. Out of 86 workers, 69 of them participated in the lung X-ray examination, during which 52 employees (75.4%) had no significant findings, 5 employees (7.2%) were diagnosed with a specific finding, and 12 employees (17.4%) had non-specific findings. A suspicious enlargement of the right hilar was observed in one X-ray finding of the lung, and a subsequent CT scan of the lung confirmed the presence of a right hilar tumor (Keramydas et al., 2020). As exposure to silica dust increases, so does the risk of mortality and increased mortality, making silica dust one of the major health problems worldwide (Requena-Mullor et al., 2021).

This research aims to represent dust as one of the chemical hazards that affect the health of workers with a focus on silicate dust, its origin, the health consequences, preventive measures, and a survey about the awareness of construction workers about silicate dust.

CHEMICAL AGENTS AS A SOURCE OF AIR POLLUTION

According to OSHA (2012), health hazards within the construction industry can be divided into three categories: chemical hazards, physical hazards, and biological hazards.

Chemical hazards mean chemical ingredients for which there is statistically significant evidence, based on at least one study conducted by established scientific principles, and that it can cause acute or chronic health effects in exposed persons (employees). Chemical hazards can appear in the form of gas, vapor, smoke, dust, fibers, and mist; and they can damage the lungs, skin, and eyes, and target certain organs in the body. The air present on construction sites and in the production of building materials contains high levels of these harmful chemical substances (OSHA, 2012).

According to OSHA (2012), there are different ways that chemical harm can be introduced into the body: inhalation, absorption, ingestion, and injection. Dust, gases, suffocating vapors, various vapors, and fog lead to different diseases that are reflected in reduced lung function, damage to body tissues and organs, fever from metal fumes, diseases such as silicosis, asbestos disease, dermatitis, and haze diseases (OSHA, 2012).

OSHA (2012) divided toxic effects into acute and chronic. Acute signs of disease are seen quickly, usually after exposure to very high concentrations of chemical pollutants. On the other hand, chronic signs usually develop more slowly, over a longer period. They are reflected in the development of diseases such as silicosis, asbestos diseases, etc.

Certain chemical substances have a systemic health effect. It implies an adverse health effect that occurs at a site far from the initial point of contact with the body (a chemical is inhaled into the lungs, and absorbed through the skin) but also affects the kidneys, liver, or some other part of the body. Substances with systemic effects often have target organs where they accumulate and exert their negative effects. Often these effects are not visible until a critical body burden is reached (OSHA, 2012). Examples of such diseases are asbestos disease, silicosis, metal fume fever, infections, kidney damage, and allergic reactions.

Dust, as one of the representatives of chemical hazards, represents solid particles that are created by handling, crushing, grinding, drilling, or explosion of materials. Fibers, on the other hand, are solid particles whose length is at least three times greater than their width (eg asbestos fibers). Dust is measured as the concentration of suspended particles in a given space (weight/volume) and is measured in milligrams or micrograms per cubic meter of air (mg/m3, µg/m3). OSHA (2012) presented the following examples of dust and fibers found in the construction sector: crystalline silica, asbestos, metal dust, lead-based paint, and glass wool.

SILICATE DUST

The working environment of the construction sector is naturally loaded with dust particles. The problem is when free crystalline silica appears in the polluted air of a construction site, which, once inhaled, causes various diseases such as silicosis, chronic obstructive pulmonary disease, and lung cancer (Keramydas et al., 2020). Exposure to dust on construction sites occurs during excavation, drilling, rock processing, tunneling, demolition of buildings, cutting and processing of concrete, brick, ceramic and granite tiles, etc. (HSE UK, 2020).

Silicon dioxide occurs naturally in three forms: crystalline, microcrystalline, and amorphous. The three most common crystalline forms of silicon that occur in the work environment are quartz, cristobalite, and tridymite (European Commission, 2016). Silicate dust is a complex mixture of particles that vary in size, shape, and composition depending on the source of the dust. Crystalline silicon is the most common form associated with the development of silicosis

and other related diseases, but it is necessary to note that non-metallic silicon can also pose a health risk if inhaled in large concentrations (Alabi & Bakare, 2011).
The effect that silica dust causes and the degree of risk depend on the size of its particles in the air. If smaller particles of this substance are inhaled, they travel to the lower parts of the lungs and cause serious damage, while larger particles (such as beach sand) are not a problem because they are too large to be inhaled (OSHA, 2012; Xiao & Li, 2023). Long-term exposure (15 to 20 years) to medium and low concentrations can lead to diseases of the respiratory system, namely bronchitis, silicosis, and cancer.

Health consequences caused by exposure to silicate dust

Silicosis is a disease that affects all sectors of industry, but its global prevalence has never been translated into a universal public health problem. In 1987, the International Labor Research Agency (IRAC) recognized the carcinogenic effect of silicon dioxide, which was re-evaluated and confirmed in 1997 and 2012. In 1995, the World Health Organization launched a campaign to eliminate silicosis from the world by 2030, but silicosis is still a significant health problem worldwide.
Silicosis is a lung disease caused by inhalation of dust containing particles of silicon dioxide, which are defined as "respirable", that is, the given form of silicon is called "respirable crystalline silicon" (RCS). RCS can go unnoticed in the workplace because it is colorless, odorless, non-irritating, and does not cause immediate health effects. For silica particles to be biologically active, they must be small enough (less than 5 μm in diameter) to reach the lower respiratory tract and the area of gas exchange (ie, alveolar spaces) where they interact with lung tissue and eventually develop fibrous nodules and scars around the trapped silica particles. Since there is no adequate cure, preventive measures should be implemented (Requena-Mullor et al., 2021; OSHA, 2012). A medical examination that includes a complete work history, chest X-ray, and lung function test is the only sure way to determine if a person has silicosis (OSHA, 2012).
Keramydas et al. (2020) and OSHA (2012) defined three types of silicosis, and the division was made based on the concentration of silica in the air to which the worker is exposed:

- Chronic silicosis - occurs after 10 or more years of excessive exposure;
- Accumulated silicosis - the result of higher exposures and develops over 5-10 years;
- Acute silicosis - occurs when exposures are highest and can cause symptoms within a few weeks or up to 5 years.

The most common form of the disease is chronic silicosis, which often goes unnoticed in the early stages. It can only be seen on X-rays of the lungs after 15 or 20 years of exposure. Due to the large amounts of dust deposited in the workers' lungs, their immunity weakens and thus they become more susceptible to diseases such as tuberculosis. As a result, workers may exhibit one or more of the following symptoms: shortness of breath during physical exertion, severe coughing, fatigue, loss of appetite, chest pain, and fever (OSHA, 2012). Also, Hoy & Chambers (2020) defined that acute silicosis has significant differences compared to chronic silicosis.

Acute silicosis is caused by a very high level of exposure to silicate dust over several weeks to 5 years. It is typical for workers who carry out sandblasting, those who work in tunnels, and when processing silicate flour. It presents as a progressive condition with nonspecific symptoms, including dyspnea, cough, fatigue, weight loss, fever, and pleuritic pain. Disease progression can be rapid, and there is a high mortality rate.

It is concluded that inhalation of crystalline silicon dust is a risk factor for workers' health. Exposed workers may suffer not only from silicosis but also from certain cardiovascular diseases, sarcoidosis, pulmonary tuberculosis, lung infections, chronic obstructive disease, certain types of tumors, lung cancer, autoimmune diseases, and kidney disorders (Kreuzer et al., 2013). Also, different studies reported that the interaction of silica exposure and smoking was associated with an increased risk of mortality (Wang et al., 2020).

Survey of workers' awareness about risks associated with silica dust

To better understand workers' awareness of the risks associated with silica dust and their relationship to the use of PPE, a survey was conducted on 30 male construction workers, where 40% of workers are between 35-44 years of age, 30% of workers are 45-54 years of age, 23.3% are between 55-64 years of age, and 6.7% are between 25-34 years of age. The largest number of respondents (30%) have been working for more than 31 years in the construction industry, while the smallest percentage (10%) has experienced between 21-30 years or less than a year. The target group was workers who are exposed to silicate dust, so the largest representation is workers who perform painting and preparatory work as the main job on the construction site, but in addition, they also do other jobs (cutting tiles, drilling concrete, etc.). The survey was made up of questions divided into several sections: general information, awareness of silica dust, use of PPE, training, awareness, and consequences of exposure. Based on the conducted research, important items that should be paid attention to when understanding workers' awareness of silica dust and the consequences of exposure have been singled out:

- The majority of workers are poorly familiar (46.7%) or not at all familiar (6.7%) with the term silicate dust and its effects on health,
- Knowledge about the consequences and diseases caused by silica dust showed that workers are aware that there is a risk of breathing problems, bronchitis, and lung cancer, but not a single worker marked silicosis as an answer,
- The risk of silicate dust in the workplace is mostly assessed as medium (46.7%), while only 30% of workers believe that they are exposed to a high/very high risk, and 23.4% of workers believe that the risk of exposure to silicate dust in the workplace is low or very low.

By summarizing the results of the survey on the use of PPE during work, it was determined on the spot that the employer provided appropriate PPE. However, during the examination of workers, it was determined that 70% of workers sometimes wear a protective mask while working in a dusty environment, and 30% of workers always wear it, which was confirmed by the conditions in the field. As the main reason for not wearing a personal protective mask, 50% of workers pointed out that they do not think they need it (Figure 1).

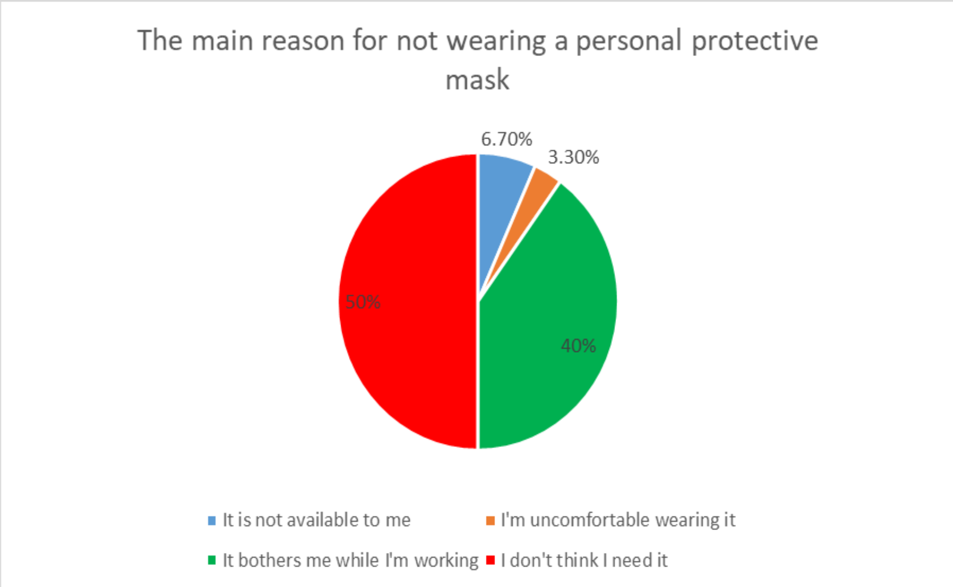

Figure 1. The main reason for not wearing a personal protective mask

The review of available documentation showed that all workers underwent the training for safe and healthy work, which was confirmed by the results of the survey, where 50% of workers cited the employer as a source of information about silica dust, and the other sources of information that were cited as used are the internet or colleagues. Also, it is necessary to point out the information that 16.7% of workers declared that they were not informed about the risks associated with silica dust, which raises the question of their attention and commitment during training for safe and healthy work. Summarizing the results of the proposal of preventive measures that should be implemented to protect workers from silicate dust, the workers highlighted the following: use of PPE (70%), cleaning of the workspace and work surfaces after the working day (10%), ventilation and airing during breaks (43.3%), use of surgical masks (20%), while none of the workers circled water curtains during work and operations with materials that create dust, as well as measuring the concentration of dust on materials. In the end, the majority of workers (76.7%) believe that adequate measures have been applied at the construction site, while only 23.3% of workers believe that the protection measures against silicate dust at the construction site in question are not adequate.

While there is awareness of silica dust among the construction workers and a familiarity with the topic, the understanding of diseases that silica can cause is still sufficiently close to the workers, which was confirmed in the survey - no one of the workers put silicosis as a consequence of exposure. There is also a low risk perception among workers, despite real exposure, which indicates a deficient hazard recognition. The fact that 50% of workers believe that a personal protective mask is not necessary indicates the absence of internal motivation for self-protection and a low personal sense of threat. The fact that everyone has undergone training for safe and healthy work and that 16.7% of workers claim that they are not informed, or claim that the surgical masks should be used as PPE, may indicate a low level of engagement, psychological absence during the training ("mechanical attendance at trainings"), and raises the question of attention and engagement during training.

PREVENTIVE MEASURES AGAINST SILICA DUST

The increased aggressiveness of silicosis is attributed to the lack of adequate preventive measures given the high levels of exposure that occur in a very short period (Requena-Mullor et al., 2021). Silicosis is an incurable but preventable lung disease. Increased worldwide efforts are needed to control known and emerging sources of exposure. According to the International Labor Organization (ILO), silicosis, an incurable disease, requires quantitative and qualitative control of respirable crystalline silica and the development of appropriate control measures (Tavakol et al., 2016).

The implementation of the rules prescribed by the Rulebook on preventive measures for safe and healthy work (Ministry of Labour, 2009/2017/2021) when exposed to chemical substances and HSE UK (2020) in environments where silicon dioxide occurs is carried out as follows: risk assessment, risk control, review of control measures. There are two main ways in which silica dust is prevented from entering the air: water curtains and extraction on the tool. However, other control measures are reflected in the organization of work tasks and in combination with other protection measures, which include: limiting the number of people near work, rotation of workers performing the work task, using partitions to isolate the workplace, general mechanical ventilation, proper selection of PPE (respiratory protective equipment, work clothes) and conducting health surveillance of exposed workers.

CONCLUSION

Air pollution in the construction industry is a significant problem that requires urgent action to prevent the increase in morbidity and mortality caused by silicosis and related diseases. It is necessary to present the problem of silicate dust as a global one, to train employees for safe and healthy work, for the proper use of PPE, and to ensure medical examinations and monitor the health status of employees. A survey conducted among construction workers who are exposed to the effects of silica dust indicates that although training for safe and healthy work has been conducted, there is a low level of information among workers, which is confirmed by the fact that not a single respondent mentioned silicosis as a potential consequence of exposure. The fact that 16.7% of workers are not informed, and have undergone training for safe and healthy work, indicates that the workers are only "mechanically present", with no engagement and attention during the training. The survey showed that even if PPE is provided, 50% of workers believe that they do not need a protective mask. The above information points to the urgent need to improve the occupational health and safety system through customized training and open communication with workers, to assess real possibilities and needs.

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RISK ASSESSMENT MODEL FOR ENVIRONMENTAL AND HUMAN HEALTH IN INDUSTRIAL ZONES

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Abstract: This paper applies an enhanced model for risk assessment in industrial systems focusing on the environment and human health impacts. Incorporating identification of hazardous substances, exposure pathways, dose-response relationships, risk characterization, and environmental impact evaluations, the model addresses industrial impacts on air quality. Results highlight primary exposure routes and risks associated with case study from Kikinda industrial zone. Implementing preventive measures such as environmental monitoring, cleaner technologies, and stricter regulations is essential for minimizing risks and supporting sustainable development. This paper also provides graphical visualizations of risk estimation, and structured case study discussions, ensuring a full systemic approach.

Key words: *Risk assessment; Environmental protection; Human health; Sustainable development; Industrial systems.*

INTRODUCTION

Technical and technological systems contribute to industrial development but simultaneously introduce significant risks to environmental health and human populations. Uncontrolled emissions, improper waste management, and industrial accidents are primary factors requiring proactive risk assessment methodologies (Jarup, 2003). This paper applies a structured risk assessment model integrating environmental and health considerations to ensure sustainable development (Figure 1).

The development of technical and technological systems has brought substantial benefits to society, primarily through industrial growth and increased productivity. However, these advancements often come with significant risks to environmental quality and public health. Improper waste disposal, uncontrolled emissions, and industrial accidents are just a few examples of threats that can arise in the absence of effective risk management. In this context, designing and applying comprehensive risk assessment models is crucial for ensuring that industrial progress aligns with principles of environmental sustainability and human well-being. (Hu et al., 2011; Savić and Stanković, 2012)

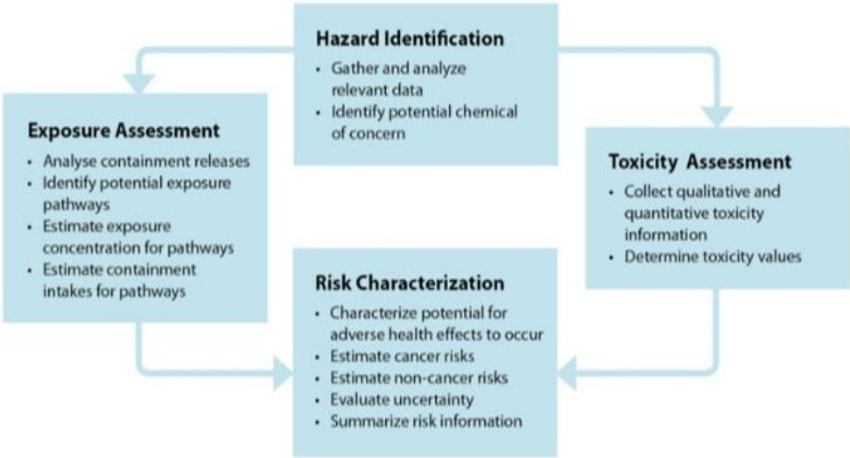

Figure 1 Risk Assessment Guidance

Modern risk management must rely on an interdisciplinary approach that includes the identification of hazardous substances, analysis of exposure pathways, evaluation of dose-response relationships, risk characterization, and environmental impact assessment (Fig. 1). Such a systemic methodology allows for informed decision-making and supports the development of preventive and mitigation measures tailored to specific industrial contexts. This paper presents an enhanced risk assessment model applied to a real-world case study of the Kikinda industrial zone, emphasizing the value of graphical visualizations in identifying and interpreting key risk factors and their implications (Adamović, 2007).

METHODOLOGY

The methodological framework includes:
- Identification of hazardous substances (e.g., heavy metals, volatile organic compounds);
- Assessment of exposure pathways (air inhalation, water ingestion, soil contact);
- Dose-response relationship analysis;
- Risk characterization;
- Environmental impact assessment following SRPS ISO 31000:2019 guidelines. (Regodić, 2011)

Risk estimation uses the general formula (US EPA 1989 and 2004):

$$\text{RISK} = \text{HAZARD} \times \text{EXPOSURE} \quad (1)$$

Where 'hazard' represents the intrinsic potential for harm of a substance or activity, and 'exposure' measures the extent to which a system or individual comes into contact with it (Anderson and Johnson, 2000).

RESULTS AND DISCUSSION

The risk assessment model was applied to case study of Kikinda industrial zone to evaluate environmental and health impacts.

The graphical visualizations included in this study serve as a critical component in the interpretation and communication of risk assessment results. Each of the four figures illustrates specific dimensions of the risk landscape. Figures 2 and 3 depict non-carcinogenic health risk in the Kikinda industrial zone for different polutants and pathways, and for adults and children, highlighting metallurgical operations as the primary sources of airborne contaminants.

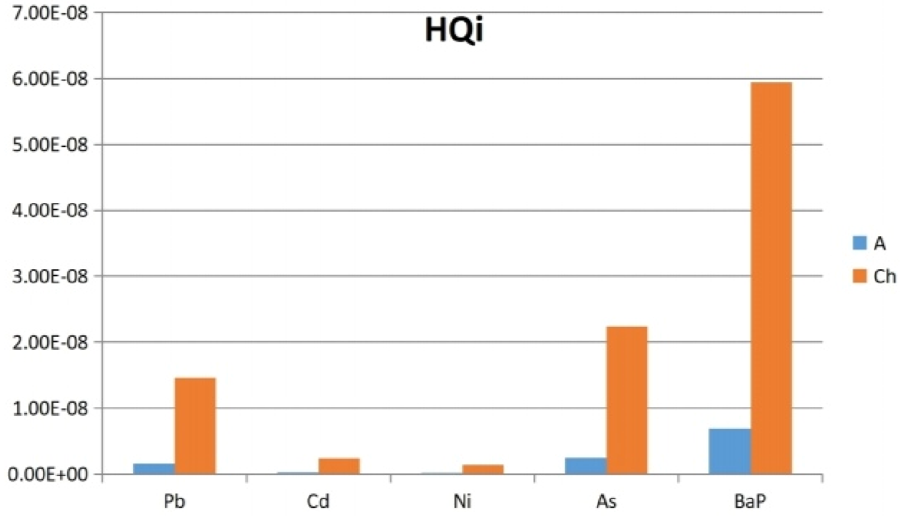

Figure 2 Estimated Non-Carcinogenic Health Risk in the Kikinda Industrial Zone for different polutants, and for adults and chilndren

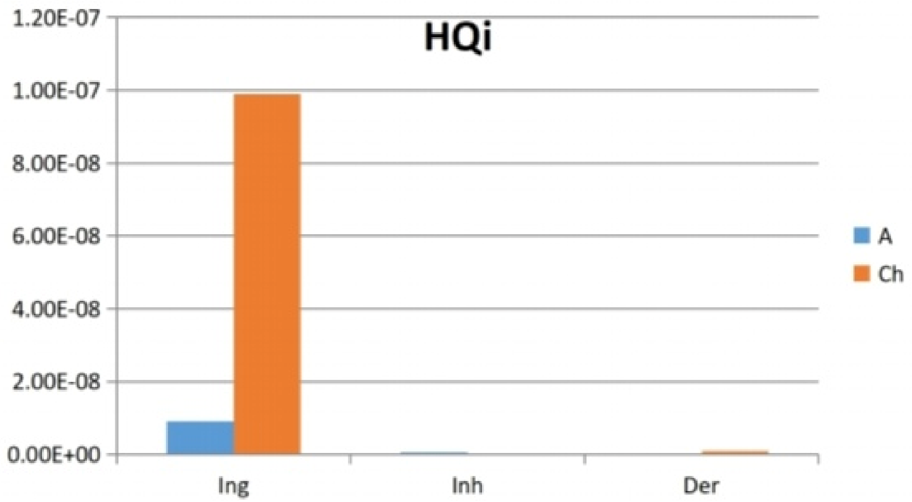

Figure 3 Estimated Non-Carcinogenic Health Risk in the Kikinda Industrial Zone for different pathways, and for adults and chilndren

Figures 4 and 5 further elaborate on exposure estimates and health risk characterization, applying the dose-response modeling to carcinogenic health risk in the Kikinda industrial zone for different polutants and pathways, and for adults and children. These visuals not only validate the theoretical framework of the model but also provide actionable insights for targeted mitigation strategies. For instance, the data can support the implementation of filtration systems, modification of industrial processes, or re-zoning initiatives to minimize population exposure. Moreover, the clear and accessible presentation of data enhances communication with policymakers and the public, fostering greater awareness and accountability in environmental risk governance

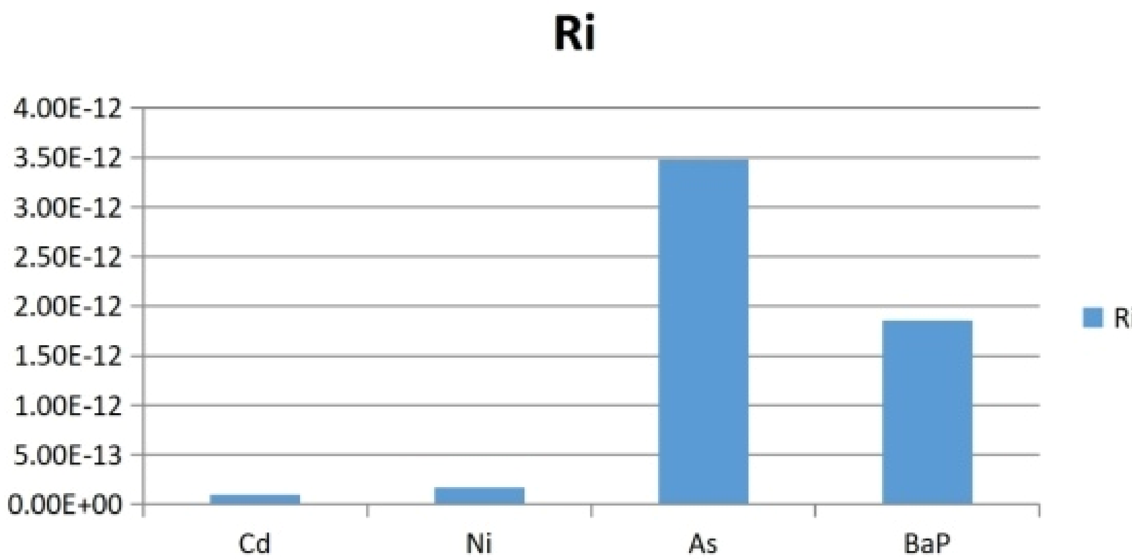

Figure 4 Estimated Carcinogenic Health Risk in the Kikinda Industrial Zone for different polutants

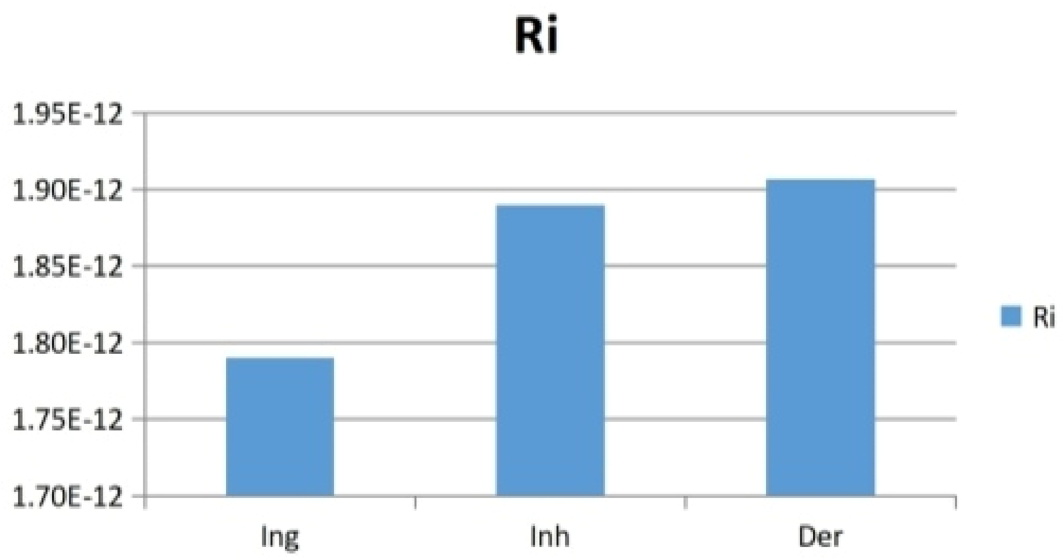

Figure 5 Estimated Carcinogenic Health Risk in the Kikinda Industrial Zone for different pathways

Based on the quantitative values of the non-carcinogenic risk, it can be concluded that even no increased level is identified risks from the technical-technological systems in the area of the Kikinda industrial zone, a significantly higher value of HQ on children can be observed, which means significantly greater non-cancerous impact of harmful elements on the younger population. Also, it is noticeable the most significant influence is BaP, followed by As and Pb. The dominance of oral intake of harmful elements can be observed by the strength of the effect, also with a far more pronounced effect on the younger population. When it comes to carcinogenic risk, As and BaP can be singled out as the biggest influence. The most significant is the dermal effect, in case of carcinogenic risk. The Kikinda industrial zone exhibited high particulate matter concentrations, primarily from metallurgical activities. This case underlines the need for improved industrial hygiene, preventive emissions control, and sustainable resource management.

CONCLUSION

The proposed risk assessment model offers a robust framework for evaluating and managing environmental and human health risks associated with technical-technological systems. Case study emphasizes the necessity for comprehensive monitoring and targeted mitigation measures. Sustainable development goals can only be achieved through systemic risk management, ongoing research, public awareness, and strict regulatory enforcement.

The enhanced risk assessment model presented in this paper offers a comprehensive and practical framework for identifying, evaluating, and managing environmental and human health risks associated with industrial systems. Through its application to the Kikinda industrial zone, the model has demonstrated its capacity to integrate complex data, highlight critical exposure pathways, and quantify potential health impacts with clarity and precision.

The inclusion of graphical visualizations significantly improves the interpretability of findings and strengthens the model's utility in real-world decision-making contexts. This study underscores the need for continuous environmental monitoring, stricter regulatory enforcement, and the adoption of cleaner production technologies to reduce industrial emissions and safeguard public health.

Sustainable development can only be achieved through systemic and proactive risk management approaches that bridge scientific analysis with policy implementation. Future work should focus on refining model parameters, expanding case study applications, and fostering interdisciplinary collaboration to enhance the robustness and scalability of risk assessment frameworks.

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A PROPOSAL TO CONTROL EXPOSURE TO LEGACY ASBESTOS AND ELIMINATE ASBESTOS-RELATED DISEASES IN SERBIA

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Abstract: Eliminating asbestos-related diseases requires comprehensive knowledge of exposure sources, legislation, and disease patterns. Although Serbia banned asbestos in 2011 and 2015, the country still faces long-term risks from legacy asbestos in buildings and the environment. Asbestos is a known human carcinogen that causes fatal diseases such as mesothelioma, lung cancer, and asbestosis, often decades after exposure. The continued presence of asbestos-containing materials (ACM) poses a serious health threat through occupational, environmental, and para-occupational exposures.
This Commentary proposes an Action Research Plan to prevent and eventually eliminate asbestos-related diseases in Serbia. The plan emphasizes a multi-disciplinary approach, integrating environmental engineering, occupational hygiene, public health, and legal enforcement. The focus is on legacy occupational exposure—especially in demolition, waste transport, and remediation—as well as environmental risks from unremediated asbestos sites and deteriorating infrastructure.
Overall, eliminating asbestos-related diseases in Serbia will require strategic, coordinated efforts across sectors. With decisive action and continued support, the country can meet European Union (EU) and World Health Organization (WHO) goals of eliminating asbestos-related diseases and reducing preventable suffering and deaths.
Keywords: *Asbestos; Disease; asbestos-containing materials.*

INTRODUCTION

Any plan to eliminate a disease requires knowledge of the causal factors and some level of quantification of the causal factors, the state of legislation to prevent exposure both environmental and occupational, and disease estimates, both retrospective and prospective. Assessment of Asbestos and Asbestos Waste Quantity (AAAQ) identifies the state of each of these factors. In this Commentary, some emphasis is placed on predictable, namely the inevitable appearance of a set of asbestos-related diseases for at least the next four to five decades.
Asbestos causes well-known fatal diseases with long-latency periods. It is equally well-known that almost all asbestos-related diseases are preventable. Many researchers and regulators place emphasis on banning new asbestos-containing materials (ACM) from further use in society. Banning is an administrative (legal) first-stage prevention measure, but other legal and practical measures are necessary to eliminate asbestos-related diseases. This first stage administrative measure was achieved in Serbia in 2011 and 2015 (Zoraja, 2021).
Once banning future exploitation of asbestos is legally achieved, however, preventing the inevitable legacy exposures to population and occupational ACM becomes the essential and the

more difficult societal task.

With the findings of AAAWQ as a foundation, this Commentary is designed to elucidate major elements of an Action Research Plan to identify, prevent, and eliminate asbestos-related diseases in Serbia. The design of the plan is based on dividing exposures into two modes, occupational and environmental. A number of physical, medical, and social science disciplines are involved in the safe remediation and disposal of ACM, as well as medical treatment. These two modes can overlap, and in most countries these two modes are regulated/legislated by different Ministries.

Therefore this Commentary proposes a multi-disciplinary collaboration of all parties with a vested interest in identifying, preventing and eliminating asbestos-related diseases in Serbia. Such a model would also include collaboration with international agencies and perhaps surrounding countries with similar issues (given the latency period of asbestos related diseases, I note that the accurate retrospective identification and quantification of asbestos-related diseases may be limited by the breakup of the former Yugoslavia).

The literature on asbestos-related disease is huge. This Commentary does not contain a full literature search. Although it contains some of the most definitive and illustrative research findings since 1980, one can be misled. For example, in a major review from 2021 (Emmett, 2021) states "as the industrial use of asbestos is phased out or eliminated, asbestos is becoming a more prominent potential cause of environmental rather than occupational disease." Emmett (2021) properly includes non-occupational sources of asbestos exposure as "para-occupational, environmental, and natural."

However, the statement is speculative and introduces a major source of error into elimination of asbestos-related diseases. Banning does not stop legacy high-dose and chronic occupational exposures involved in:

- building remediation,
- demolition,
- separation from other demolition waste,
- transportation to safe landfills,
- haphazard disposal.

Emmett (2021) does not completely ignore the fundamental toxicological principal of dose-response. However, it does take into account that, with certitude, workers exposed to asbestos will have higher time-weighted and chronic exposure values (including community exposure while off the job) than those exposed by the environmental-only or para-occupational routes.

Emmett (2021) also states, "Because of these multiple uncertainties in characterizing risk from past and present community exposures, we will need to be prudent in risk assessment to include all potential sources of risk when remediating or removing community asbestos sources." This begs the question of how to parse "community exposure" from "occupational exposure." This commentary proposes the term legacy occupational exposure as a means of differentiating environmental from occupational exposure.

A critical point from the previous discussion is that both occupational legacy exposures and environmental exposures need to be taken into account in any comprehensive program to eliminate asbestos-related diseases from any society, developing, transitional, or developed. To attain this goal in Serbia, a comprehensive and carefully designed review of the literature is a necessary step following the elaborations contained in AAAWQ.

The steps in this Action Research Plan are also designed to meet the administrative requirements of the European Union (EU) and the noble goals of agencies such as World Health Organization (WHO), International Labour Organization (ILO), and International Agency for Research on Cancer (IARC) to eliminate the human misery and economic toll, not only asbestos-related diseases, can serve as a starting point for other diseases, including cancer sites/histologies.

SCOPE OF PROBLEM: THE BURDEN OF ASBESTOS-RELATED DISEASE

The burden of asbestos-related diseases among workers is well known since Selikoff published their findings in 1980 (Selikoff, 1980a; Anonymous, 2025a). Asbestos was determined to be a Class 1 Human Carcinogen in 1987 by the IARC (1987). ACM cause a range of fatal diseases, the principle of which are pneumoconioses (asbestosis) (ICD, 2025a), lung cancer, and mesothelioma (ICD, 2025b). These are diseases with very long latency periods. Depending on the specific disease and type of asbestos, the period between exposures to clinical manifestation ranges from two to five decades depending on type of asbestos and the specific disease and histology (Marinaccio, 2007).

Mesothelioma, in particular, is a rare cancer of the pleura and peritoneum. Mesothelioma has a unique fingerprint quality useful to researchers and exposure prevention scientists: its etiology is invariably exposure to asbestos.

While some treatment protocols are available, survival from mesothelioma is null and the disease is typically fatal within two years of diagnosis (IARC, 2025a). Tobacco smoking is synergistic with asbestos exposure for disease causation (Selikoff, 1980b) with a multiplication factor up to 80 times. This finding is of particular importance for Serbia, a country with the fifth highest incidence of tobacco smoking in the world (39.5% population average) (Anonymous, 2025b).

Any plan to eliminate asbestos-related diseases should consider that agencies with a mandate to reduce tobacco smoking can be important allies.

The Burden of Asbestos-Related Disease in Serbia

The true burden of asbestos-related disease is Serbia is unknown. As AAAQ elucidates, Serbia does not have a population-based cancer registry or a registry for occupational exposure to asbestos. Speculating on the latency model, if all asbestos in Serbia were safely remediated from building infrastructure and scattered mixed waste dumps by the end of 2025, new cases of asbestos-related disease would cease appearing in about 2050. Unfortunately, transition economies like Serbia are a long way from safely removing asbestos from the built environments and disposing of it in safe landfills (Zoraja, 2021). New cases of preventable asbestos-related disease will appear for decades in the future.

Asbestos Experience in Canada and its Province British Columbia

Canada completed the complete banning of asbestos only in 2018 (Government of Canada, 2025), lagging behind Serbia's ban in the years 2015 and 2022. CAREX (CARcinogen EXposure) Canada (Anonymous, 2025c) estimated that about 235,000 workers were exposed to asbestos in 2016. The leading occupational groups were "Specialty Trade Contractors" (67%), and building construction. Exposure is also documented in elementary and secondary schools, and hospitals adding to the potential development of disease in children, teachers, and support staff.

Exposure in schools is what the literature classifies as para-occupational, often taken to mean "take- home" exposures (for example clothing and shoes contaminated in the workplace are taken home for laundering). The term para-occupational should also include non-occupational exposure in asbestos- insulated buildings which are also workplaces (Goldberg, 2009) such as schools and hospitals. In these cases, exposure to asbestos is both to workers and "civilians." (To illustrate, a parallel situation exists with a respiratory disease like COVID-19. An infected person will carry the hazard into a hospital (defined as a workplace) and infect healthcare workers and other patients. These infected workers and patients can then multiply the effect when the leave the hospital, going into the public and to home).

British Columbia (BC) is the westernmost Province of Canada. BC has a population of about 5.6 million (Anonymous, 2025d), in the same range as Serbia's 6.7 million. Major industrial classifications in BC using asbestos were traditionally agriculture, metal and coal mining, forestry, rail transportation, and shipbuilding and ship repair. These are somewhat similar to workplaces in Serbia and its neighbouring countries with extensive coastlines and major rivers. Each of these industries has their tertiary repair/support industries.

Asbestos was widely used in BC as a building construction material until the early 1990s, when new use was phased out. Asbestos was a common material in buildings for insulation in heating and ventilation systems, as fire-retardation for structural steel I-beams, in floor tiles and even window-sealant compounds. That makes buildings with asbestos-containing materials 35 years old as a minimum value. As land use becomes urbanized or as their life cycle ends, many buildings are being demolished with consequent exposure to legacy asbestos.

Even in a developed economy such BC, the leading cause of documented occupational mortality (including acute accidents) are asbestos-related diseases based on Workers' Compensation claims (WorkSafeBC, 2017). Between 1998-2008 there were 437 Mesothelioma compensated claims (298 fatal, 121 pre-fatal) (Lippel, 2010). These numbers are certainly an underestimation of mesothelioma, since they rely on attending physicians and workers reporting the disease. Due to the long latency period, older workers and their families may not seek compensation and attending physicians may lack the knowledge that still-living but elderly workers and

surviving families are eligible for workers compensation benefits (Kirkum, 2011).
This is the case even though the regulatory agency, WorkSafeBC, has a long history of requirements (WorkSafeBC, 2025) to protect workers from ACM exposure. Preventing exposure in existing buildings includes identification warning signs and managing in place through encapsulation, and removal. Inevitably, however, buildings will have to be demolished, workers exposed, the asbestos waste be differentiated from other waste materials, and safely transported and deposited into dedicated landfills according to environmental laws.
BC has a long-standing regulation that any building potentially contaminated by asbestos must conduct an inventory and label asbestos-containing materials. In addition, companies remediating/encapsulating, and demolishing buildings must register a “Notice of Project Asbestos with WorkSafeBC.
However, an underground economy of illegal and inexpensive demolition has developed, especially exposing young and new immigrant workers in lower-paying and exhausting work conditions. New regulations recently came into force requiring training before any worker can be employed in asbestos remediation work. These regulations include licensing of pre-demolition exposure assessors and laboratory analysts (Lippel, 2010).

EXPOSURES TO ASBESTOS-CONTAINING MATERIALS

International experience dictates that asbestos is a dynamic toxic substance exposing multiple levels of the Serbian population over the course of decades. In the vernacular, one might say asbestos is a traveling, four dimensional toxic substance. The following examples include environmental, para- occupational, and occupational modes of exposure.

Environmental and Para-Occupational Exposures

- Children playing in casually disposed waste materials, transferring them to the home environment;
- Ambient air contamination from the two closed but un-remediated asbestos mines (Korlaće and Stragari) exposing local populations (Milošević, 1988);
- Ambient air concentration from casually-disposed waste materials;
- Ambient air concentrations of asbestos affecting the localized general population during demolition of old buildings;
- Non-occupational inhalation of asbestos fibers in the vicinity of demolition and remediation of buildings.

Occupational Exposure Characteristics

- The Threshold Limit Value (8-hour time-weighted average) for all forms of asbestos is 0.1fibers/ cc, based on A1 carcinogenicity (ACGIH, 2025). This value is typical of regulatory limits. However, laboratory analysis is tedious, and although asbestos-specific portable instrumentation based on the principle of electric-field-induced fiber alignment and oscillation has been developed, commercial instrumentation is not widely available (an opportunity for Serbian engineering research & development).

- Exposure exceeding regulatory limits is most probable during demolition and transportation of waste materials;
- Exposure during maintenance and renovation of older buildings (building-age cut-off unknown);
- Dose expressed as air concentration and duration is presumed be highest among remediation, demolition, and disposal workers;
- Research Hypothesis: the most easily identifiable, quantifiable, controllable and preventable asbestos exposures are occupational;
- The rationale for "identifiable, quantifiable, controllable" is that workplace Asbestos is regulated by the Ministry of Labour and a new Occupational safety and health (OHS) Law, article 62 (Anonymous 2023). Employers are obliged to maintain records of employees exposed to asbestos, their training in safe work procedures and personal protective equipment (PPE), and other measures (Article 62).
- This kind of record-keeping could be the occupational equivalent of what AAAWQ found, the baseline data most useful for prospective research studies and disease prevention.
- Methods of regulatory inspections, enforcement;
    - Hypothesis: well-defined occupational surveillance systems and population-based cancer registries are the most likely systems to identify the true burden of asbestos-related disease.
    - Such systems are also a systemic means to ensure workers and surviving families are identified and properly compensated for occupational diseases according to Serbian law.
    - Hypothesis: Environmental and General Population Exposures capture the public and political imagination far more easily than occupational exposures. This quality may make environmental research easier to fund. However, Environmental and General Population Exposures are less reliable and accurate for the purpose of evaluating morbidity, mortality, and quantitative dose-response.

Occupational Hygiene

"The science of anticipating, recognizing, evaluating, controlling, and confirming protection from hazardous workplace conditions that may cause workers injury or illness. Through a continuous improvement cycle of planning, doing, checking, and acting, Occupational, Environmental, Health and Safety (OEHS) professionals make sure workplaces are healthy and safe" (AIHA, 2025a; OHTA, 2025).

This science is also known, depending on country and time period, as Industrial Hygiene, and OEHS. In todays' world, OEHS professionals work in almost every primary, secondary, and tertiary occupational category, including health care. The discipline is represented by the International Occupational Hygiene Association (IOHA), an association of associations. The author of this Commentary is a member of the AIHA and its Local Section in BC Canada.

The relevance is that OEHS professionals are specifically trained to develop and implement hazard identification - quantitative/qualitative risk assessment - and control mechanisms for asbestos. OEHS Professionals are trained in air sampling instrumentation, sampling protocols, and laboratory methods of quantification for asbestos.

Control methods are based on the Hierarchy of Controls (US NIOSH, 2025). In order of effectiveness they are usually stated as elimination, substitution, engineering, administrative, and PPE. OEHS Professionals also specialize in writing comprehensive safe work procedures and training managers and workers in them to prevent Asbestos-Related diseases. Environmental Engineers have similar training and the crossover is apparent.

Appendix A identifies the rubrics in which OEHS professionals are trained for the purposes of professional certification as well as training organizations relevant to control of asbestos, and international professional Associations such as the IOHA and the AIHA.

The Research Action Research Plan: Some Elements for Consideration in Serbia

The data and history outlined above suggest the need for an Action Research Plan based on integrated multi-discipline collaboration into two allied categories:

- Occupational Exposures
- Environmental Exposures.

The principle objective is to Eliminate Asbestos-related Diseases from Serbian society by preventing legacy exposure to occupational and environmental asbestos in the built and waste-contaminated environment.

Multi-disciplinary refers to the broad number of scientific, governmental, professional, and social organizations with vested interests in eliminating asbestos-related diseases from Serbian society. The basics are the inter-weaving of the medical, environmental engineering, occupational health and safety, and social disciplines with the missions of related governmental departments according to well- established international and EU standards. The role of Serbia's OHS inspectors from the Ministry of Labour, Employment, Veterans and Social Policy Occupational Safety and Health Directorate is critical.

For a comprehensive description what is meant by "multi-disciplinary" please refer to a publication of the ILO, Eye Health and the World of Work (ILO, 2025) (page 23) written by the author of this Commentary.

Some Elements of an Action Research Plan to Control Exposure to Asbestos and Eliminate Asbestos- Related Diseases

The elements discussed in this section are a few of multiple possibilities; they should be considered as starting points for the elimination of Eliminate Asbestos-related Diseases in Serbia. Apart from the need for a comprehensive literature search some principal elements are:

- A Develop the infrastructure required for a population-based Cancer Registry (IARC, 2025b). This is a huge task requiring multiple disciplines. To demonstrate the need and to provide the pathway of an iterative approach, a pilot project could be started by developing a relatively simple Registry for Mesothelioma and other Asbestos-related cancers/diseases. A pilot study could pick an area where there is a known excess of mesothelioma and examine hospital records and interview local MDs for their experience.

  Mesothelioma is a well-defined fingerprint and surrogate for other asbestos-related diseases since it is invariably has one-cause. In contrast, pneumoconioses have many causes, as does lung cancer. Anecdotally it is also a well-remembered disease by families, since once diagnosed, patients have short survival. Geographic areas for a pilot study could be proximity to the closed asbestos mines or other areas such as factories where asbestos was installed. Point below discusses an older and complex study in Stragari.

Korlaće has been more recently studied for types of asbestos and potential for environmental contamination (Hargitai, 2012) but does not appear to have been studied epidemiologically for morbidity and mortality of asbestos-related diseases. Google Earth imagery from 2024 demonstrates that mine buildings are still standing, the mine in proximity to a populated area.

As speculation, other areas for a pilot study could be former military and heavy industrial bases such as railroad manufacturing.

- B Conduct an epidemiological follow up study to the 1988 Environmental Exposure to Chrysotile Asbestos and Cancer Epidemiology (IARC, 2025a) in Stragari, Serbia. This was a carefully and beautifully designed study quantitatively examining airborne, waterborne, and dust asbestos, wind patterns, smoking data and health effects among women and men.

  If the original records still exist, or even partially exist, baseline follow up for all the quantitative elements are possible through contemporary air and water instrumental are possible with much greater accuracy.

  The follow up of study participants would be difficult given the passage of time, mortality, migration, identification of health and disease status and other factors: Difficult and with multiples sources of error, but not impossible. It would require in-depth searching of vital statistics records and a great deal of investigation imagination, but these aspects are typical pre-requisites of retrospective exposure assessment studies. Contemporary statistical methods, including Bayesian statistics for small sample size and approximating intractable posterior distributions might be applicable (Anonymous, 2025e; AIHA, 2025b).
- C Points A and B above obviously require the knowledge of medical professions, especially Epidemiologists. The Medical Associations could also amplify the need to identify, document, and treat asbestos-related diseases. Medical doctors are not necessarily well-trained to ask a singular question when treating patients: "what did you do for a living?" (De Morbis Artificum Diatriba Bernardino Ramazzini, 1700). This measure has profound implications to properly compensate workers and families for occupational diseases like mesothelioma.
- D According to the new Serbian OHS Law, each enterprise is required to have a trained OHS representative. It might be advisable to begin training of a national cohort of safety representatives of construction companies involved in demolition of older buildings and the transportation of construction waste in the fundamentals of recognizing and preventing exposure to asbestos This training would be conducted according to the Rulebooks being developed by the Ministry

of Labor and the Ministry of Environment.

- E Similar to Point C, training for the inspectors of the Ministry of Labor and the Ministry of Environment might be required. The topics include asbestos identification in enterprises and the means of self-protection, including fit-tested respirators and other PPE.
- F International resources include the Occupational Hygiene Training Association (Occupational Hygiene Training Association, 2025f) has specific modules on the topic of asbestos as does the British Columbia Institute of Technology contained in modules approved by WorkSafeBC. The author is not knowledgeable about educational resources in Europe.
- G In light of this Commentary, the author has examined the possibility of using portable instrumentation to measures occupational and environmental asbestos legacy materials. Occupational Exposure Limits (ACGIH, 2025) are universally based on fiber counts/cc. Laboratory analysis is based on phase contrast and transmission electron microscopy, laborious and expensive processes (National Library of Medicine, 2001). Research into portable, real time instrumentation using light scattering and paramagnetic fibre re-orientation technology has been conducted for decades. Instruments such as Alert Pro (Alert Pro, 2025g) have been developed commercially but have not caught on as desirable alternatives to laboratory methods for reasons which are unclear. The Alert Pro and a similar instrument have been discontinued by their manufacturers.
  An opportunity exists for a research institute like the University of Novi Sad, Department of Environmental Engineering, Faculty of Technical Sciences to develop cost-effective light scattering and paramagnetic fibre re-orientation technology with appropriate algorithms as part of an Action Research Plan to Control Exposure to Asbestos and Eliminate Asbestos-Related Diseases.
- H Begin training in asbestos identification, quantitative and qualitative risk assessment, and safe work procedures for safety representatives and managers of companies with the hazards of asbestos. Appendix A outlines one possibility.

The elements outlined above are based on progressive and parallel endeavours proceeding from hypothesis-generating and pilot projects of lower statistical power to more exacting research of higher statistical power. The elements are also based on educational, pragmatic, and regulatory programs designed to reduce the future decades-long process of appearance of asbestos-related disease.

The suggested elements are not exhaustive, nor are they stated as a chronological chain of step-by- step events. They can be implemented in parallel as independent entities according to resources and priorities of the relevant institutions, or asymmetrically by legislatively-mandated ad hoc entities according to actual conditions in Serbia. The important issue is that they are strategically implemented as comprehensive plan to Eliminate Asbestos-Related Diseases.

A preferred method to help ensure funding, resources, and authority could be to legislatively mandate an ad-hoc scientific organization to carry out the plan to eradicate asbestos related diseases by a fixed date with annual reports.

CONCLUSION

The effort has already begun with the publication of AAAWQ. The University of Novi Sad, Department of Environmental Engineering, Faculty of Technical Sciences, with its current level of expertise concerning asbestos, may be poised to take the lead in becoming a Center of Excellence to lead the pragmatic and scientific efforts to Eliminate Asbestos-Related Diseases in Serbia according to international standards.

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Appendix A

1. Knowledge Bases for OEHS Professional Certification as a CIH

https://gobgc.org/applicants_CIH/ outlines the rubrics that all OEHS professionals must master in order to pass the academic and experience-based requirements to becomes a CIH (Certified Industrial Hygienist). Examinations are rigorous, and the last data I have available suggest that first time examinees have a 50% success rate.

IOHA maintains a process of mutual recognition of certification according to the certifying bodies, for example, South Africa, United States, UK, and Canada.

The Board for Global EHS Credentialing set criteria for multiple occupational and environmental credentials. Note that tough Ethical Standards are a requisite of such credentials.

- The sixteen (16) rubrics or knowledge bases to write the CIH exam are: Air Sampling & Instrumentation,
- Analytical Chemistry
- Basic Science Biohazards
- Biostatistics & Epidemiology Community Exposure Engineering Controls/Ventilation Ergonomics
- Health Risk Analysis & Hazard Communication IH Program Management
- Noise
- Non-Engineering Controls
- Radiation – Ionizing and Non-ionizing Thermal Stressors
- Toxicology
- Work Environments & Industrial Processes

2. Pragmatic Educational Programs for OEHS Training

One of these Programs is set by the Occupational Hygiene Training Association (OHTA).

“The Occupational Hygiene Training Association is a not-for-profit organization with a mission to provide consistent, quality training on the core aspects of occupational hygiene (also known as industrial hygiene) and related health and safety topics. We are a global organization with approved trainers in both underserved and developed countries.”

Training is done in person and on-line by “appoint OHTA Trainers who have the required capability and resources to run these courses successfully.” Each course has an invigilated (supervised) exam process. Asbestos training is but one of the modules.

OHTA modules are already delivered in English, some modules are available in French, and the possibility exists to translate into Serbo-Croatian.

ANALYSIS OF THE CAUSES AND ENVIRONMENTAL CONSEQUENCES OF ELECTRIC VEHICLE FIRES

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Abstract: This paper analyses thermal, mechanical and electrical effects which result in overheating, ignition of batteries and fire of the electric vehicle (EV), especially in the cases of extreme working conditions and traffic accidents. The paper also analyses consequences of vehicle fires in the open air and the effects of fire extinction on the environment. There is also a risk of re-ignition of the EV fire. Although a battery monitoring system (BMS) monitors temperature and voltage to maintain optimal working conditions, in the event of a failure, batteries may overheat, burst, throw sparks, release flammable gases and toxic fumes, which can further lead to ignition and fire, throwing flames and gas explosions. Typical electric vehicle fires include: spontaneous combustion fires, fires during charging, traffic accident fires, re-ignition fires, and external factor fires. A particular danger is the spread of EV fires in closed spaces. Besides waste water, the consequences of EV fires are toxic gases and vapours released in the air, various metals in the soot, as well as organic compounds of polycyclic aromatic hydrocarbons and water-soluble anions present in both soot and ash. In order to minimize the harmful effects and environmental pollution, advanced firefighting procedures and techniques are applied.

Keywords: *Electric vehicles; Environmental protection; Toxic gases; Vehicle fires.*

INTRODUCTION

In extreme working conditions and in case of traffic accidents, batteries in electric vehicles (EVs) are subjected to different external influences: thermal, mechanical and electrical (Sun, 2020), (He, 2020). There is also the risk of fire due to self-ignition of batteries. Lithium-ion batteries used in most portable electronic devices usually do not have extreme working conditions during exploitation. In the case of electric vehicles, batteries suffer constant and rapid changes due to acceleration and deceleration in complex driving conditions in city traffic, as well as on the road. The capacities of batteries in electric vehicles are thousands of times higher than in portable devices, so the risk of fire is significantly higher and therefore safety measures are more advanced.

A battery monitoring system (BMS) monitors temperature and voltage to maintain optimal conditions. It is necessary to ensure proper distribution of electricity and voltage and to provide cooling. In the event of a failure in the BMS, batteries may overheat, burst, throw sparks, release flammable gases and toxic fumes, which can further lead to ignition and fire, throwing flames and gas explosions (Lecocq, 2012). Typical electric vehicle fires include: spontaneous combustion fires, fires during charging, traffic accident fires, re-ignition fires, and external factor fires. A particular danger is the spread of electric vehicle fires in closed spaces (RISE, 2023) such as tunnels and multi-vehicle parking garages. There are also consequences of vehicle fires in the open air and the effects of fire extinction on the environment.

CAUSES OF ELECTRIC VEHICLE FIRES

Thermal effects on EV batteries

Extremely high and extremely low temperatures affect battery performance. Batteries work best at temperatures between 20 and 30 °C. The temperature and voltage ranges required for optimal battery operation, as well as the critical temperatures and voltages for compromised safety of an electric vehicle battery, are given in Figure 1. Long-term use of an EV in extreme temperatures reduces the life of the batteries. In conditions of high temperatures, unwanted chemical reactions take place in the batteries, so if the ability of thermal dissipation is reduced, it can result in overheating, ignition of the batteries and fire of the electric vehicle. At low temperatures, the internal resistance of batteries is increased, which leads to metal deposition and heating effects inside the batteries. It can also cause batteries to catch fire.

Overheating of the battery, that is, an increase in temperature by more than 10 °C/min, occurs due to violent exothermic thermochemical and electrochemical chain reactions that exceed cooling capabilities. The risk of thermal breakdown occurs when the battery temperature exceeds about 150 °C. As processes take place within individual cells, the risk of fire increases if overheating spreads throughout the battery. After overheating, a large amount of smoke is released through the safety valve or cracks in the battery case (Larsson, 2017). This smoke consists of a mixture of flammable and toxic gases, such as hydrogen fluoride (HF), hydrogen cyanide (HCN), carbon monoxide (CO), etc. Inhaling these gases can be very dangerous and cause fainting, headache, coma and even death. Fluorides as ingredients in lithium-ion batteries can form phosphorus oxy fluoride (POF_3), which can be even more toxic than hydrogen fluoride. The chemical reactions that occur during the formation of HF and POF_3 are given by the following equations:

$$LiPF_6 \rightarrow LiF + PF_5 \quad (1)$$

$$PF_5 + H_2O = POF_3 + 2HF \quad (2)$$

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF \quad (3)$$

Gas emissions vary depending on the manufacturer and battery type. The test (Stephens, 2019) found that HF concentrations were higher in lithium-iron-phosphate (LFP) cells than in lithium-nickel-manganese-cobalt (LNMC) and lithium-manganese-oxide (LMO) cells, which emitted more gas in a shorter time, while the total amount of HF released was approximately the same. The total amount released in an electric vehicle fire is believed to be about 2 times higher than that measured in internal combustion engine vehicle (ICEV) fire testing (Lecocq, 2012). By testing three ICEVs and two battery electric vehicles (BEVs) in fires, emissions of combustion products were measured, and the presence of various metals in the soot was determined, such as: aluminium (Al), cadmium (Cd), lead (Pb), cobalt (Co), chromium (Cr), copper (Cu), lithium (Li), manganese (Mn), nickel (Ni), zinc (Zn), as well as organic compounds of polycyclic-aromatic-hydrocarbons (PAHs) and water-soluble anions: fluoride (F-), chloride (Cl-) and bromide (Br-), present in both soot and ash. The measured amounts of toxic gases (CO_2, CO, THC – total hydrocarbons, NO, NO_2, HF, HCl, HCN) are given in Table 1. In the tests of ICEV and BEV from manufacturer A, and BEV from manufacturer B (Table 2), the results of chemical analyses of soot, ash and smoke during vehicle fires were obtained (Willstrand, 2020).

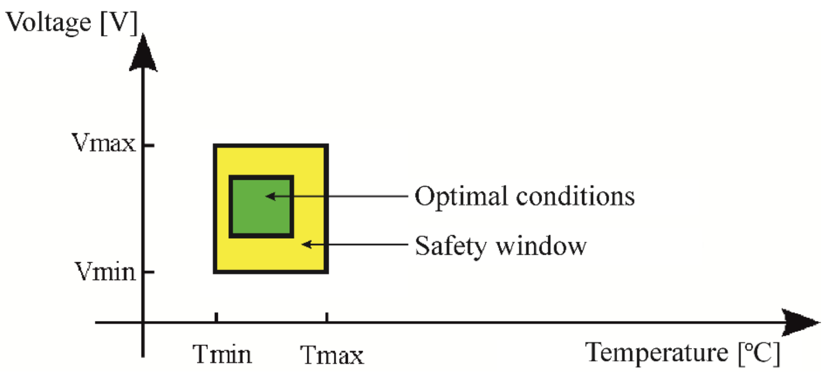

Figure 1. Temperature and voltage ranges for optimal battery operation.

Table 1. Toxic gas emissions during vehicle fire testing (Lecocq, 2012; Truchot, 2016; Lönnermark, 2006).

Vehicle type	Mass (kg)	Stored energy	Total amount of combustion products							
			CO_2 [kg]	CO [kg]	THC [kg]	NO [g]	NO_2 [g]	HF [g]	HCl [g]	HCN [g]
ICEV1	1128	Full tank of diesel fuel	508	12.0	2.4	679	307	621	1990	167
BEV1	1122	16.5 kWh 100% SOC	460	10.4	2.4	500	198	1540	2060	113
ICEV2	1404	Full tank of diesel fuel	723	15.7	2.9	740	410	813	2140	178
BEV2	1501	23.5 kWh 100% SOC	618	11.7	2.7	770	349	1470	1930	148

Table 2. The total heat released and mass loss during vehicle fire testing (Willstrand, 2020).

Vehicle type (year of production)	ICEV A (2011)	BEV A (2019)	BEV B (2016)
Stored energy	44 l of diesel fuel	40 kWh, SOC=80%	24kWh, SOC=80%
Total heat released (GJ)	5.9	5.2	6.7
Mass loss (kg)	252	247	400
Percentage mass loss (%)	19.0	15.6	25.6
Effective heat of combustion (MJ/kg)	23	21	17

The total heat released, effective heat of combustion and mass loss in vehicle fire testing are given in Table 2 (Willstrand, 2020). The heat release rate (HRR) is an even more important fire parameter than the total amount of heat released. This factor represents the fire strength or intensity and determines the fire hazard. The heat release rate in ICEV and BEV fires measured in testing is usually in the range of 2 MW to 11 MW. Other important parameters are: toxicity of gases and vapours, occurrence of dense smoke, explosion risk, occurrence of afterburning, etc.

According to the regulation, testing is carried out at four levels: at the cell level, at the module level, at the vehicle battery pack level and at the entire vehicle level. The test setup for the battery pack level fire is shown in Figure 2 (Willstrand, 2020). The same setup is used for the whole vehicle fire test as given in Figure 3 (Willstrand, 2020).

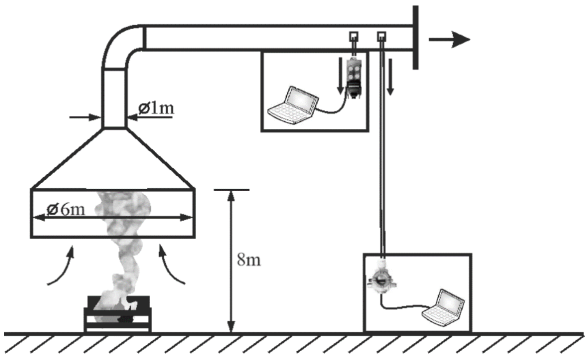

Figure 2. Battery pack fire test setup.

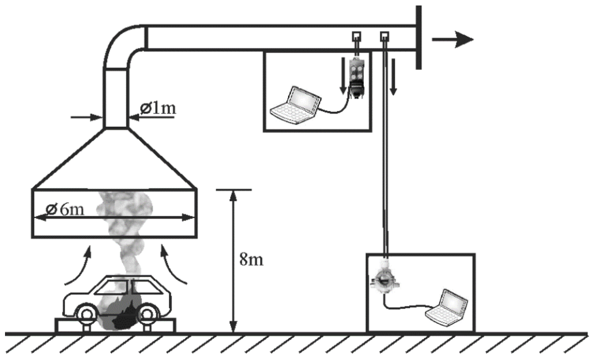

Figure 3. Vehicle fire test setup.

Flammable gases can be ignited by sparks, an electric arc, or other ignition source. The resulting flame can further heat the battery. If the rate of gas release from the battery case is less than the rate of gas generation, the battery cell may rupture. Venting the gases through a safety valve does not prevent external heating of the cell in the event of a flame or burning batteries in the vicinity of the cell. If the released gases accumulate in a confined space and mix with ambient oxygen and there is an ignition source, an explosion is possible. The energy released in a battery fire in an electric vehicle (models manufactured in 2018) with a range of 200 km is approximately equal to the energy released in a fuel tank fire sufficient for 700 km of driving in an ICEV, according to a report by the (US Department of Energy, 2024).

If we assume that the thermochemical energy released in an electric vehicle battery fire is 5 to 10 times greater than the electrical energy of the battery, it can be determined that in an electric vehicle battery fire of 90 kWh the total energy value is between 1.64 GJ and 3.28 GJ. With such a battery the range is 400 km. The same range would be achieved by an ICEV that can travel 100 km with 7.3 litres of fuel, if there are about 30 litres in the tank. In this case, it can be determined that the heat released from the combustion of the fuel from the tank would be approximately 1 GJ if the fuel releases 47 MJ/kg and if the mass-to-volume ratio is 0.75 kg per litre. Depending on the amount of fuel in the tank, proportionally less energy will be released, but this is not the case of a lithium-ion battery fire, because the heat release does not depend so much on the battery's state of charge (SOC), which ranges from 20 to 100%. From this consideration, it is obvious that an electric vehicle fire is more difficult to extinguish than a fossil fuel vehicle fire. In an EV, in addition to the battery that stores energy as well as the fuel tank in an ICEV, there is a significant amount of other flammable materials.

The mass of plastic in an EV is between 100 and 200 kg, while in an ICEV the mass of plastic is usually less than 50 kg. The heat of combustion of common plastic materials without combustion product is e.g. 38.4 MJ/kg for polyethylene, 27 MJ/kg for polystyrene, 17.95 MJ/kg for polyvinyl chloride, and is not much lower than the heat of combustion of gasoline, which is about 47 MJ/kg. This significantly increases the total amount of heat released by the EV fire.

Mechanical impact on EV batteries

As with all other vehicles, electric vehicles can be expected to suffer traffic accidents and mechanical damage during use. This is why battery cells are protected in module frames and battery pack enclosures. A new technology under development is the direct placement of batteries in the vehicle body (Cell to Body), for even better protection. The battery is usually located in the safest part in terms of mechanical influences (safety zone), as in Figure 4.

Figure 4. Battery location in the vehicle safety zone (Markus, 2016)

At the high speeds, possible with electric vehicles in a traffic accident, even the highest level of mechanical protection is not sufficient to prevent battery damage and a possible vehicle fire. The fire of a Tesla Model S due to a high-speed impact with a concrete bumper at the entrance to a tunnel in Austria on October 17th, 2017. is shown in Figure 5. In extinguishing the fire 35 firefighters, 5 fire engines and an ambulance were involved. After extinguishing the fire, a large amount of water was used to cool the battery, and the vehicle was quarantined for 48 hours after the accident to monitor for possible re-ignition.

Figure 5. Tesla Model S fire in Austria on October 17th, 2017 (Electrek, 2017)

Electrical cause of EV fires

Batteries have electrical characteristics that can be compromised by frequent and rapid charging and discharging of the batteries, as well as by negative effects due to extremely harsh conditions. Usually, a change in electrical characteristics is accompanied by Joule losses, battery heating and internal chemical reactions, which can further lead to a short circuit in the battery. Short circuits in the high-voltage circuit, overcharging of the battery and overheating are also possible, especially in the case of inadequate control of the electrical energy transfer or a failure in the BMS.

ENVIRONMENTAL CONSEQUENCES OF ELECTRIC VEHICLE FIRES

Electric vehicle and battery fires are difficult to extinguish and require a large amount of extinguishing agent. EV's fires are particularly dangerous because they can re-ignite suddenly days after the initial fire. One way to prevent re-ignition is to allow the vehicle or battery to burn completely, thus consuming all the active material. In practice, this is not the case, as fire extinguishing and fire suppression are most often required. Dry powders that are normally used to extinguish fires can be used to control electric vehicle fires, but they cannot cool the battery pack and prevent re-ignition. If water is used for extinguishing, it can suppress the fire and cool the electric vehicle, but it can cause electrical faults and react with the lithium in the batteries, releasing various toxic gases and leaving toxic water after extinguishing. Flammable gases can also be released, and re-ignition can also result in an explosion. Since the capacity of any fire extinguishing device inside an electric vehicle would have to be limited, such a device would not be sufficient to suppress the fire. Although the primary task is to reduce the temperature of a battery that has begun to overheat, the access to the batteries in electric vehicles is a significant problem. The batteries are hermetically sealed to prevent moisture and dust from entering, and are armoured to ensure resistance to mechanical shock. Therefore, water used for extinguishing only affects visible flames and the external surface of the battery pack, as well as the materials surrounding it. Tests have shown that around 10 000 litres of water are needed to extinguish a fire in the entire vehicle, which also depends on the size, type and location of the battery. The flow rate of about 200 l/min for cooling and extinguishing the fire is high. This can generate large amounts of waste water. Large amounts of fire extinguishing agents will also be dissolved in this water, which is why it is necessary to find the optimal proportion of the amounts of agents used for extinguishing. In order to minimize waste water and prevent it from polluting the environment in an uncontrolled manner, firefighting submersion pools are used (Figure 6), as well as containers into which the burning vehicle is transferred and immersed in a sufficient amount of water (Figure 7).

Figure 6. Water submersion pool (Garrison Flood Control, 2025)

Figure 7. Container with the immersed vehicle (Firehouse, 2021)

CONCLUSION

Electrical vehicle fires are initiated by thermal, mechanical and electrical causes, especially in the cases of extreme working conditions and traffic accidents. There is also a risk of re-ignition of the EV fire and a risk of self-ignition of batteries. The total amount of heat in the case of EV fire is greater than in the case of ICEV fire, so that it is more difficult to extinguish the EV fire and it is necessary to use extinguishing agents and water in larger amounts. Besides waste water, the environmental consequences of EV fires are toxic gases (CO_2, CO, NO, NO_2, HF, HCl, HCN, THC, …) and vapours released in the air, various metals in the soot (Al, Cd, Pb, Co, Cr, Cu, Li, Mn, Ni, Zn, etc.), as well as organic compounds of polycyclic aromatic hydrocarbons and water-soluble anions (F-, Cl- and Br-), present in the soot and ash. In order to minimize the harmful effects and pollution of the environment, advanced firefighting procedures and techniques are applied, such as submersion pools and containers into which the burning vehicles are transferred and immersed in a sufficient amount of water.

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CHEMICAL SAFETY AND OCCUPATIONAL HEALTH IN EDUCATIONAL AND RESEARCH LABORATORIES

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Abstract: Working with chemicals in educational and scientific research institutions involves specific risks to the health of employees, students, and the environment. The increasing complexity of laboratory activities, driven by advances in equipment and technology, necessitates a comprehensive and systematic approach to chemical risk management. This paper analyzes the concept of the Chemical Hygiene Plan (CHP) as a regulatory requirement in the United States and examines the European Union's approach, which, through integrated regulations such as REACH and CLP, ensures a high level of protection without mandating a unified document. The practice in the Republic of Serbia is also reviewed, where certain elements of the CHP are implemented through various laws and regulations. Particular attention is given to the challenges and shortcomings in Serbian educational and research institutions, such as the absence of a comprehensive document, reliance on individual responsibility, and inconsistent application of standard procedures. Based on this comparative analysis, the paper proposes the development of a national guide or template for a document based on the model of CHP, tailored for educational and scientific research institutions. By integrating existing regulations and good practices, such a document would support a systematic improvement in occupational safety and health in laboratories.

Keywords: *Chemical Hygiene Plan; Chemical Safety; Laboratory Risks; Occupational Safety and Health; Educational and Scientific Institutions.*

INTRODUCTION

Working with chemicals in educational and scientific research institutions entails specific risks to the health of employees and students, as well as to the environment. The increasing number of laboratories, alongside advancements in experimental equipment and technologies, has contributed to the growing complexity of laboratory operations and increased the risks associated with conducting chemical experiments (Xu et al., 2023). Potential hazards in academic laboratories are up to 11 times higher than those in commercial laboratories across various industrial sectors, with incidents including injuries and fatalities resulting from fires, explosions, equipment failures, as well as acute and chronic poisonings (Fatemi et al., 2022).
Despite the key role of chemical laboratories in advancing scientific research and innovation, occupational health and safety management systems, along with the awareness of laboratory

staff, have failed to keep up with the growing complexity and volume of modern experimental activities (Wang et al., 2025). In laboratories where numerous users with varying levels of knowledge and experience operate, the systematic management of chemical risks is essential. Although the legal framework in the Republic of Serbia (RS) mandates risk assessment, employee training, and the use of personal protective equipment (PPE), there is often a lack of a comprehensive document that integrates all aspects of chemical safety in laboratory settings. In contrast, laboratories in the United States that use hazardous chemicals are required to develop and implement a Chemical Hygiene Plan (CHP), a document that outlines specific procedures, responsibilities, exposure control measures, and emergency protocols, as mandated by OSHA regulation 29 CFR 1910.1450 (Occupational Exposure to Hazardous Chemicals in Laboratories). The presence of a CHP, along with the appointment of a Chemical Hygiene Officer (CHO), is considered essential for maintaining a safe laboratory environment (Weil, 2016).

Bearing in mind that the current practice in educational and research institutions in Serbia shows a decentralized approach to chemical safety, with the existence of numerous partial acts and uneven application of procedures, this paper will analyze the concept of CHP, its basic elements and goals, then the approaches of the EU and the Republic of Serbia in this area, as well as the need for a systemic solution through the introduction of a unique approach to chemical risk management. Special emphasis will be placed on the role of a unique chemical safety management document as an engineering and managerial tool in improving the safety and culture of working with chemicals.

COMPARATIVE OVERVIEW OF CHEMICAL RISK MANAGEMENT APPROACHES IN THE USA, EU, AND SERBIA

Chemical risk management in the USA: Chemical Hygiene Plan (CHP)

The Laboratory Safety Chemical Hygiene Plan (CHP) is a document that defines safety measures, procedures, and protocols for the safe handling of hazardous chemicals in laboratory or industrial settings in the USA, as proposed by The Occupational Safety and Health Administrations (OSHA) Occupational Exposure to Hazardous Chemicals in Laboratories standard (29 CFR 1910.1450), to protect laboratory workers from harm caused by hazardous chemicals. This plan is of particular importance in educational and research laboratories and is often part of a wider occupational safety and health plan. In accordance with the requirements of the mentioned standard, each employer is required to establish and implement a CHP that must contain the following elements:

- Standard Operating Procedures (SOPs) relating to the safety and health aspects of activities involving hazardous chemicals.
- Criteria for the determination and implementation of control measures, including

engineering controls (e.g. fume hoods), use of personal protective equipment (PPE) and implementation of hygiene practices.
- Regular checking of the functionality of protective equipment and implementation of specific measures to ensure its proper operation.
- Access to laboratory staff to the following information: the content of the laboratory standard and appendices, location and availability of CHP, permissible exposure limits (PELs) for OSHA regulated substances or recommended exposure limits (RELs) for other hazardous chemicals, symptoms of exposure to hazardous chemicals, location of reference material, including safety data sheets (SDS).
- Defining situations that require the prior approval of the employer or his representative for the performance of certain activities.
- Designation of the Chemical Hygiene Officer (CHO) and, if necessary, the formation of the Chemical Hygiene Committee.
- Provision of additional protection measures for particularly dangerous substances, such as selective carcinogens, reproductive toxins, and substances of high acute toxicity, including marking of special work zones, use of protective systems (e.g. fume hoods and glove boxes), special procedures for waste removal and decontamination.
- Evaluation of the effectiveness of the CHP and update the CHP as necessary, at least once a year.

Employee training must include methods for detecting the presence of hazardous chemicals, information on physical and health hazards, as well as protective measures that include proper work and emergency procedures and the use of PPE. The employer is obliged to provide medical assistance and consultation free of charge to all employees who handle hazardous chemicals, in the event of symptoms of exposure, exceeding the permitted exposure levels, or incidents such as leaks, explosions, and other adverse events.

Chemical risk management in the EU

EU-OSHA (European Agency for Safety and Health at Work) does not have a single document called "Chemical Hygiene Plan (CHP)", as OSHA has in the USA, but it has developed guidelines and tools covering the same or similar areas, applying different normative and organizational approaches. EU uses an integrated approach through laws and tools, the most important of which are:

- The REACH regulation (EC 1907/2006) is the main EU law for the protection of human health and the environment from the risks posed by chemicals. It covers the registration, evaluation, authorization and restriction of chemicals with a focus on the safe use of chemicals and communication through SDS.
- The CLP regulation (EC 1272/2008) refers to the classification, labelling and packaging of chemicals, which is the basis for hazard labelling in the workplace. It aligns previous EU legislation with the GHS (Globally Harmonized System of Classification and Labelling of Chemicals), the United Nations system for identifying hazardous chemicals and notifying users of those hazards. The CLP Regulation is

closely related to the REACH Regulation.

- Directive 98/24/EC on the protection of the health and safety of workers from the risks related to chemical agents at work, establishes that employers are obligated to identify the presence of hazardous chemical agents in the workplace and assess the associated risks to the safety and health of employees. Based on this assessment, employers must inform and train workers, and implement control measures to eliminate or minimize the risks arising from exposure to hazardous chemicals.
- Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work, mandates stricter control measures and record-keeping requirements for these substances, along with mandatory worker information and health surveillance.

Instead of one prescribed document like CHP, EU-OSHA promotes various guides, manuals, checklists and tools for hazard identification, and risk assessment (OIRA tools (Online Interactive Risk Assessment). The question arises why the European Union has not adopted a single document like CHP. The European legal framework is primarily oriented towards results (what should be achieved) rather than prescribing the format of the document (how to do it). Member States are left with the flexibility to develop their own documents, provided they meet the objectives defined by the relevant directives.

Chemical risk management in the Republic of Serbia

As in the EU, in the Republic of Serbia, there is no single document called the "Chemical Hygiene Plan (CHP)", but its key elements are incorporated into the existing legislative framework. Therefore, the domestic legislative framework includes a series of regulations that deal with chemical risk management and to a significant extent cover the elements that such a plan would contain.

- The Law on Occupational Safety and Health ("Official Gazette of RS", No. 35/2023) mandates the obligation to conduct a risk assessment at every workplace, including chemical risks. It also requires the development of a risk assessment document, implementation of preventive measures, employee training, use of PPE, and the preparation of safe work instructions.
- The Rulebook on Preventive Measures for Safe and Healthy Work when Exposed to Chemical Substances ("Official Gazette of RS", No. 106/2009, 117/2017, and 107/2021) prescribes the minimum occupational safety and health requirements that employers must fulfill to ensure the implementation of preventive measures to eliminate or reduce the risks of injuries or health impairments that may arise from exposure to chemicals in the workplace.
- The minimum requirements that employers must accomplish to ensure the implementation of preventive measures aimed at eliminating or reducing the risks of health impairments in employees exposed or potentially exposed to carcinogens or mutagens in the workplace, are prescribed by the Rulebook on Preventive Measures for Safe and Healthy Work when Exposed to Carcinogens or Mutagens ("Official

Gazette of RS", No. 96/2011 and 117/2017).

- The Law on Chemicals ("Official Gazette of RS", No. 36/2009, 88/2010, 92/2011, 93/2012, and 25/2015) regulates the trade, storage, and use of chemicals and is aligned with the European REACH and CLP regulations. The availability of SDS for all chemicals is mandatory, as well as the proper labelling and storage of chemicals.
- The Law on the Control of Major Accident Hazards Involving Dangerous Substances ("Official Gazette of RS", No. 94/2024) and the Law on Disaster Risk Reduction and Emergency Management ("Official Gazette of RS", No. 87/2018) introduce additional obligations for entities handling larger quantities of hazardous substances, including the development of internal and external protection and emergency response plans in the event of chemical accidents.

A comparison of chemical risk management in the USA, EU, and Serbia shows alignment in core safety principles, such as the identification of chemicals, risk assessment, access to SDS, implementation of preventive measures, use of PPE, and training of personnel, but notable differences in implementation and structure (Table 1).

Table 1. Comparative overview of chemical risk management approaches in the USA, EU, and Serbia.

Element	USA	EU	Serbia
Regulatory Basis	OSHA Standard 29 CFR 1910.1450	REACH, CLP, 98/24/EC, 2004/37/EC	Laws and by-laws
Key Document	√ (CHP)	×	×
Identification of chemicals	√	√	√
Risk Assessment	√	√	√
SDS Access	√	√	√
SOPs	√	○	○
Preventive Measures	√	√	√
PPE	√	√	√
Training of Personnel	√	√	√
Emergency Planning	√	○	○
Appointed Role	√	○	○
Exposure Monitoring	○	√	√
Revision and Evaluation	√	○	○

√ (existing/mandatory); × (not existing); ○ (partially existing)

In the USA, chemical safety is centrally regulated through OSHA Standard 29 CFR 1910.1450, which mandates a Chemical Hygiene Plan (CHP). In contrast, the EU and Serbia manage chemical risks via multiple regulations, without a unified document. SOPs are legally required in the US as part of the CHP, while in the EU and Serbia, they are optional, although some institutions may develop them internally. Emergency planning is another area of difference and it is explicitly defined in US CHPs, whereas in the EU and Serbia, it is addressed more broadly through general safety laws and often not integrated into daily lab routines. Another key difference concerns the designation of personnel responsible for chemical safety. In the USA, appointing a CHO is mandatory to ensure compliance with the CHP. The EU does not mandate an equivalent role, although Laboratory Safety Officers may be appointed at the institutional level. In Serbia, there is no legally defined position dedicated specifically to chemical safety; instead, these responsibilities are typically assigned to occupational safety professionals (OSH officers), often employed through external agencies. This outsourcing model can reduce supervision and break continuity in daily chemical safety management. Exposure monitoring requirements are clearly defined in the USA, where regular monitoring must occur if chemical exposure is likely to exceed permissible limits. Similar obligations exist in the EU under chemical agents directives, but their implementation varies by country. In Serbia, although regulations provide for exposure monitoring, in practice this is infrequent and typically limited to high-risk industrial settings rather than educational or research laboratories. Lastly, the US mandates annual review of the CHP, while the EU leaves updates to national discretion. In Serbia, documents are only updated when workplace conditions change, with no systematized review process.

Chemical risk management practices in educational and research laboratories in Serbia

Although there is no legal obligation to develop a single document entitled the CHP, many educational and research institutions in Serbia implement various internal acts and procedures that, collectively, functionally cover certain elements of the CHP. The CHP is a unified, comprehensive document with clearly defined responsibilities, procedures, and emergency response plans. In Serbia, these contents are mostly distributed across several different documents and are often implemented inconsistently, especially in smaller institutions. However, the approach is frequently decentralized and varies significantly from one institution to another, depending on work organization, staffing resources, and available equipment. It is common for such institutions to engage an external agency for occupational safety and health services, which often leads to confusion among employees regarding whom to contact on these matters. This highlights the need for systemic standardization through the development of a national guide or recommendations for creating a document modeled on CHP, which would integrate all relevant legal requirements and best practices into a single document applicable in laboratory and educational-research settings.

All public institutions in the Republic of Serbia have a Risk Assessment Act for employees, including chemical risks in laboratories. However, these acts are often general in nature and do not include specific chemicals used in individual practical exercises or research projects. Students are not always formally included in these documents, except in the sections concerning the use of PPE and laboratory conduct rules. Most higher education institutions have internal laboratory work regulations, which typically include basic rules: mandatory use of PPE, prohibition of food and drink, prohibition of conducting experiments without supervision, and procedures in case of chemical spills or injuries. In some institutions, SOPs have also been developed for specific activities (working with acids, flammable solvents, glassware, autoclaves, waste management), but their availability and consistent implementation vary even within the same institution. In research institutes, the safety system is more highly organized, with the implementation of standards such as ISO 45001. Many institutes apply quality standards and good laboratory practices, which include safety regulations, documented procedures for the use and storage of chemicals, chemical waste management, and emergency response plans. In secondary schools with chemical laboratories, as well as in vocational colleges, basic laboratory regulations and the requirement to wear PPE are often present. However, formal chemical-specific risk assessments are rare, and training for teaching and non-teaching staff is often formal and periodic, without deeper specialization.

Taking all of this into account, the following challenges in practice have been observed: (1) Lack of a unified document that integrates all aspects of chemical hygiene; (2) Reliance on personal responsibility without systematic oversight; (3) Weak linkage between theoretical training and actual laboratory procedures; (4) Incomplete records of chemicals and exposures in certain institutions. These examples indicate the need for a systemic approach to chemical risk management through the development of a national guide and templates that would standardize practice, ensure clear documentation, and enable consistent implementation of all safety measures when working with chemicals in educational and research laboratories.

CONCLUSION

Safe handling of chemicals in laboratories requires a comprehensive and systematic approach, which includes the identification of chemical hazards, implementation of control measures, and continuous education of staff and laboratory users. While in the USA the implementation of a CHP is a legal requirement in academic and research laboratories under OSHA standards, in the EU, a high level of protection is achieved through regulations such as REACH and CLP, as well as through EU-OSHA guidelines, without a formal requirement for a unified document like the CHP. The Republic of Serbia, aligning its legislation with the European framework, applies similar principles through mandatory risk assessments, chemical regulations, and occupational health and safety rules. Although there is no formal obligation to develop a CHP in Serbia, its key elements are already partially implemented through existing legal acts. However, in practice, the application of safety measures in Serbia is often fragmented, and systemic standardization is largely lacking. Therefore, there is a strong need to improve staff education, as well as to develop a national guide or a CHP template that would consolidate all relevant regulations and good practices and serve as a tool for educational and research institutions in the field of chemistry and related sciences.

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PHYTOCHEMICAL RESPONSE OF MEDICINAL PLANTS TO ECOLOGICAL STRESSORS: A CASE STUDY OF *PRIMULA VERIS*

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Primula veris L. (Primulaceae), commonly known as cowslip, is a medicinal plant of significant pharmacological and ecological interest, traditionally valued for its expectorant, anti-inflammatory, and antioxidant properties. This condensed review investigates the influence of ecological stressors, such as climate variability, cultivation methods, and environmental pollution, on the phytochemical profile of *P. veris*, as a representative medicinal plant. The focus is placed on key secondary metabolites including flavonoids, saponins, and phenolic glycosides, which are most abundant in the flowers and leaves. Evidence shows that wild populations of *P. veris* exhibit greater phytochemical diversity and higher metabolite concentrations than cultivated counterparts, likely due to natural exposure to abiotic and biotic stress. Moreover, populations distributed across different climatic gradients show marked variability in the accumulation of bioactive compounds, underscoring the plant's metabolic plasticity and environmental adaptability. While direct studies on the effects of pollutants such as heavy metals or ozone are limited, indirect data suggest that such stressors can induce the synthesis of protective secondary metabolites, enhancing both the plant's ecological adaptability and medicinal quality. These findings support the potential use of *P. veris* as a bioindicator species and highlight the need to integrate environmental parameters into the evaluation and management of medicinal plants. Understanding these phytochemical responses is essential for developing sustainable cultivation practices, conserving wild populations, and ensuring consistency and efficacy in herbal product development.

Keywords: Primula veris *L.*; *Medicinal plants; Phytochemical variability; Environmental stress; Bioindicators; Flavonoids.*

INTRODUCTION

The genus *Primula*, belonging to the Primulaceae family, is one of the largest and most diverse groups of flowering plants, predominantly distributed across the cold and temperate regions of the Northern Hemisphere. Among its numerous species, *Primula veris* L., commonly known as cowslip, holds particular significance due to its long-standing use in traditional European herbal medicine. As a perennial herbaceous species, *P. veris* has been widely recognized for its expectorant, anti-inflammatory, and sedative properties. Its therapeutic value is primarily attributed to its rich phytochemical composition, which includes flavonoids, phenolic glycosides, saponins, tannins, and volatile oils. These secondary metabolites not only contribute to the plant's medicinal efficacy but also serve important ecological functions, such as antioxidant defense and protection against herbivores and environmental stressors (Colombo, 2017; Jetter, 2006; Richards, 2003).

In recent decades, the increasing demand for *P. veris* in the herbal and pharmaceutical markets has led to intensified harvesting, posing a threat to wild populations. At the same time, escalating environmental challenges, such as climate change, habitat degradation, and anthropogenic pollution, have raised questions about how ecological variables influence the biosynthesis and accumulation of bioactive compounds in medicinal plants. Notably, environmental stressors such as elevated UV-B radiation, tropospheric ozone, drought, soil salinity, and nutrient imbalances have been shown to modulate secondary metabolic pathways (Harborne, 2000; Steinkellner, 2007), thereby affecting both the yield and composition of pharmacologically active constituents. These factors not only affect the quality and concentration of phytochemicals but may also lead to the emergence of novel compounds, highlighting the adaptive capacity and ecological sensitivity of the species.

Given the pronounced sensitivity of its secondary metabolism to ecological conditions, *P. veris* represents a promising candidate for use as a bioindicator species in environmental monitoring. Furthermore, understanding how environmental stress shapes its phytochemical expression can provide valuable insights for the sustainable management of medicinal plant resources, as well as for the development of standardized herbal preparations. This condensed review aims to synthesize current knowledge on the phytochemistry of *P. veris*, ecological variation in secondary metabolites, and the impact of environmental pollution on its chemical profile. By integrating ecological and phytochemical perspectives, this work highlights the potential of *P. veris* as a model species for ecosystem health assessment, and contributes to the broader discourse on plant-based strategies in environmental engineering and resource management.

PHYTOCHEMICAL DIVERSITY AND ENVIRONMENTAL RESPONSIVENESS OF *PRIMULA VERIS*

Phytochemistry of *P. veris*

P. veris is a medicinal plant with a long history of use in traditional European herbal medicine. Its therapeutic properties are largely attributed to a diverse profile of phytochemicals, which vary across different plant organs, roots, leaves, and flowers (Bączek, 2017; Colombo, 2017; Richards, 2003). Among these compounds, flavonoid exudates are particularly noteworthy. They accumulate on the surfaces of aerial parts and are predominantly synthesized and secreted by glandular trichomes, microscopic structures located on the plant’s epidermis (Wagner, 2004; Richards, 2003). Within the plant, flavonoids serve multiple functions: they act as pigments, antioxidants, and exhibit anti-inflammatory and antimicrobial properties. These bioactivities are directly linked to the traditional use of *P. veris* in the treatment of respiratory and inflammatory disorders (Steinkellner, 2007).

Beyond their pharmacological potential, flavonoid exudates play critical ecological roles, including chemical defence against herbivores and pathogens, and protection from abiotic stressors such as ultraviolet radiation and drought (Jetter, 2006; Harborne, 2000; Steinkellner, 2007). Importantly, the concentration and composition of flavonoids are influenced by environmental conditions, such as light exposure, soil quality, and harvest timing, which can significantly affect the plant's medicinal quality and efficacy (Korkina, 2007; Werner, 2010).

In addition to flavonoids, the roots of *P. veris* are a rich source of phenolic glycosides, notably primverin and primulaverin, which are believed to be responsible for its expectorant, sedative, and anti-inflammatory actions. These compounds promote mucus secretion and help to alleviate coughing. Moreover, triterpenoid saponins, found in both roots and flowers, exhibit mucolytic and anti-inflammatory properties, further supporting the use of the plant in treating bronchitis and upper respiratory tract infections.

P. veris also contains volatile oils in smaller quantities, consisting of aromatic and terpenoid compounds that contribute to the plant's characteristic scent and exert mild antimicrobial effects. Additionally, tannins, which are mainly concentrated in the roots, contribute to the plant's medicinal value through their antimicrobial properties (Colombo, 2017).

Phytochemical Variability Across Ecological Conditions

Wild vs. Cultivated Populations. The phytochemical profile of *P. veris* exhibits considerable variation depending on ecological context. A comparison between the phytochemical profiles of wild and cultivated populations of *P. veris* demonstrates notable variations in both the concentration and diversity of bioactive constituents (Graikou, 2023, Stefanis, 2023). Wild populations consistently exhibited higher levels of key secondary metabolites, particularly flavonoids and saponins, a trend attributed to natural exposure to environmental stressors such as temperature fluctuations, ultraviolet (UV) radiation, interspecific competition, and herbivory. These biotic and abiotic pressures act as drivers of metabolic adaptation, promoting the accumulation of chemically diverse and functionally significant metabolites. In contrast, cultivated plants grown under standardized agronomic practices tend to experience fewer abiotic and biotic stresses, which may lead to a downregulation of defense-related metabolic pathways. This results in a more uniform but chemically less complex phytochemical profile. The reduced variability in metabolite content among cultivated populations could impact not only the medicinal potency of plant material but also its ecological adaptability (Graikou, 2023).

These findings have several important implications. First, from a conservation perspective, they underscore the ecological value of preserving wild populations, which serve as reservoirs of phytochemical diversity and genetic adaptation. Second, from an agronomic standpoint, they suggest that cultivation practices may need to be refined, perhaps through controlled stress exposure or selective breeding, to better replicate the chemical richness found in wild plants. Third, from a pharmaceutical and herbal quality control perspective, sourcing raw material from wild or semi-wild populations may be preferable when a high concentration of active constituents is desired (Apel, 2017; Stefanis, 2023). Therefore, understanding the biochemical consequences of cultivation versus natural growth conditions is vital for the development of sustainable harvesting strategies, conservation of phytochemical diversity, and standardization of plant-derived therapeutics within the context of environmental protection.

Climate Gradient Effects. P. veris growing along different climatic gradients exhibited notable differences in phytochemical profiles, particularly in the concentrations of flavonoids, saponins, and phenolic acids. These compounds, which are synthesized via specialized metabolic pathways, play essential roles in plant defense, stress tolerance, and ecological interactions. The most pronounced variability was observed in flowers and leaves, which are metabolically more active and directly exposed to environmental conditions, such as sunlight, temperature fluctuations, and moisture availability (Colombo, 2017, Jetter, 2006).

These findings support the concept that secondary metabolite accumulation in *P. veris* is highly responsive to abiotic factors. For instance, higher altitudes and lower temperatures may promote flavonoid biosynthesis due to increased UV radiation exposure, while drier or more nutrient-limited environments may enhance saponin production as a protective response. Phenolic acid levels may also fluctuate depending on oxidative stress levels caused by temperature extremes or varying soil compositions (Stapleton, 1992).

Such metabolic plasticity suggests an ecological adaptation of *P. veris* to diverse habitats, where its chemical defences are modulated to maximize survival and reproductive success. This variability not only affects the plant's interaction with herbivores and pollinators but also has implications for its medicinal value, as the therapeutic efficacy of plant-derived products is closely linked to the concentration and composition of these bioactive compounds (Colombo, 2017, Jetter, 2006).

From a conservation and sustainable use perspective, understanding how environmental gradients shape phytochemical expression is vital. It informs habitat-specific conservation strategies, guides the selection of optimal harvesting sites, and underscores the importance of environmental standardization in medicinal plant collection protocols to ensure consistent bioactive content. In this context, *P. veris* serves as a valuable model species for examining the intersection of ecological stress, chemical ecology, and sustainable resource management.

Environmental Pollution and Chemical Profile. Medicinal plants, including *P. veris*, are continuously exposed to environmental stressors that influence their physiology and phytochemical profiles. Abiotic factors such as light intensity, temperature, soil moisture, salinity, ozone, and nutrient availability significantly affect the synthesis of secondary metabolites, key compounds responsible for the medicinal quality of plant-derived raw materials. These substances, including flavonoids, saponins, and phenolic acids, are central not only to plant defense but also to the pharmacological potential of herbal products used as immunosuppressants, antimicrobials, and anticancer agents (Pant, 2021).

Although the reviewed studies do not directly evaluate the effects of specific pollutants such as heavy metals, nitrogen oxides, or persistent organic compounds on *P. veris*, indirect evidence suggests that environmental stress significantly influences its secondary metabolism. Abiotic stressors, including UV-B radiation, ozone exposure, soil salinity, drought, and temperature fluctuations, are known to trigger plant defence mechanisms that lead to the upregulation of biosynthetic pathways for secondary metabolites. In particular, increased production of phenolic compounds, including flavonoids and phenolic acids, has been documented in numerous plant species as a response to oxidative stress induced by polluted environments (Graikou, 2023; Korkina, 2007; Luo, 2021). This metabolic response likely serves multiple adaptive purposes: mitigating oxidative damage through antioxidant activity, enhancing UV protection, and reinforcing plant tissue against pathogens and herbivores. In the case of *P. veris*, which is naturally rich in antioxidant flavonoids and saponins, such stress-induced accumulation could enhance its medicinal potential, although it may also shift the balance of active constituents in ways that affect its traditional uses.

Binxhija and Ylli (2022) assessed heavy metal accumulation in *P. veris* collected from Kosovo, examining concentrations of Cd, Cu, Fe, Pb, Ni, and Zn in soil and plant tissues (roots, leaves, and flowers). Notably, elevated iron levels detected in the soil were mirrored in the roots and flowers, emphasizing the plant's capacity to uptake and reflect its surrounding chemical environment. These findings support its potential role as a bioindicator species.

Moreover, recent ecological studies suggest that plants growing in contaminated or degraded habitats may exhibit significant changes in their phytochemical profiles compared to those from unpolluted areas. These changes can be qualitative, new compounds appear, or quantitative, concentration of known compounds increases or decreases, (Pant, 2021). Such variations highlight the sensitivity of phytochemical pathways to environmental inputs, and this property positions *P. veris* as a promising candidate for use as a bioindicator species. As *P. veris* occurs across a wide range of ecological zones, from alpine meadows to forest margins, it may serve as a valuable model for tracking environmental quality. Future research should include experimental designs that expose *P. veris* to controlled levels of known pollutants (e.g., cadmium, lead, or SO_2) and monitor corresponding changes in metabolite levels using chromatographic and spectrometric methods. Additionally, field studies comparing wild populations from polluted and pristine areas would further clarify the plant's responsiveness to environmental degradation.

CONCLUSION

P. veris represents a botanically and pharmacologically valuable species, characterized by a diverse phytochemical profile that includes flavonoids, phenolic glycosides, saponins, and other secondary metabolites with proven bioactive potential. Due to the pronounced sensitivity of its phytochemical composition to external factors, *P. veris* holds potential for use as a bioindicator of environmental quality changes, which is particularly relevant in the context of contemporary challenges in ecological engineering and biodiversity management. The therapeutic efficacy of this plant is closely linked to the qualitative and quantitative composition of these compounds, which are influenced by a variety of ecological and environmental factors. Evidence presented in this paper underscores the pronounced phytochemical variability observed between wild and cultivated populations, as well as among plants growing along different climatic gradients and in polluted environments. Wild populations, shaped by natural selection and continuous exposure to abiotic stressors, tend to produce higher levels of key secondary metabolites compared to their cultivated counterparts. This highlights the ecological importance of preserving wild genetic resources and suggests that cultivation protocols may benefit from the incorporation of controlled stress conditions to enhance metabolite production. Additionally, emerging data suggest that *P. veris* responds sensitively to environmental pollution, with shifts in its phytochemical composition potentially serving as a marker of ecosystem health. Overall, a deeper understanding of the biochemical plasticity of *P. veris* in response to its environment not only supports its continued use in traditional and modern medicine but also positions the species as a promising model for future research in plant ecophysiology, pharmacognosy, and conservation biology. Further studies, especially those involving metabolomic analyses under controlled environmental conditions, are essential for optimizing both the therapeutic application and sustainable use of this medicinal plant.

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LITERATURE REVIEW: ENHANCING SAFETY MANAGEMENT SYSTEMS THROUGH INDUSTRY 4.0 TECHNOLOGIES

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Abstract: Traditional Safety Management Systems (SMS) operate reactively, addressing issues only after incidents occur. This reactive nature opens up opportunities for improvement, through the integration of advanced technologies that enhance SMS performance. Therfore, this research investigates how incorporating Industry 4.0 technologies can transition Safety Management Systems towards more proactive and preventive approaches. A comprehensive literature review identifies the key enabling technologies – Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and Augmented Reality (AR), as the most impactful in improving workplace safety. These technologies support real-time monitoring, predictive analytics, and more effective risk prevention strategies. Integrating them within existing safety frameworks not only improves working conditions but also strengthens safety culture, reduces workplace incidents, and boosts employee engagement. The study highlights the transformative potential of Industry 4.0 in reshaping Safety Management Systems.

Key words: *Safety Management Systems; Industry 4.0; Safety 4.0; Enabling technologies.*

INTRODUCTION

Traditional safety management is viewed as reactive, dealing with issues only after an injury occurs. (Joel M. Haight, Patrick L. Yorio, Kristen Rost, D.R. Willmer, 2014) (Ahmad Wahid, Muhammad Yamin Jinca, Taufiqur Rachman, Johny Malisan, 2024) Although this approach reduces the frequency of incidents, it often falls short of creating a completely incident-free workplace. (Jones, 2009) Consequently, there is an increasing need to improve safety systems by making them more proactive and preventive.

This challenge can be addressed through technological advancements, which have proven to be a valuable tool for enhancing safety performance management. (Kang, 2024)The new production paradigm, as known as Industry 4.0, presents numerous opportunities to make significant changes in production, such as work organization and the way work acitivites are performed. (Marija Savković, Marica Dašić, Marko Djapan, Miladin Z Stefanovic, Arso

Vukicevic, Ivan Macuzic, 2021) These transformations are increasingly influencing worker health and safety, and maximizing the benefits of these advancements requires a clear understanding of the ways in which emerging technologies can strengthen safety management systems and improve overall workplace safety. (Zeeshan Haider, Rein Brouwer, 2025)

While the potential of Industry 4.0 technologies to improve safety management is evident, there is still a need for more detailed research on how specific technologies can facilitate the transition from reactive safety systems to more proactive and preventive models. Therefore, this research examines which Industry 4.0 technologies are most promising for advancing safety management and overall workplace safety, with the aim of identifying the most enabling technologies and understanding how they can evolve Safety Management Systems.

METHODOLOGY

This research conducts a comprehensive, following the ProKnow - C (Knowledge Development Process – Constructivist) methodology to systematically identify relevant studies that explore the compatibility between Industry 4.0 and Safety Management Systems. (Naijela Janaina, Costa Silveira, Diogo Ferraz, Diego Scarpa de Mello, 2021)

The ProKnow – C methodology was selected for its structured approach to selecting and analysing the most impactful studies. (Everton Luiz Vieira, Sergio Eduardo Gouve a da Costa, Edson Pinheiro de Lima, Caio Ferreira, 2019)

The primary objective is to understand how Industry 4.0 technologies can support the Safety Management Systems.

In line with the first stage of ProKnow - C, the process begins with the definition of search axes and relevant keywords. (Naijela Janaina Costa Silveira, Diogo Ferraz, Diego Scarpa de Mello, Eduardo Polloni-Silva, Daisy Rebelatto, Herick Fernando Moralles, 2021) For this research, three central axes were established: *Industry 4.0*, *Safety 4.0*, and *Safety Management Systems*. Keywords such as "improvement of safety management systems," "correlation between Industry 4.0 and SMS," and "Safety 4.0" were identified and combined, resulting in nine keyword combinations that formed the basis of the literature search.

Following the second stage of ProKnow - C, the literature search was conducted across selected academic databases, including Google Scholar and ResearchGate. The review covers the past four years (2021-2025) reflecting the latest advancements and trends in both Industry 4.0 and SMS integration. As a result of this methodology, 40 articles were identified and included in the analysis.

The selected literature was analyzed to identify the most frequently mentioned enabling technologies. A Pareto Diagram was used to highlight and prioritize their importance in the context of SMS. The analysis aims to clarify how these technologies contribute to the advancement of safety management and workplace safety performance.

The research methodology is presented in Figure 1.

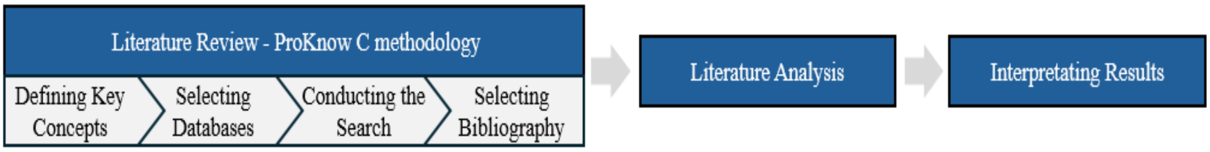

Figure 1 – Research methodology

LITERATURE ANALYSIS

As part of the ProKnow – C methodology, the literature review identified 30 studies that discuss both Safety Management Systems and Industry 4.0 technologies. To make meaningful comparisons, these studies were analyzed to determine which specific Industry 4.0 technologies they referenced.

To simplify this process and avoid repetition, this research uses an established framework that classifies the "core technologies" of Industry 4.0 based on the existing literature. Since there are several models of Industry 4.0, this study adopts the one presented in *Bridging the Gap: Qualitative Comparative Analysis of Industry 4.0 and Industry 5.0* (Argilovski et al., 2024). The core technologies in this framework include Additive Manufacturing, Internet of Things (IoT), Cybersecurity, Artificial Intelligence (AI), Big Data, Cloud Computing, Simulation, Autonomous Robots, System Integration, and Augmented Reality. This model helps to structure and assess the technologies identified across the studies. The comparison can be seen in Table 1.

Table 1 – Literature Analysis Based on the Pillars of Industry 4.0

Pilars of Industry 4.0	Sources	References
Additive Manufacturing	0	/
IoT	12	(Singh, 2024); (Fakhar Sina, Rein Brouwer, 2025); (Brancati, 2024); (Mario Battaglini, Monica Andriescu, Kyrillos Spyridopoulos, Niklas Olausson, 2024); (Annadurai Chinnamuthu, Nelson Iruthayanathan, X.N. Ranald Nivethan, M. Senthil Kumar, 2021); (Md. Ashraful Islam, L.M. Mahir Labib, Shahriar Abrar Himel, Murashahun-Al-Masud Srashad, 2025); (Kazi Nafisa Anjum, Ayuns Luz Ayuns Luz, 2024); (Elangovan Muniyandy, D Surrya Prakash, P Sasidharan, 2021); (Muhammad Rusdi, Yuvina, Fitria Nova Hulu, Riza Ria Wirasari, 2025) (Mario Battaglini, Monica Andriescu, Kyrillos Spyridopoulos, Niklas Olausson, 2022), (Ivett Schmidt, Wyn Morriss, Andrew Thomas, Louise Manning, 2022); (Ivett Schmidt, Wyn Morriss, Andrew Thomas, Louise Manning, 2022); (Francesca Santuccidel, prete ernesto,pera fabio,Roberto Setola, 2021);

Cyber Security	0	/
Artificial Intelligence	10	(Zeeshan Haider, Rein Brouwer, 2025); (Mario Battaglini, Monica Andriescu, Kyrillos Spyridopoulos, Niklas Olausson, 2022); (Harikrishnan Muraleedharan Jalajamony, Soumadeep De, Renny Edwin Fernandez, 2024); (Singh, Lifting Safety Monitoring: An AI-Powered Workplace Safety Guide, 2024); (Jakub Fiegler-Rudol, Karolina Lau, Alina Mroczek, Janusz Kasperczyk, 2024); (Elangovan Muniyandy, D Surrya Prakash, P Sasidharan, 2021); (Jiyoung Park, Dongheon Kang); (Aayush Raghuvansh, Priyam Anilkumar Parikh, Parth Atulkumar Shah, 2025); (Jakub Fiegler-Rudol, Karolina Lau, Janusz Kasperczyk, 2025); (Gargi Pant Shukla, Priyanka Panday, Satish Chandra Pant, 2024)
Big Data	11	(Kang, 2024); (Mario Battaglini, Monica Andriescu, Kyrillos Spyridopoulos, Niklas Olausson, 2022); (Singh, 2024); (Jabbar Al-Dulaimi, John Cosmas, Maysam F Abbod, 2019) ; (Fakhar Sina, Rein Brouwer, 2025) ; (Brancati, 2024); (Harikrishnan Muraleedharan Jalajamony, Soumadeep De, Renny Edwin Fernandez, 2024); (Annadurai Chinnamuthu, Nelson Iruthayanathan, X.N. Ranald Nivethan, M. Senthil Kumar, 2021); (Md. Ashraful Islam, L.M. Mahir Labib, Shahriar Abrar Himel, Murashahun-Al-Masud Srashad, 2025); (Elangovan Muniyandy, D Surrya Prakash, P Sasidharan, 2021); (Muhammad Rusdi, Yuvina, Fitria Nova Hulu, Riza Ria Wirasari, 2025)
The Cloud	3	(Kang, 2024); (Jabbar Al-Dulaimi, John Cosmas, Maysam F Abbod, 2019) ; (Elangovan Muniyandy, D Surrya Prakash, P Sasidharan, 2021)
Simulation	3	(Ivett Schmidt, Wyn Morriss, Andrew Thomas, Louise Manning, 2022); (Singh, 2024); (Fakhar Sina, Rein Brouwer, 2025)
Autonomous Robots	1	(Diego I. Quintero-Sanchez, Emma E. De La Garza-Inzunza, Josué García-Ávila, Erick Ramirez-Cedillo, 2024)
System Integration	4	(Ivett Schmidt, Wyn Morriss, Andrew Thomas, Louise Manning, 2022); (Singh, 2024) ; (Safin Rahman,Mengru Xue,Md Farhad Hossain,Md TARIQUZZAMAN Azad, 2023); (Fakhar Sina, Rein Brouwer, 2025)
Augmented Reality	10	(Singh, Computer Vision for PPE Compliance: A New Era of Workplace Safety, 2024); (Jabbar Al-Dulaimi, John Cosmas, Maysam F Abbod, 2019); (Brancati, 2024); (Mario Battaglini, Monica Andriescu, Kyrillos Spyridopoulos, Niklas Olausson, 2024); (Diego I. Quintero-Sanchez, Emma E. De La Garza-Inzunza, Josué García-Ávila, Erick Ramirez-Cedillo, 2024); (Jakub Fiegler-Rudol, Karolina Lau, Alina Mroczek, Janusz Kasperczyk, 2024); (Elangovan

		Muniyandy, D Surrya Prakash, P Sasidharan, 2021); (Aayush Raghuvansh, Priyam Anilkumar Parikh, Parth Atulkumar Shah, 2025); (Gargi Pant Shukla, Priyanka Panday, Satish Chandra Pant, 2024); (Singh, Enhancing Workplace Safety with Ergonomic Assessments Using REBA and RULA Powered by Computer Vision Technology , 2024)
Total	54	

INTERPRETING RESULTS

To bettter understand Table 1, Figure 2 presents a Pareto Diagram.

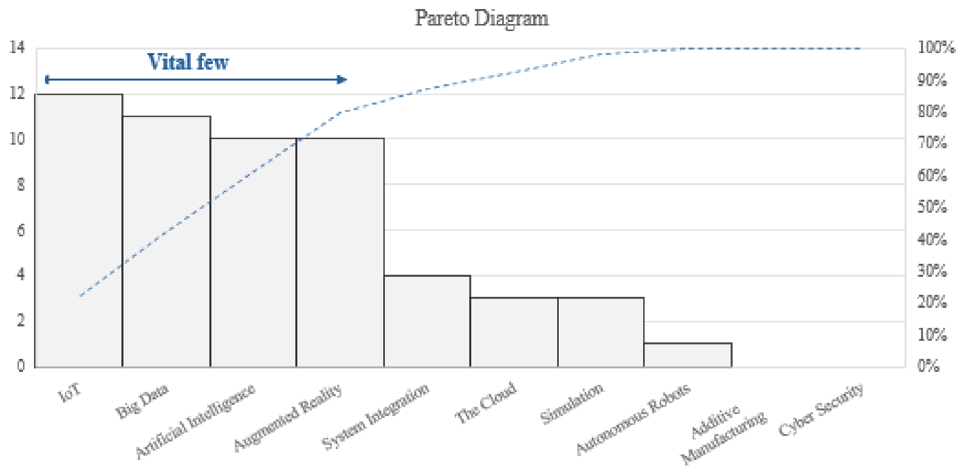

Figure 2 – Pareto Diagram

The Pareto Diagram in Figure 2 highlights the enabling technology for enchanging the Safety Management Systems, separating them into the „Vital Few“, which have the most significant influence (with 80%) and the trivial many which are less impactful individually but stil contribute to the overall process. This analysis identifies the enabling technologies that should be prioritized: IoT, Big Data, AI and Augmented Reality. While each author presents a unique perspective on the application of the technologies, a general synthesis of their contributions reveals common patterns in how these technologies support Safety Management Systems (SMS).

Internet of Things (IoT) – enhances safety by interconnecting devices, sensors, and networks to enable real-time monitoring, data aggregation, and timely responses to potential threats, ultimately improving situational awareness and proactive safety management.

Big Data – enables continuous improvement through the systematic collection, analysis, and feedback of large volumes of safety performance data. It supports the development of a comprehensive, data-driven safety framework that improves decision-making, optimizes protocols, and strengthens the ability to prevent errors by identifying patterns, trends, and potential hazards in complex work environments.

AI - improves workplace safety by analyzing historical and real-time data to predict high-risk areas, prevent accidents, and provide safety recommendations.

Augmented Reality - enhances workplace safety by providing real-time visualization of critical information, enabling immersive training, and supporting hazard identification, remote assistance, and guided decision-making directly in the worker's environment.

A summary of the literature and suggested fields for these technologies' application is provided in Table 2.

Table 2 – Fields in which Industry 4.0 can improve Safety Management Systems

Technology	Application benefits
IoT	Real – time monitoring
Big Data	Enhanced analysis Improved decision-making Optimization of safety protocols
Artificial Intelligence	Prediction of high-risk areas Accident assessment Recommendations for preventive actions
Augmented Reality	Improved assesment Real – time visualization Interactive training Remote assistance

CONCLUSION

This research highlights the potential of Industry 4.0 technologies to transform Safety Management Systems (SMS) by shifting them from reactive to proactive systems. Findings from a comprehensive literature review demonstrate that integrating IoT, Big Data, AI, and Augmented Reality allows SMS to move towards real-time risk monitoring, predictive safety measures, and more efficient incident prevention strategies. By incorporating these advanced technologies into existing safety management frameworks, substantial improvements can be made in the work environment. These advancements not only enhance working conditions but also promote a stronger safety culture among employees. Ultimately, a safer environment leads to greater employee engagement, fewer accidents, and a more secure workplace overall.

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SAFETY AT WORK WHEN WORKING WITH THE MACHINE FOR LASER METAL CUTTING

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Abstract: Modern manufacturing often requires extreme precision on extremely tough materials. Although laser cutting machines have brought certain improvements in terms of quality and productivity, at the same time, certain dangers and harms have emerged when using them. All potential dangers and hazards related to using the machine are listed in this paper. By applying the Kinney method, a risk assessment was carried out for the workplace of an operator who handles a laser cutting machine.

Keywords: *Laser cutting machine, Risk assessment, Material, Safety*

INTRODUCTION

Laser cutting is a technologically advanced method of metal processing that uses concentrated light energy to perform cutting. The process of laser cutting metal itself enables high precision, speed, and flexibility in the metalworking industry. When cutting metal in the cutting zone, the metal melts, burns, or vaporizes (Powell, 2016), or excess material is removed with the help of compressed air, leaving a high-quality cut.

Although laser cutting machines have brought certain improvements in terms of quality and productivity, at the same time, certain dangers and harms have emerged when using them. In the paper (Palega, 2020), the identification of hazards when working as an operator of a laser cutting machine was carried out to assess the risks. The method used in this research included workplace observation (using a checklist), an interview with the employer, an interview with selected employees and a person in the position of a specialist for occupational safety and health, and an analysis of the company's internal documentation. The application of the Risk Score method, through which the risk assessment was conducted, showed that many different risk factors lead to accidents or illnesses for employees operating laser metal cutting machines. Since during metal cutting, harmful particles in the air in the form of smoke, dust, and aerosols appear, which pose a significant threat to the health of workers, the paper (Salem, 2023) presents a method for detecting harmful products using modern, new-generation techniques. The method itself represents a new material classification technique that uses a new deep learning model architecture to classify materials being cut based on processing a large number of images during the cutting process itself. The proposed approach involves training a convolutional neural network (CNN) on a large set of graphical data during the cutting process to recognize different types of materials for safe and efficient cutting. The results obtained show that the proposed method achieves high accuracy in the categorization of materials, especially those that have increased emission of harmful particles during cutting. The microclimate and air quality in facilities where the cutting process is carried out are of great importance for the health of employees who are in the positions of cutting process operators. To reduce the level of air pollution in production facilities, technical solutions such as the installation of fume hoods and filtration systems are used. In the paper (Taranyuk, 2025), an analysis of the emission of harmful products was carried out, an assessment of the efficiency of the ventilation and filtration system for harmful gases generated during the cutting process was carried out, and calculation methods for determining the concentration of harmful substances were proposed.

TYPES OF METAL LASER CUTTING MACHINES

According to the design, there are two types of laser metal cutting machines: Open-type laser metal cutting machine (Fig. 1-a) and closed-type machine (Fig. 1-b). The components of these machines are the same, with the only difference being the construction of the machines themselves. In the closed-type machine, there is a housing (capsule) that completely encloses the working space of the machine. Therefore, the machine is significantly safer compared to the open-type machine, because the worker is protected from laser radiation, fumes, dust and waste that occur during the machine's operation (Fig. 1-a), and it allows the worker greater flexibility because it significantly reduces the use of personal protective equipment, which in some situations significantly complicates the work process (Fig. 1-b).

Figure 1. A representation of a worker working on a closed-type machine (a) and a worker working on an open-type machine (b)

POTENTIAL HAZARDS AND HARMFUL DAMAGES DURING THE OPERATION OF A LASER METAL CUTTING MACHINE

When using laser metal cutting machines, there may be potential hazards due to exposure to laser light, exposure to high temperatures that can cause fire, or the risk of inhaling toxic substances from the air. Proper machine setup, employee training, proper handling, and safety precautions must be implemented to ensure the safe use of a laser metal cutting machine.

Mechanical hazards

In addition to the dangers that may arise from radiation or the presence of chemicals, the operation of a laser cutting machine is also accompanied by mechanical dangers:

- Circular movement of the cutting head,
- Material splashing during cutting and kickback,
- Hazards related to high voltage,
- Handling sharp parts and edges of machines or materials,
- Fire hazard.

Physical hazards (radiation)

According to its operating principle, a laser metal cutting machine involves focusing and using a laser beam. The operating principle of a laser cutting machine involves focusing and using high-energy laser beams, and for this reason, radiation poses a great danger. Laser radiation is in the form of high-energy photons and has the following specific hazards:

- Risk of vision damage,
- Risk of skin burns,
- Other potential hazards related to the use of personal protective equipment.

Chemical hazards

During the cutting process, laser cutting machines often create certain chemical hazards, which include:

- Release of toxic gases,
- Hazardous dusts and fumes,
- Handling toxic materials,
- Cutting specific materials has the potential to produce laser-generated air pollutants.

Physical hazards (noise and vibration)

Noise hazard is one of the hazards that is often overlooked when working with laser cutting machines:

- Noise level,
- Psychosomatic illnesses.

In addition to the above dangers and harms, it is important to mention the harmful effects of the microclimate that occur due to elevated temperatures in the cutting zone, where skin burns and other health problems may occur due to the lack of use of PPE (Personal Protective Equipment).

PREVENTIVE MEASURES TAKEN TO ELIMINATE DANGERS AND HARMFULNESS

Machines for laser cutting of materials undoubtedly represent one of the most sophisticated tools for precise cutting and engraving of materials. However, as a result of improper handling, unplanned injuries may occur to persons who operate the mentioned machine, and for this reason, certain preventive measures must be taken, such as:

- Persons handling the machine (operators) must be familiar with the principle of the machine,
- Maintenance and inspection of the machine must be done regularly,
- The working environment around the machine must be controlled,
- Dispose of waste generated during the cutting process promptly,
- Use the machine manufacturer's instructions,
- Persons who operate the machine must be trained for safe work,
- Fire extinguishers must be arranged near the machine,
- Never leave the cutting machine running without the supervision of an employee,
- It is necessary to know which materials and thicknesses can be safely cut on the machine.

RISK ASSESSMENT FOR WORKING WITH A METAL LASER CUTTING MACHINE

According to the definition, risk represents the probability of injury, illness, or damage to an employee's health due to hazards and harm in the workplace. According to the Law on Safety and Health at Work ("Official Gazette of RS", No. 35/2023), 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, i.e. the way to prevent, eliminate or reduce risks at the workplace and in the working environment.

Risk assessment using a 5×5 matrix

One of the methods that can be used to assess and manage OH&S risks is the Kinney method. In the Kinney method, risk fulfillment is viewed as the occurrence of danger and harm (Risk Assessment Manual, 2010). Therefore, by identifying potential hazards and harms, potential risks to work safety are determined.

Table 1 shows the risk assessment using the 5x5 matrix (Kinney method) for working with a laser metal cutting machine.

Table 1. Risk Assessment

No.	Code	Identified Hazards	S	E	P	Level of Risk	Preventive Measures
1	02	Free movement of materials that can cause injury to the employee (the material may be splashed during the cutting process).	3	2	6	MEDIUM RISK	Installing a protective barrier that prevents material from splashing. Use personal protective equipment, such as safety glasses to avoid eye injuries, or a protective mask that protects the worker's face.
2	07	Hazardous surfaces that the employee comes into contact with, which have sharp edges and corners, spikes, rough surfaces, protrusions, etc. (injury may occur due to handling processed material that has sharp edges).	4	2	8	MEDIUM RISK	After laser cutting, the material must be further processed by grinding. Workers must be trained in how to handle materials properly. Using personal protective equipment. Training workers in providing first aid in case of injury;
3	15	Danger from direct contact with live parts of electrical installations and equipment	2	3	6	MEDIUM RISK	Before any maintenance, repair, or cleaning of the machine, it is mandatory to

		(contact with high-voltage electrical systems may occur due to improper use or maintenance).					turn off the power to the machine and ensure that it is completely disconnected from the power source - LOTO procedure. Regular maintenance of the machine's electrical installations. Installation of protective barriers around high-voltage components and posting warning signs.
4	24	High temperature (during the working process, the machine emits high temperatures that can adversely affect the health of employees, causing e.g. burns)	2	3	6	MEDIUM RISK	Installation of cooling systems; It is important to organize periodic breaks and allow workers exposed to high temperatures to rest in cooler parts of the workplace. Work areas where there is a risk of high temperatures should be marked with safety signs warning of the danger of burns.
5	26	Laser radiation (laser rays can cause eye damage, such as retinal burns).	2	3	6	MEDIUM RISK	Place signs indicating the presence of high-power lasers, which should be prominently displayed in visible locations. It is best to use closed-type machines to prevent the laser beam from scattering in the work area. Wear protective glasses that have filters specific to the class of laser.

CONCLUSIONS

To ensure safe working conditions with a laser metal cutting machine, the operator must be trained to work with the machine itself. Workers should be familiar with the technical description of the machine, how to operate it, the materials being cut, and the safety measures taken to prevent injuries to workers. It is also important to carry out regular inspections and maintenance of the machine. Maintaining the work area is also of great importance, as is the placement of various signs indicating potential hazards. The use of personal protective equipment greatly contributes to reducing the occurrence of hazards and harm in the workplace of the operator of the laser material cutting machine.

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WORK AT HEIGHT: LEGAL FRAMEWORK AND APPLICATION OF THE HIERARCHY OF CONTROLS

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Abstract: Work at height remains one of the most significant causes of work-related deaths/fatalities and serious injuries globally. While recognized as a critical risk, regulatory approaches vary—as some countries enact dedicated legislation, while others address it within general occupational safety laws. This paper contributes to ongoing discussions on regulatory effectiveness and risk management, offering evidence-based recommendations for improving work-at-height safety. It is especially relevant for policymakers, safety practitioners, and organizations aiming to reduce fall-related accidents through structured, proactive measures. A core focus is the practical application of the Hierarchy of Controls—elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE)—in managing work-at-height risks. Real-world examples demonstrate how each control type can be applied effectively.

Keywords: *Work at Height; Hierarchy of Controls; Safety and Health at Work*

INTRODUCTION

Work at heights is the leading cause of serious injuries and fatalities in workplaces worldwide. As one of the most hazardous workplace activities, it's challenging from a health and safety standpoint. Work at height can be defined as any work where, if appropriate precautions are not taken, a fall from a height may result in injury (HSE, 2014).

Various countries have different legal frameworks regulating work at height. For example, some countries don't give a specific definition of work at height in their regulations, but rather determine above which height is mandatory to use fall protection. The existing legal definitions of work at height generally fall into two categories: one defines it as work conducted above a specific height (e.g., 2 meters), while the other defines it as any work where there is a risk of falling that could result in injury. Also, some countries have specific regulations dedicated to work at height (Table 1), while other countries regulate work at height within broader health and safety acts, like Construction Health and Safety Regulations or similar.

Table 1. Countries with dedicated regulations for work at height

Country	Regulation
UK	Work at Height Regulations 2005
Singapore	Workplace Safety and Health (Work at Heights) Regulations 2013
Mexico	NOM-009-STPS-2011 – Safety Conditions for Working at Heights
Serbia	Preventive Measures for Safe and Healthy Work at Height Rulebook 2025

The height of the fall itself is a strong indicator of the eventual outcome and the survival rate (Alizo et al, 2018). A height of approximately four storeys or around 15 meters is considered a median lethal distance for falls, even a fall from a height of two meters can result in fatal or life-altering injuries (Parvis, 2022). According to WHO estimates, falls from height result in approximately 684,000 deaths annually, making them the second leading cause of fatal injuries globally, while more than 37.3 million falls each year require medical attention (WHO, 2021).

Work-related accidents related to work at height

The number of work-related deaths/fatalities and serious injuries on a global level due to falls from height is staggering. For example, in Great Britain, 50 work-related deaths/fatalities due to falls from height were recorded in 2023/24, representing 36% of the total number of work-related deaths/fatalities (HSE, 2024). In the USA, approximately 300 work-related deaths/fatalities and 20,000 work-related injuries caused by falls from heights are recorded annually among construction workers (Harris et al., 2024). Falling from height is the second most common cause of work-related deaths/fatalities in Australia, where 29 workers died due to falls in 2023, or 14.5% of the total number of work-related deaths/fatalities that year (SafeWork, 2024). Sweden had slightly better statistics on work-related injuries, where for the 10 years from 2013 to 2023, 30 work-related deaths/fatalities due to falls from a height were recorded, which is 15.3% of the total number of work-related deaths/fatalities for these ten years (Afa Forsakring, 2024). According to available Eurostat data for 2022, there were 513 work-related deaths/fatalities due to slipping, tripping, and falling on the territory of EU member states, which is 15.61% of the total number of work-related deaths/fatalities (Eurostat, 2025).

Unsafe work at height is the most common cause of workplace injuries in Serbia, according to the Labour Inspectorate's annual report for 2024 (Labour Inspectorate, 2025). However, the exact number of injuries and fatalities caused by falls from height can't be determined from the data in this report. Safety and Health at Work Administration in their annual report stated that out of 1588 work-related deaths/fatalities and serious injuries recorded in 2024 in Serbia, 211 or 13,29% were caused by falls from height (Safety and Health at Work Administration of the Republic of Serbia, 2025).

Falls from height have been a leading cause of most serious safety accidents in the steel industry in the last decade and one of the leading causes of work-related deaths/fatalities in the construction industry (Parvis, 2022; Zaini et al., 2020). Among workers across all industries in 2022, falls from height accounted for approximately 81% of all fatal and 20% of all nonfatal slip, trip, and fall accidents (BLS, 2023a; BLS, 2023b).

Work at height in Serbia

The topic of work at height in Serbia is regulated in a somewhat confusing way. The latest changes in the legal framework for safety and health at work in Serbia have tried to solve this problem, but there are still some issues. Currently, work at heights is regulated within the laws/rulebooks given in Table 2.

Table 2. Legal framework for work at height in Serbia

Legal document
Health and Safety at Work Law (Official Gazette of the Republic of Serbia, no. 35/2023)
Preventive Measures for Safe and Healthy Work at Height Rulebook (Official Gazette of the Republic of Serbia, no. 5/2025)
Safety and Health at Work on Temporary or Mobile Construction Sites Decree (Official Gazette of the Republic of Serbia, no. 14/2009, 95/2010, 98/2018, 35/2023 – other law and 76/2024)
Preventive Measures for Safe and Healthy Work When Using Work Equipment Rulebook (Official Gazette of the Republic of Serbia, no. 23/2009, 123/2012, 102/2015, 101/2018 and 130/2021)
Occupational Safety During Construction Works Rulebook (Official Gazette of the Republic of Serbia, no. 53/1997)

Review of current regulations in Serbia

Occupational Safety During Construction Work Rulebook and Safety and Health at Work on Temporary or Mobile Construction Sites Decree are specifically intended as normative acts that regulate occupational safety and health during construction work, while the Preventive Measures for Safe and Healthy Work When Using Work Equipment Rulebook is closely related to activities involving the use of work equipment.

Safety and Health at Work Law in Serbia states that “work at a height is any work that an employee performs using supports at a height of two meters or more from a solid surface, where the work area is not protected from falling from a height” (Safety and Health at Work Law, 2025).

Activities performed by an employee in the following circumstances: on scaffolding, work platforms, or ladders; while maintaining installations in industrial facilities; on vehicles (e.g., truck trailers); in trees; when using work equipment intended for temporary work at height to access structures (e.g., exterior parts of buildings, maintenance of building facades, roof work, etc.); on vessels; on telecommunications poles or masts; on industrial chimneys; on electrical and power transmission poles; near excavations or other openings; for the purpose of placing posters on billboards, advertising signs, video displays, etc.; any other work performed by an employee using support at a height of two meters or more above a solid surface, where the work area is not protected against falls from height; work is also considered to be at height if it is determined as such by the employer in the risk assessment act for the workplace and work environment, in accordance with occupational safety and health regulations; are considered as work at height (Preventive Measures for Safe and Healthy Work at Height Rulebook, 2025). This Work at Height Rulebook was been criticized by safety professionals, which led to the postponement of the application of this regulation until the beginning of 2026. However, it's unknown if the Rulebook will be improved or not at this time.

The latest Safety and Health at Work Law in Serbia states that any work at height must be considered high-risk work, which somewhat makes the risk assessment process pointless. One important change introduced by this law in Serbia is the mandatory use of a permit-to-work system in case of work at height, among others.

HIERARCHY OF CONTROLS

The Hierarchy of Controls, first introduced by the U.S. National Security Council in the 1950s, is essentially a systemic approach to assessing the effectiveness of existing and planned risk reduction measures (Gojdics, 2019; Popov, Lyon & Hollcroft, 2016). The hierarchy of controls is most commonly presented through five types of control measures: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (Figure 1).

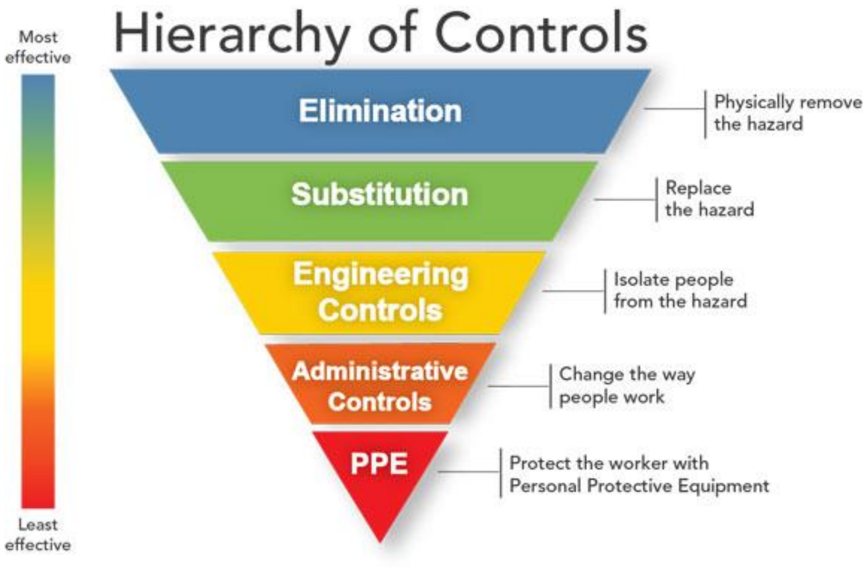

Figure 1. Hierarchy of Controls (NIOSH, 2024)

As a generally accepted strategy for risk control in the workplace, the hierarchy of controls has been incorporated into numerous legislative frameworks in occupational safety and health, including the Safety and Health at Work Law of the Republic of Serbia.

The hierarchy of controls approach is extremely important when working at height, and the following are examples of each specific type of control.

Controls for work at height

Elimination essentially represents the type of control that manages risk most effectively by simply removing a hazard from the workplace. This type of control is always the most desirable for risk control in the workplace. In the case of work at height, control of this type would be to perform the task at ground level — for example, instead of climbing to a height, telescopic tools can be used, or the equipment that needs to be worked on can be brought down to the ground.

Substitution, as a type of control, means that one hazard is replaced with a safer alternative. For work at height, replacing a greater hazard with a lesser one might involve using a lift platform or scaffolding instead of working from a ladder. Essentially, this type of control measure aims to provide a safer way to access the work area when working at height.

Elimination and substitution are essentially the most effective risk controls and most preferred, however, these controls are not always applicable.

The application of engineering controls reduces workers' exposure to hazards and harmful conditions in the workplace or prevents them from coming into contact with the hazard altogether. Engineering controls for working at height involve specific modifications to the workplace itself, such as the installation of additional equipment or fall protection systems. Some examples include installing guardrails at edges, safety nets, or platforms over fragile surfaces through which a worker could fall. Essentially, these are collective measures aimed at ensuring health and safety at work.

Administrative controls are reflected in changes to the way work is performed through the provision of instructions, guidelines, prohibitions, and similar actions. These control measures reduce only the duration, frequency, or intensity of exposure to a specific hazard (NIOSH, 2024). Examples of administrative controls for working at height include: training for work at height, procedures for work at height, a permit-to-work system for work at height, supervision during work at height, access restrictions, placement of safety signs, and similar**.**

The use of personal protective equipment (PPE) as a method of risk control is the last line of defense against hazards and is applied only when other types of control measures cannot sufficiently reduce the risk. The main reason why this type of control measure is considered the least effective lies in the fact that it relies entirely on the worker, whether the worker will wear the equipment, choose the correct gear to use, and check its condition before use.

Personal protective equipment for work at height, or fall protection equipment, consists of a full-body harness and lanyards that secure the worker to an anchor point. This represents the so-called ABCD of fall protection, where A stands for Anchor, B for Body support (harness), C for Connectors, and D for Descent and Rescue — a response plan in case a fall occurs.

CONCLUSION

Work at height continues to pose a critical safety challenge across industries, with falls remaining a leading cause of occupational fatalities. The height at which work is performed is a critical factor, as the severity of potential injuries in the event of a fall is directly proportional to the height from which the fall occurs. Work at height requires effective risk management to mitigate these risks. The Hierarchy of Controls offers a structured and proven method to mitigate fall risks, prioritizing proactive measures such as elimination and substitution over other types of controls. By aligning legal frameworks with best practices in risk control and ensuring their implementation across all sectors, we can significantly improve worker safety and reduce accidents related to working at height.

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RISK ASSESSMENT FOR DUMPER OPERATOR WORKPLACE IN MINING COMPANY

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Abstract: In occupational safety & heath system, for the purpose of providing safe work environment on work place risk assessment is necessary and irreplaceable activity. Through risk assessment process it should be identified, quantify and assess all hazards that employee can be exposed on work place, based on that determine acceptable level of risk, and design adequate protective measures. Also, the investigation of incident/accident situations that occurred in the workplace and the determination of their cause provides additional information on the basis of which correction of occupational safety measures is carried out in order to prevent the occurrence of similar incident/accident situations in the future. Applied occupational safety measures should reduce the possibility of accidents at work that can manifest themselves in the form of: injuries at work, interruptions in the production process, damage to work equipment, etc.

The paper presents a risk assessment for the workplace of a dumper operator in a mining company using the Fine and Kinney method, as well as an analysis of accident situation at the same workplace using a cause-effect diagram (Ishikawa diagram).

Key words: risk assessment, dumper operator, incident/accident situation

INTRODUCTION

Risk assessment is an empirical process of determining all the hazards present in the workplace, assessing the risks they cause and, based on this, designing corrective measures. The goal is to ensure favorable working conditions and increase safety and health in the workplace through the implementation of occupational safety measures. The procedure is carried out using selected and so far known and recognized methods. Risk assessment is an indicator of the direction of the long-term survival of the company, improving capacity, productivity and profit (NSW Government, 2009). Risk assessment is also a legal obligation for employers, which is materialized through a special document, a Act of risk assessment. This document addresses all elements of the business system that can affect the level of risk of injuries, occupational and work-related diseases, and serves as a basis for designing measures to eliminate, reduce or prevent risks.

An accident at work occurs as a result of the existence of certain causes, objective and/or subjective, which create conditions for the realization of a dangerous condition or situation in the work environment (Vranješ et al., 2021). Incident situations occur as a result of the presence of risk in the work environment but are of a smaller scale and do not always result in injury to the worker, while an accident is a risky event that results in death, injury and temporary or permanent loss of a man's working capacity, all of which can be encompassed by the term accident at work. The consequences of accident at work can manifest themselves as: injury to workers, interruption of the technological production process and damage to material and natural resources (Krstić and Anđelković, 2013).

Mining is a work activity with specific and predominantly difficult working conditions, where accidents at work are not a rare occurrence. The main hazards in mining are the presence of dust, chemicals, harmful gases, electrical hazards, fires and explosions, dynamic phenomena, radiation, mechanical hazards and the environment at the workplace (microclimatic conditions, lighting, noise and vibrations) (Heleta, 2010). In mining production, a whole series of plants, machines, devices and various equipment are used as means of work: separation plants, mining machinery, various means of transport and systems, machines for the maintenance of mining plants, etc. All machinery and apparatus that is used in surface mines should be robust, fitted with appropriate protective safety devices and maintained in good condition (International Labour Office, 2001). An important part of the means of work in mining is transport systems and means, both those for transporting the raw material itself, which is the subject of mine exploitation, and other means of external and internal transport. In mines with surface exploitation for the transport of ore from the pit to the ore preparation, beneficiation and separation plant, in addition to stable systems (various types of conveyors, rail transport, cable cars, etc.), numerous mobile means of transport are also used: various types of trucks, most often dumpers, small trucks, etc. All operators or drivers of mobile equipment should be trained, competent and authorized for the equipment they operate and the areas they operate it in (International Labour Office, 2018).

This paper presents the risk assessment procedure for the position of dumper operator and an example of a specific accident situation when operating mining machinery (dump truck) at an open pit mine using a cause-and-effect diagram model. It is a systematic way to precisely define the problem (incident/accident at work), determine all causes, define the main one, determine the connection between cause and effect, and design appropriate corrective/preventive solutions.

MATERIAL AND METHODS OF WORK

The company in which the research was conducted is mining exploitation of ore and limestone. The ore obtained through process of gravitational-magnetic separation on open pit, and the limestone through classic procedure of separation (pit production, crushing, ore screening and classification). Mining plants and machinery are used in separation. The transport of ore and limestone from the open pit to the primary crusher is performed by dumpers. Two type of CATERPILLAR manufacturers' dumpers are used: CAT 777C (year of production 1980-1985, weight of empty dumper is 62 tones, and carrying capacity is 77 tones – total weight is around 138 tones), and CAT 775F (year of production 2010, weight of the empty dumper is 46 tons, carrying capacity is 64 tones – total weight is around around 112 tons). The length of the dumpers is about 10m, width about 5m, height about 4m, and while unloading around 9m.

The risk assessment was conducted for all jobs and this was documented by a valid Act of risk assessment. For each place of work, the risk assessment of the working activities carried out through risk assessment procedure by applying the Fine and Kinney method. The workplace of the dumper operator, named *driver of the vehicle over 20 tons* was recognized as a workplace with increased risk and due to the specifics of the workplace, work in difficult working conditions.

Fine and Kinney are semi-quantitative tabular risk assessment methods. The Kinney risk assessment method is based on expressing risk as a product of three factor quantities: probability, exposure and consequence. In combination with the Fine method, it allows the classification of risk consequences, in addition to consequences in the form of damage to the health of workers, to also be expressed in material losses resulting from the realization of a risky event. For the analysis of the incident that occurred at the workplace of a dumper operator, a cause-effect diagram, or Ishikawa diagram, was used.

RISK ASSESSMENT FOR THE WORKPLACE OF DUMPER OPERATORS

A combination of the Fine and Kinney methods was used to assess the risks of work activities performed by dumper operators at the workplace, Figure 1. The application of this method for risk assessment involves the following steps (Netro et al., 2018):

- identification of all potential hazards/harmfulness,
- identification of possible causes,
- analysis of each hazard/harm.

RISK ASSESSMENT BY FINE AND KINNEY

R = Probability x Exposure x Consequences					
P	Probability of the Risk	E	Duration of the exposure to dange	C	Size of the potential impact
10	Can be expected, almost surely	10	Constantly	100	Disastrous, many fatalitys or damage over 500 000 KM
6	Very possible	6	Every day, during working hours	40	Disaster, several fatalitys or damage over 150 000 KM
3	Unusual, but possible	3	Weekly or occasionally	15	Seriously, 1 fatality or damage over 50 000 KM
1	Only possible on longer duration	2	Monthly	7	Significant, life-threatening injuries or damage over 5 000 KM
0.5	Very unlikely	1	A few times per year	3	Important, temporary incapacity or damage over 500 KM
0.2	Virtually impossible	0.5	Very rare	1	First Aid needed or damage up to 500 KM
0.1	Impossible				

R = Probability x Exposure x Consequences		
R	Risk	Action required
> 320	Very High Risk	STOP work and ensure that the risk is eliminated immediately
160 - 320	High	Immediate action required. Ensure that risk is eliminated immediately
70 - 160	Extensive	Correction is required. Ensure that the risk is reduced. Report risk to manager immediately
20 - 70	Potentail	Risk requires attention
< 20	Readily	No attention requierd.

Figure 1. Kinney & Fine Risk assessment (Vranješ, 2020)

Through the risk assessment process, hazard identification and risk assessments were carried out for all work activities performed at the workplace of CAT 775F and CAT 777 dumper operators. These include arrival at the company premises, preparation for work, departure to the workplace, inspection of the machine, work tasks (loading, transport, unloading) and activities related to dump truck maintenance. The work activity “Passing dump trucks on transport roads” was assessed as a high-risk activity (R = 180), which is maintained at an acceptable (tolerable) risk level by applying corrective measures. The applied corrective measures are: regular widening and filling of roads, compliance with internal safety procedures for vehicles and vehicle movement, and priority for loaded dump trucks.
Also, the work activities "Interruption of signaling and lighting" (R = 90) and "Disposal of materials at the landfill", "Increased frequency of dumpers at the wasteyard", "Operator fatigue in the 3rd shift" (R = 180) are assessed as high risk and are reduced to the level of acceptable (tolerated) risk by applying corrective measures. The applied corrective measures are:

- urgent repair of signaling, otherwise stop work;
- placing the material away from the edge of the wasteyard with the mandatory creation of a bank at a distance of 0.5 m from the edge as a movement limiter for the rear dumper wheels;
- organized schedule and movement of dumpers on wasteyard; expansion of the landfill space; banning and controlling the stopping and detention of dumpers at wasteyard after the end of shifts,

- control of the operator's readiness for work at the beginning of the shift (capable, rested, sober, etc.), otherwise extend the rest time or make a replacement.

Other work activities performed at this workplace fall into the category of possible or tolerable risk.
Handling of all vehicles in this mining company, including dump trucks, is based on a specially implemented safety procedure:

- all vehicles used for work purposes must be subject to a risk assessment,
- if heavy industrial vehicles or vehicles with a blind spot for the driver leave the company premises due to the performance of their tasks (e.g. crossing street between the factory and the warehouse, work out of the site, etc.) at all locations they leave, it is necessary to provide the following: warning signs of the presence of the risk of the movement of heavy vehicles, directing safe movement, organized escort for the vehicle, etc.,
- for all vehicles before use, check the correctness of key safety equipment based on risk assessment, e.g. brakes, signaling, tires, etc.,
- all vehicles used for work purposes must have seats and seat belts for the driver and all passengers unless otherwise determined by risk assessment (International Labour Office,2018; AM Safety ST 006 Procedure, 2008).

Analysis of the incident/accidental situation dumper operator - case example from practice

The complexity of the conditions of the working environment in mining production, the intensity of use of work tools and the human factor that influence the occurrence of incident situations are not rare. Using the example of the analysis of an incident situation that occurred at the dumper operator's workplace, we will show the procedure for applying the cause-and-effect diagram. This diagram is also called the Ishikawa diagram after its author (Kaori Ishikawa). The diagram is widely used in many industries, including risk management and occupational safety and health.

The cause-and-effect diagram is carried out in six steps (Ishikawa, 1976):

- Defining the research problem - when the research problem is correctly defined, it is entered in the box on the right side of the diagram.
- Defining the main categories of the cause of the problem - in the production environment, the categories are: machines/equipment, methods, materials, people. In a service organization, the categories are: policies, procedures, facilities, people.
- Brainstorming – thinking about the causes of the accident. This is the stage where most of the work in forming the Ishikawa diagram takes place.
- Categorization of the cause of the problem - when the list of causes is generated, then they are placed in the appropriate category on the diagram.
- Determining the root causes of the problem - each cause on the chart is then further analyzed to determine if there is a root cause for that aspect.

- Identification of the main causes of the problem - this can be done in several ways: look for recurring causes, select causes using group consensus methods, select causes based on frequency of occurrence, etc.

The incident occured in the 3rd shift, when during the last round of tailings from the excavator that was excavating to the landfill, the rear wheels of the dump truck CAT 777C/46 slipped on the frozen surface and the dump truck overturned on its right side (Figure 2). The consequence of this situation for the dumper operator is a minor injury in the leg and shoulder area.
The risk assessment, using the Fine and Kinney methods, for this event determined that it falls into the category of significant risk (R = P x E x C =15 x 2 x 3 = 90) which requires correction to ensure that the risk is reduced.
The estimated level of costs due to the loss caused by the incident is 10,000 €.
The principle of root cause analysis is based on finding answers to five key questions: What, Where, Who, When and How a specific incident took place.

Figure 2. Photo of incident situation which consequences are overturn of dumper

The procedure for applying the cause-effect diagram in the analysis of the described accident is shown in Figure 3. In the procedure of accident analysis, the following were used:

- statements of the participants and record of the alcohol test control,
- photos from the scene and during the investigation,
- conclusion of the Commission for the investigation of the cause of dump truck 46 overturning.

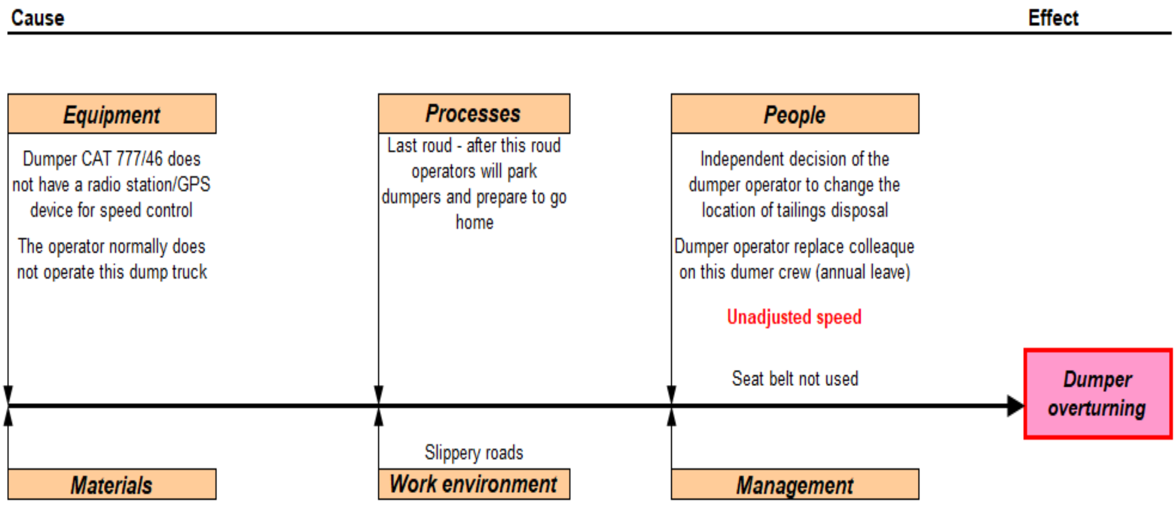

Figure 3. Analysis of incident situation using cause-effect diagram

The main cause of this incident situation was identified as "unadjusted speed", which is a cause that belongs to the category of subjective causes related to the influence and effect of the human factor.
In order to reduce the risk and prevent recurrence, the recommended corrective and preventive activities are:

- sprinkling of roads with a fraction of limestone for better adhesion of vehicle tires and reduced sliding of them,
- more active monitoring of working conditions by the supervisory and technical staff of each shift at the surface mine and timely action to improve working conditions,
- more active monitoring of the operation of the machines by the supervisory and technical staff and warning the operator to adjust the operation to the current conditions,
- installing seat belts in vehicles that do not have them and insisting on their mandatory use while in the vehicle,
- operator training on how to act in these and similar scenarios,
- training of supervisory and technical staff in conducting incident investigation procedures,
- editing the system and determining the procedure on the way of conducting, monitoring, reporting and maintaining the radio communication system, including GPS tracking,
- adequate training and checking of the training of participants in the radio communication system, especially the dispatcher as the head of the system,
- bringing all devices in the connection system to the correct state.

CONCLUSION

The risk assessment process is an indispensable part of the occupational safety system, and also a legal obligation of the employer. In all areas of work, risk assessment is mandatory, and it is of particular importance in those activities where multiple and complex risks are present, such as mining activity. Risk assessment plays an important role in the occupational safety and health system, because only on the basis of the identified hazards/harmfulness to which the worker is exposed at his workplace and the estimated level of risk caused by them we can design adequate occupational safety measures.

In mining, an important segment of the technological process is the transportation of ore material from the pit to the separation plant, as well as waste from pit to the wasteyard and the presence of jobs for operators of mining machinery is high. That's why in this paper we decided to present a practical example of risk assessment and analysis of an incident/accident situation for the position of dumper operator.

For the purpose of preventive action in the occupational safety and health system, in addition to the assessment itself, it is also important to analyze all incident/accident situations in order to prevent the recurrence of similar events in the future through the correction of protective measures. The cause-and-effect diagram is a suitable practical tool for the analysis of a concrete accident situation, important for discovering and analyzing the basic causes of incidents/accidents in the organization, with the aim of defining preventive and corrective measures for the improvement and improvement of processes primarily with increased risk.

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TOXIC LEGACY: UNRAVELING THE HAZARD INDEX OF HEAVY METALS IN LANDFILL LEACHATE – A CASE STUDY

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Abstract: Non-sanitary landfills represent a significant source of environmental pollution, primarily through the generation of leachate, a chemically complex effluent. In the absence of adequate management and treatment strategies, leachate poses a serious threat to groundwater quality due to its high potential to percolate through landfill soil. This research investigates the presence of six heavy metals - chromium (Cr), iron (Fe), zinc (Zn), nickel (Ni), manganese (Mn), and copper (Cu), in landfill leachate collected in 2022 from a non-sanitary waste disposal site in Zrenjanin, Serbia. To evaluate the potential non-carcinogenic health risks posed to both adults and children, hazard index (HI) values were calculated for each metal. Current findings are that Cr and Ni exhibited the highest HI values (HI > 1), suggesting considerable potential for adverse effects. Mn presented borderline HI values for adults (0.896) and exceeded the threshold for children (1.839), highlighting increased vulnerability in younger populations due to higher relative exposure. In contrast, Fe, Zn and Cu exhibited HI values below the safety threshold (HI < 1) for both adults and children, suggesting minimal non-carcinogenic health risks from these metals. The aim of this assessment is to underscore the urgent need for further research into the environmental and public health impacts of pollution arising from landfills, particularly in the context of inadequate waste management practices and the absence or inefficiency of leachate monitoring systems. The findings are intended to encourage future research exploring the broader implications of heavy metal contamination in landfill-affected environments.

Keywords: *landfill leachate; health risk; hazard quotient; hazard index; heavy metal.*

INTRODUCTION

Heavy metals may be introduced into the human body via contaminated water, air, and food grown on contaminated soil. This is an inevitable environmental and human health issue that arose from rapid urbanization, industrialization, and inadequate waste management practices (Badeenezhad et al., 2023). Landfills have become repositories of a variety of contaminant residues, due to the disposal of household items, food waste, old machinery, oil and rubber industry waste, as well as unwanted/expired household medicines and products (Wang et al., 2020). A series of biological and physico-chemical processes begin immediately after municipal solid waste is deposited in a landfill. A major drawback of this type of waste management is that the infiltration of rainwater through the landfill produces a highly polluted effluent loaded with organic and inorganic substances. This resulting effluent, known as leachate, requires confinement in a regulated pond (Luo et al., 2020). As a result of infiltration groundwater is at risk, as it becomes a reservoir for trace elements that pose serious health threats. Amidst this complexity, the focus in this research will be shifted towards understanding selected heavy metals and their health effects which are crucial for deciphering contaminated groundwater hazards and the significance of leachate treatment and management plans.

This study aims to enhance understanding of the presence and distribution of six heavy metals, chromium (Cr), iron (Fe), zinc (Zn), nickel (Ni), manganese (Mn), and copper (Cu) in landfill leachate from the municipal waste disposal site in Zrenjanin, Republic of Serbia. The research specifically evaluates the potential human health risks associated with exposure to these metals by calculating the hazard index for both adults and children. The findings offer valuable insights into the environmental impact of landfill leachate and its role in contaminating surrounding water resources.

MATERIALS AND METHODS

Sampling site and sample analysis

The sampling site in Serbia was chosen considering factors like population density, occupation, and lifestyle. Three sampling campaigns were carried out in 2022, specifically in February, May, and November. The landfill in Zrenjanin is located approximately 1.2 kilometers from the nearest residential area and 4.5 kilometers from the city center. It began working in 1995 as a non-sanitary landfill with an estimated average daily amount of municipal waste of about 450 m^3, including a certain amount of inert and non-hazardous industrial municipal waste (*Regional Waste Management plan for the city of Zrenjanin and the municipalities of Sečanj, Titel and Kovačica, 2011*). There is no leachate collection or treatment system present at the landfill. The samples were collected from a peripheral canal at 45°21'15.92", 20°21'57.01" (Fig. 1). Furthermore, it is important to note two landmarks near the landfill: a sand mining site located approximately 500 meters away, and the city swimming area “Peskara” situated 1.1 kilometers from the landfill.

Figure 1. Map of the collection point and important landmarks near the Zrenjanin landfill

Sample analysis was carried out in the Laboratory for environmental and occupational monitoring, Department of Environmental Engineering and Occupational Safety and Health, Faculty of Technical Sciences, University of Novi Sad. The heavy metal concentrations were determined utilizing standard laboratory EPA and HACH procedures.

HAZARD INDEX

The Hazard Index (HI) is a risk assessment tool used to evaluate non-cancer health risks from exposure to one or more chemical substances in water. It is commonly used in environmental health and toxicology. The primary exposure pathways considered for HI are direct ingestion and dermal absorption (Jun et al, 2019, Zeng et al., 2015). Based on risk guidelines of USEPA (2004), the exposure dose for direct ingestion (ADDingestion) and dermal absorption (ADDdermal) are calculated as follows:

$$ADD_{ingestion} = \frac{C_w \times IR \times ABS_g \times EF \times ED}{BW \times AT} \quad (1)$$

$$ADD_{dermal} = \frac{C_w \times SA \times K_p \times EF \times ET \times ED}{BW \times AT} \quad (2)$$

where *Cw* was the mean concentrations of trace elements in samples (μg/L), *IR* was the ingestion rate (L/day), 2.0 for adults and 0.64 for children (Wang et al., 2017). *ABSg* was the gastrointestinal absorption factor, with the following values of 3.8% for Cr, 57% for Cu, 1.4% for Fe, 6.0% for Mn, 4.0% for Ni and 20% for Zn (Wang et al., 2017). *EF* was the exposure frequency (days/year), 365 in this study. *ED* was the exposure duration (years), 70 for adults and 6 for children (USEPA, 2004). *BW* was the body weight (kg), 65 for adults and 20 for children (Jun et al., 2019). *AT* was the average time for non-carcinogens (days), 25,550 for adults and 2190 for children (USEPA, 2004). *SA* was the exposed skin area (cm^2), 18,000 for adults and 6600 for children (Wang et al., 2017). *ET* was the exposure time (h/day), 0.58 for adults and 1.0 for children (Wang et al., 2017); *Kp* was the dermal permeability coefficient in samples (cm/h): 0.001 for Mn, Fe and Cu, 0.003 for Cr, 0.0006 for Zn (USEPA, 2004) and 0.004 for Ni (Zeng et al., 2015) in this study.

Next, the hazard quotient (HQ) was calculated for each heavy metal using the following formula (USEPA, 2004):

$$HQ = \frac{ADD}{RfD} \quad (3)$$

where RfD was the reference dose, RfDdermal and RfDingestion are shown in Table 1.

Table 1. Values for RfDdermal and RfDingestion (Jun et al., 2019)

Heavy metal	RfDdermal (μg/kg/day)	RfDingestion (μg/kg/day)
Cr	0.075	3
Fe	140	700
Zn	60	300
Ni	0.80	20
Mn	0.96	24
Cu	12	40

In addition, the total potential non-carcinogenic risks caused by different pathways were assessed by calculating HI as follows:

$$HI = \sum(HQ_{ingestion} + HQ_{dermal}) \quad (4)$$

If the HI were ≥ 1, the adverse effect on human health should be considered (USEPA, 2004).

RESULTS AND DISCUSSION

The concentrations of heavy metals in the Zrenjanin landfill leachate are presented in Table 2. It is assumed that when leachate percolates through soil into groundwater, its constituents are diluted at a ratio of 1:100 (Chaudhary et al., 2021), this dilution factor (DF) was considered to obtain *Cw* values that were used in Eq. 1 and 2 to calculate ADD.

Table 2. Overview of the heavy metal concentrations in landfill leachate at the Zrenjanin Landfill and calculated *Cw* values in leachate and groundwater

Heavy metal	February (mg/L)	May (mg/L)	November (mg/L)	Cw, leachate (mg/L)	Cw, groundwater (mg/L) (DF=1:100)	Cw, groundwater (μg/L)
Cr	0.24	0.75	0.33	0.44	0.0044	4.40
Fe	1.46	37.9	n.a.	19.68	0.1968	196.80
Zn	0.29	0.34	0.4	0.34	0.0034	3.43
Ni	2.57	2.53	n.a.	2.55	0.0255	25.50
Mn	0.11	0.96	n.a.	0.54	0.0054	5.35
Cu	0.57	0,3	n.a.	0.57	0.0057	5.70

Two plausible scenarios are considered, each demonstrating how heavy metal concentrations in leachate can affect human health:

- percolation of landfill leachate through soil into groundwater polluting the drinking water sources;
- percolation of the landfill leachate towards the nearby city swimming area "Peskara" where the diluted pollutants come into direct contact with human skin and/or can be directly ingested.

Both scenarios are highly probable in landfill environments lacking protective liners and leachate collection systems, which are essential components outlined in Waste Management Standards. Within the European Union, compliance is ensured through adherence to the Landfill Directive (1999/31/EC), supported by corresponding CEN standards (EN 10430–10433), which provide the necessary technical and engineering specifications. Whereas the Environmental Protection Agency enforces the Resource Conservation and Recovery Act (RCRA) Subtitle D for landfill design and operation, with additional guidance provided by relevant ASTM D-series standards. At non-sanitary landfills, the complex constituents of landfill leachate can dilute and subsequently enter nearby water sources. Several key factors influence this dilution, including the flow rate of the water body, leachate volume and concentration, as well as local hydrology and rainfall patterns (Borga and Ruus, 2016). The examined region experiences a humid continental climate, characterized by significant seasonal variations. The calculated HI for both adults and children is summarized in Table 3.

Table 3. Overview of the HI of heavy metals at the Zrenjanin Landfill for adults and children

Heavy metal	HQingestion		HQdermal		HI	
	Adults	Children	Adults	Children	Adults	Children
Cr	1.71E-03	1.78E-03	2.83E+01	5.81E+01	**2.83E+01**	**5.81E+01**
Fe	1.21E-04	1.26E-04	2.26E-01	4.64E-01	2.26E-01	4.64E-01
Zn	7.04E-05	7.32E-05	5.51E-03	1.13E-02	5.58E-03	1.14E-02
Ni	1.57E-03	1.63E-03	2.05E+01	4.21E+01	**2.05E+01**	**4.21E+01**
Mn	4.12E-04	4.28E-04	8.95E-01	1.84E+00	8.96E-01	1.84E+00
Cu	2.50E-03	2.60E-03	7.63E-02	1.57E-01	7.88E-02	1.59E-01

Chromium (Cr) exhibited the highest HI values, with 28.27 for adults and 58.08 for children, indicating a significant potential health risk for both groups. The Agency for Toxic Substances and Disease Registry (2012) states that acute ingestion of Cr (VI) compounds, results in acute, potentially fatal effects in the respiratory, cardiovascular, gastrointestinal, hepatic, renal, and neurological systems. Whereas dermal exposure to Cr due to its corrosive nature can lead to dermal ulcers. Similarly, nickel (Ni) showed elevated HI values of 20.48 for adults and 42.08 for children, also suggesting a serious risk of adverse health effects. These are contact dermatitis resulting from an allergic response or in contrast, oral exposure studies of soluble nickel compounds have reported developmental effects. Observed effects include fetal loss, decreased survival, decreased offspring body weight, and skeletal abnormalities (ATSDR, 2024). Manganese (Mn) presented an HI of 0.896 for adults which is borderline in terms of safety, and 1.839 for children, exceeding the safety threshold. This indicates that children may be at risk, while adults are near the limit of acceptable exposure. An actual threshold level at which Mn exposure produces neurological effects in humans has not been established. However, children consuming the same concentration of manganese in water as adults are ultimately exposed to a higher mg/kg-body weight ratio of manganese than adults. Children are also potentially more sensitive to manganese toxicity than adults. Furthermore, ATSDR (2014) suggests that exposure to excess levels of Mn in drinking water ($\geq$ 0.2 mg/L) may lead to neurological deficits in children, including poor school performance, impaired cognitive function, abnormal performance on neurobehavioral tests, and increased oppositional behavior and hyperactivity. In contrast, the HI values for iron (Fe), zinc (Zn), and copper (Cu) were well below the threshold of 1 for both adults and children, indicating no significant non-carcinogenic health risks from these metals.

CONCLUSIONS

This study has successfully assessed the hazard index for six heavy metals (chromium, iron, zinc, nickel, manganese and copper) and the exposure risk of adults and children living near the Zrenjanin landfill in Serbia, highlighting the need for increased awareness regarding their presence in the environment. It is important to note that the groundwater concentrations of the heavy metals are only an estimate based on a literature dilution factor. The variation in the dilution factor is influenced by the flow rate of the water body, leachate volume and concentration, as well as local hydrology and rainfall patterns which should be thoroughly researched for Zrenjanin landfill and considered to provide a complete hazard risk assessment. Based on the research data obtained in this study, results show that chromium and nickel pose the most significant concerns, especially for children, while manganese requires careful monitoring. The other metals analyzed are within safe exposure limits. This paper provides an important overview of the potential impacts of landfill-related contaminants and the risks associated with them, which may ultimately affect human health. The findings call for further investigation into the groundwater levels, hydrology maps of the area, exposure levels and bioconcentrations of these heavy metals in humans to fully understand their adverse health implications.

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SUSTAINABLE WATER RESOURCE MANAGEMENT, WATER RESILIENCE AND CLIMATE CHANGES

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Abstract: Sustainable water resources management is a critical foundation for ensuring the long-term security, quality, and equitable distribution of water, especially under the increasing pressures of global climate change. As climate-related disruptions such as altered precipitation patterns, prolonged droughts, intensified floods, and rising temperatures become more frequent and severe, the resilience of water systems is increasingly recognized as a central component in climate adaptation strategies. This paper investigates the intricate and dynamic interrelationship between sustainable water resources management, water system resilience, and the evolving impacts of climate change on hydrological cycles, water availability, and quality. The analysis is grounded in an interdisciplinary framework that synthesizes insights from hydrology, climate science, environmental policy, and sustainability studies. Particular emphasis is placed on the role of resilient water governance in reducing vulnerability and enhancing adaptive capacity, both of which are essential for protecting ecosystems, supporting livelihoods, and achieving multiple Sustainable Development Goals (SDG 6, SDG 11 and SDG 13). The study reviews the current legal and institutional mechanisms regulating water resources at the international level and within the Republic of Serbia, identifying strengths, limitations, and opportunities for reform. By analysing legal documents, strategic plans, and related legal data, the paper provides a comprehensive evaluation of existing management practices in light of emerging climate risks. The findings highlight the urgent need for integrated, inclusive, and adaptive policy responses that prioritize long-term sustainability over short-term exploitation. Based on the conducted research, the paper proposes a set of targeted policy recommendations aimed at strengthening institutional resilience, fostering cross-sectoral cooperation, and promoting participatory governance. Ultimately, the research affirms that proactive and sustainable water management is not only essential for mitigating the adverse effects of climate change but also for enabling the equitable and efficient achievement of the broader 2030 Agenda for Sustainable Development.

Keywords: *Water resources, Management, Climate change, Policy, Legislative.*

INTRODUCTION

Water protection represents a set of measures and activities by which the quality of surface and groundwater is protected and improved in order to preserve human life and health. It also represents a set of measures and activities aimed at reducing pollution and preventing further deterioration of water conditions, ensuring harmless and undisturbed use of water for various purposes, and protecting aquatic and coastal ecosystems (Jovanović, 2016). The demand for

water has outpaced population growth, and half the world's population is already experiencing severe water scarcity at least one month a year. Water scarcity is projected to increase with the rise in global temperatures as a result of climate change (Pontius & McIntosh, 2024). There are many challenges in providing drinking water, because potable and easily accessible land water only accounts for 0.014% of the planet's total water potential (Amidžić, 2021). In 2022, 2.2 billion people still lacked safely managed drinking water, including 703 million without a basic water service; 3.5 billion people lacked safely managed sanitation, including 1.5 billion without basic sanitation services; and 2 billion lacked a basic handwashing facility, including 653 million with no handwashing facility at all. By managing our water sustainably, we are also able to better manage our production of food and energy and contribute to decent work and economic growth. Moreover, we can preserve our water ecosystems, their biodiversity, and take action on climate change (UN, 2015).
Bearing in mind the above problems, the paper analyses the need and importance of sustainable water resource management in the context of climate change. It reviews the current legal regulations in this area at the international level and in the Republic of Serbia. Based on the research conducted and the data obtained, proposals are made for improving water resource management policy in the context of climate change.

GOAL 6 OF THE SUSTAINABLE DEVELOPMENT AGENDA AND CLIMATE CHANGE

Goal 6 of the UN Sustainable Development Agenda, "ensure availability and sustainable management of water resources for all", plays a key role in achieving an overall sustainable future for humanity. Water is essential for life, health, economic activity and the conservation of ecosystems, and its responsible management is a fundamental prerequisite for achieving most of the other SDGs, including poverty reduction, food security, health and well-being, and access to energy. In the context of climate change, achieving Goal 6 becomes particularly challenging. In many countries access to safe drinking water remains limited and climate change is further exacerbating this situation. Given the inter-relationships between water and other dimensions of sustainable development, Goal 6 is at the heart of the fight against climate change. There is a clear link between water resource management and climate change (UN, 2015). Water availability is becoming less predictable in many places. In some regions, droughts are amplifying water scarcity and thereby negatively impacting people's health and productivity and threatening sustainable development and biodiversity worldwide. Ensuring that everyone has access to sustainable water and sanitation services is a critical climate change mitigation strategy for the years ahead. Without better infrastructure and management, millions of people will continue to die every year from water-related diseases, and there will be further losses in biodiversity and ecosystem resilience, undermining prosperity and efforts towards a more sustainable (Firoiu et al, 2023). The implementation of Goal 6 requires an integrated approach to water resource management that includes coordination between the water, agriculture, energy and environmental sectors, with the active participation of local communities and all stakeholders. It is also necessary to strengthen institutional capacities, develop infrastructure systems for water supply and sanitation, as well as improve technologies for purification and rational use of water. Of particular importance is the improvement of community resilience to climate change through investments in nature-based solutions - NbS, such as wetland conservation and river restoration, followed by improving early warning systems and planning in accordance with risks (Mahmoud et al, 2022).

WATER RESOURCE MANAGEMENT AND RESILIENCE IN THE WATER SECTOR

The EU Water Resilience Strategy marks a vital shift in water governance, driven by an urgent need to address escalating water-related challenges across the EU continent. This strategy acknowledges that traditional water management models are insufficient to cope with the increasing complexity, frequency, and severity of hydrological disturbances. Droughts, floods, water scarcity, and declining water quality once considered sporadic phenomena have become structural threats to the EU economic stability, social equity, and ecological sustainability. The Strategy is therefore not only a policy innovation but also a critical instrument for aligning water governance with the transformative ambitions of the SDGs, particularly SDG 6, SDG 11, and SDG 13. One of the core strengths of the Strategy lies in its systemic approach. Rather than addressing water challenges in isolation, the Strategy is framed around the interconnectedness of water with energy, agriculture, health, biodiversity, and climate systems. This holistic orientation is essential in the era of climate change, where linear solutions no longer suffice. Water systems are under increasing pressure from reduced snowfall, disrupted rainfall patterns, heatwaves, and rising evapotranspiration rates all of which affect the timing, quantity, and quality of water resources. By promoting integrated water management practices and investing in nature-based solutions, the strategy aims to build adaptive capacity and resilience within both natural and human systems (Pankow at al, 2024). In the context of SDG 6, the Strategy directly supports efforts to ensure availability and sustainable management of water and sanitation for all. The EU recognizes that water scarcity is no longer a regional issue confined to the Mediterranean basin but a Pan-European concern. Through mechanisms such as enhanced monitoring, digitalization of water infrastructure, and cross-border cooperation, the strategy facilitates more efficient water use, improved wastewater treatment, and better groundwater protection. In doing so, it advances targets such as 6.1 (universal access to safe drinking water), 6.3 (improving water quality and wastewater management), and 6.4 (increasing water-use efficiency) (Margeta, 2023). Moreover, the Strategy's implications for SDG 11 are substantial. As urbanization accelerates and cities become increasingly vulnerable to water-related disasters, resilient urban water systems are essential for safeguarding public health, infrastructure, and livelihoods. The strategy promotes sustainable urban drainage systems, green infrastructure, and floodplain restoration as key components of climate-resilient cities.

These measures not only mitigate flood risks but also enhance urban liveability and biodiversity, contributing to the creation of inclusive, safe, resilient, and sustainable urban environments (Poli et al, 2024).

The alignment with SDG 13 (Climate Action) is particularly pronounced. Water is both a victim and a vector of climate change, and its effective governance is central to adaptation and mitigation strategies. The EU Strategy places strong emphasis on climate risk assessments, vulnerability mapping, and the integration of climate considerations into all water-related planning and decision-making processes. By fostering investment in climate-resilient infrastructure and supporting Member States in implementing adaptation measures under the EU Climate Law and National Adaptation Strategies, the strategy acts as a cornerstone for achieving long-term climate resilience (Küfeoğlu, 2022). Importantly, the Strategy also reflects the principles of environmental justice and intergenerational equity. It promotes inclusive stakeholder engagement, equitable access to water services, and transparency in water governance. This participatory dimension reinforces democratic legitimacy while ensuring that vulnerable populations are not disproportionately affected by water insecurity. The EU Strategy stands for the type of transformative policy action required to confront the intertwined crises of climate change, ecological degradation, and resource scarcity. By fostering resilience at multiple levels—ecological, institutional, and infrastructural the strategy directly contributes to the realization of key SDGs, offering a replicable model for integrated water governance in a climate-constrained world. As such, it is not merely a sectoral initiative but a foundational element of Europe's broader sustainability and climate agenda, similar to WEF Nexus approach (Vasovic et al, 2025).

LEGAL FRAMEWORK FOR WATER RESOURCES MANAGEMENT

The starting point for the international regulation of water resources management are the documents of the United Nations, as the most influential international organization of a global nature, and the European Union, as the most important regional organization in Europe.

Starting from the UN, its most important document aimed at ensuring sustainable development is the Agenda for Sustainable Development (A/RES/70/1). Goal 6 of this Agenda relates to water resources – ensure availability and sustainable management of water and sanitation for all. This means that a number of more specific goals are to be achieved by 2030 such as achieve universal and equitable access to safe and affordable drinking water for all, etc. In The Sustainable Development Goals Report (2024) it is highlighted that despite some improvements, progress in water and sanitation remains insufficient. At the current speed, in 2030, 2 billion people will still live without safely managed drinking water, 3 billion without safely managed sanitation and 1.4 billion without basic hygiene services. In 2022, roughly half the world's population experienced severe water scarcity for at least part of the year. One quarter faced "extremely high" levels of water stress. Climate change worsens these issues, posing significant risks to social stability. Between 2015 and 2022, the proportion of the population using safely managed drinking water increased from 69 to 73 per cent. Using millions of satellite images, scientists mapped permanent water bodies globally from 2005 to 2022. The analysis revealed a net global increase of 2.1 per cent (53,672 km2) in permanent water area since 2005. Much of the increase comes from climate change and reservoir filling. While the global net gain in permanent water is positive, global data also reflect losses of permanent water linked to droughts and rising water demand in some regions, notably Australia and New Zealand, Latin America and the Caribbean, and Central Asia (The Sustainable Development Goals Report, 2024). Within the UN, the activities of UNEP, which also works to achieve Goal 6, have a particularly significant role. This organization helps countries protect and restore freshwater ecosystems to sustain their services for generations to come (UNEP, 2015). To do this, UNEP collects data and reports on the status of water quality and the health of freshwater ecosystems; provides training and policy advice to help countries and communities better manage their water resources, especially in the face of the climate crisis and supports innovative pilot projects, including nature-based solutions, to protect and restore freshwater sources. In addition to the Agenda for Sustainable Development, important UN documents in the field of water resources management are: Ramsar Convention on Wetlands (1971), Watercourses Convention (1997), Water Convention and the Protocol on Water and Health (1992), etc. In the context of climate change and water resources, the Paris Agreement on climate change (2015) stands out, which recognizes water resources as key to climate change adaptation and ecosystem resilience.

When it comes to the legal sources of the European Union, the Water Framework Directive stands out first. This Directive (2000) focuses on ensuring good qualitative and quantitative health, i.e. on reducing and removing pollution and on ensuring that there is enough water to support wildlife at the same time as human needs. Since 2000, the Directive has been the main law for water protection in Europe. In addition to the Water Framework Directive being an umbrella document, the following are also important for water management: Council Directive concerning urban waste water treatment (1991), Council Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources (1991), Council Directive concerning the quality required of surface water intended for the abstraction of drinking water in the Member States (1975), Council Directive on the quality of water intended for human consumption (1998), Directive on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council (2008), Directive on the assessment and management of flood risks (2007), etc.

In terms of national legislation, of particular importance for water resources management in Serbia are: the Law on Waters, as the basic law in the field of water resources management in Serbia, and the Law on Environmental Protection, as the basic law in the field of environmental protection, as well as some other laws in an indirect sense (Amidžić, 2021). The Law on Waters (2010), as the umbrella document for water resources management in Serbia, regulates the legal status of waters, integrated water management, management of water facilities and water land, sources and methods of financing water activities, supervision of the implementation of this law, etc. The Law on Environmental Protection (2004) represents the basis for the protection of natural resources, including water, as well as the framework for the integration of water policy into broader environmental policy. In addition to the above, the Law on Environmental Impact Assessment, the Law on Strategic Environmental Impact Assessment, the Law on Nature Protection, etc. are also important for the field of water resources. Also, it is necessary to emphasize a strategic document - Water Management Strategy on the Territory of the Republic of Serbia until 2034 (2017). This document represents the basis for implementing reforms in the water sector in order to achieve the necessary standards in water management.

REFLECTION ON PROMINENT CASE STUDIES

1. The Danube River Basin, Europe's second-largest river system, encompasses multiple EU member states, necessitating transboundary cooperation for effective water resource management. Recognizing the shared challenges posed by climate change, such as increased flood risks and water scarcity, the EU Strategy for the Danube Region has prioritized water quality and environmental risk management. Under the EUSDR framework, countries within the Danube Basin have established collaborative mechanisms for data collection, early warning systems, and uniform methodologies for emissions data. These cooperative efforts aim to mitigate adverse impacts on ecosystems and ensure the provision of clean drinking water. Hungary, for instance, has played a central role in coordinating activities related to water quality and environmental risks, fostering regional partnerships and joint project proposals. This case exemplifies the alignment with SDG 6 through the promotion of clean water and sanitation, SDG 11 by enhancing the resilience of communities along the Danube, and SDG 13 by facilitating regional adaptation strategies to climate-induced water challenges (Ngampramuan, 2022).

2. The Puglia region in southern Italy faces significant water-related challenges due to its Mediterranean climate, characterized by increasing temperatures and decreasing precipitation. These climatic shifts have led to recurrent droughts, groundwater depletion, and heightened vulnerability of coastal zones to sea-level rise and saltwater intrusion. In response, the regional authorities have adopted an integrated approach to water and coastal management, emphasizing cross-sectoral strategies that incorporate climate change adaptation into traditional planning processes. Key initiatives include the development of climate modelling to assess future atmospheric and oceanic conditions, risk assessments for drought and sea-level rise, and the implementation of Integrated Coastal Zone Management plans. Additionally, Puglia has engaged in the Bologna Charter 2012, promoting strategic actions for coastal protection and sustainable development. These efforts contribute to SDG 6 by promoting sustainable water

management practices, to SDG 11 by enhancing the resilience of urban and coastal communities, and to SDG 13 by integrating climate adaptation into regional planning (Ellena et al, 2025).

3. Ljubljana, the capital of Slovenia, relies heavily on the Ljubljana Field porous aquifer for its drinking water supply. Recognizing the vulnerabilities posed by climate change such as increased frequency of droughts and potential contamination risks the city's water management authorities undertook a comprehensive assessment to adapt their water supply system. The study evaluated various management scenarios, including the establishment of new water well fields in Koseze, located southwest of the existing aquifer. These new wells are designed to diversify the water sources, thereby reducing the dependency on a single aquifer and enhancing the system's resilience to climate-induced stresses. Additionally, water treatment options for existing well fields were considered to ensure water quality under changing environmental conditions. This proactive approach exemplifies how urban centers can adapt their water infrastructure to the challenges posed by climate change, ensuring a sustainable and safe water supply for their populations (Cencur Curk et al, 2020).

CONCLUSION

Successful implementation of water resilience based initiatives requires a multi-scalar approach that bridges EU-level vision with national regulatory coherence and localized adaptive capacity. National governments must not only transpose EU directives into binding national legislation but also modernize existing regulatory frameworks to reflect the urgency of climate risks, water scarcity, and the importance of ecological resilience. This includes updating water laws, strengthening institutional mandates, and ensuring effective enforcement mechanisms that support sustainable water allocation, quality standards, and ecosystem-based management. Equally critical is the role of local adaptation strategies, which serve as the operational frontlines of resilience-building. Municipalities and regional authorities must develop context-sensitive plans that account for localized hydrological conditions, socio-economic vulnerabilities, and climate projections. Integrated Water Resource Management and Nature-Based Solutions should be prioritized at the local level, enabling adaptive infrastructure development, sustainable land use planning, and risk-informed decision-making. Local authorities also play a vital role in facilitating cross-sectoral cooperation between water utilities, agriculture, energy, and civil protection services, thereby fostering climate-resilient urban and rural systems. Also, the emergence of citizen science as a participatory model of knowledge generation offers significant potential to complement official water monitoring systems. Engaging local communities in data collection, ecosystem monitoring, and early warning efforts can enhance public awareness, democratize environmental governance, and fill data gaps in regions where institutional capacity is limited. By empowering citizens as active stakeholders in water resilience efforts, governments and institutions can foster a culture of shared responsibility, strengthen adaptive capacity, and ensure that water management strategies are grounded in both scientific evidence and local realities.

Based on all of the above, a logical question arises: What can we do? There are many options available to environmental policy and law subjects. Civil society organizations should work to keep governments accountable, invest in water research and development, and promote the inclusion of women, youth and indigenous communities in water resources governance. Generating awareness of these roles and turning them into action will lead to win-win results and increased sustainability and integrity for both human and ecological systems.

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Water Management Strategy on the Territory of the Republic of Serbia until 2034 ("Official Gazette" of RS, No. 3/17)

ANALYSIS OF DUST PARTICLES EMISSIONS AT TOOL STEEL OXYFUEL AND PLASMA CUTTING PROCESSES

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Abstract: Oxyfuel cutting and plasma cutting are material processing technologies that are strongly associated with particulate matter emissions.

These particles have a negative impact on the health of the operator because they penetrate deep into the lungs due to their small size. The impact is determined by measuring the amount of particulate matter emissions, particles morphology, analyses of particles chemical composition, and particles size and their size distribution. The methods for measuring and evaluating these parameters are regulated in the standard ISO 13322-1.

In the presented study, the emitted particles generated during flame cutting and plasma cutting of S460 grade tool steel were analysed. The sampling of the particles was performed with the personal particle sampler, the weighting of the particles was performed on an electronic balance, while particle size, their morphology and chemical composition were determined under a field emission scanning electron microscope ThermoFisher Scientific Quattro S.

By comparing the measurement results, it was determined how the processing technology, the processed material and the use of the extraction filter device affect the emission of fine dust to which the operators during working process are exposed.

Keywords: *dust particles; emissions; tool steel; oxyfuel cutting; plasma cutting.*

INTRODUCTION

To achieve the desired shape of the product, it is necessary to choose the most suitable machining process. If we want to separate two metal parts, the easiest way to do this is to use thermal cutting. Flame cutting is most commonly used, where an exothermic metal oxidation reaction is used to melt and cut the material (Krajcarz, 2014; Ashby, 2018). We also know plasma cutting, which allows the cutting of materials that conduct electricity well, because here the material melts due to the electric arc.

In the frame of our investigation work, we chose both the flame and plasma cutting process for cutting S460 tool steel (Jocić, 2008). Both the flame and plasma cutting process apply to machining technologies that are strongly related to dust particle emissions. These particles are dangerous from a health point of view as they can penetrate deep into the lungs of the operator performing these processes. Therefore, it is very important to determine the level of risk to the human respiratory system that is related to the nature, shape and size of the particles (Wahab, 2014; Ilić Mićunović, 2020). The resulting particles can be of different sizes, the most dangerous being particles with a diameter of less than 10 μm, which are respiratory particles and due to their small size are most easily dispersed in the working environment (Ilić, 2015; Kosec 2021).

For cutting processes, the resulting particles can be divided into two groups. Namely, these are particles larger than 20 μm. These are caused by metal injection. Another type of particle is represented by particles with a size of about 1 μm, which are the result of condensation of metal vapours. Upon closer analysis, it was found that ultrafine particles (less than 0.1 μm) are also present, representing only about 7% of the total mass of all formed particles.

Chemical analysis of the filters on which the particles were trapped showed that in the cutting of aluminium the particles contain organic and elemental carbon, iron and aluminium. In steel cutting, however, the particles contained iron, organic carbon, zinc, and copper. The presence of these elements can be attributed to organic coatings on metals, aluminium, galvanized steel or electrodes.

Adverse effects on humans can be divided into three categories:

- chemical hazard (caused by particulates and gases),
- mechanical hazard (electricity, heat, noise, vibration), and
- danger due to radiation (electromagnetic radiation in the area of visible, UV and IR waves).

Of all the above, the chemical hazard has the greatest impact, as the resulting flue gases and harmful gases have the most negative impact on human health. Epidemiological studies of full-time cutters and welders have shown that they developed febrile illness from inhaling metal fumes, respiratory tract irritation, changes in lung function, lung infections, and an increased likelihood of developing lung cancer (Agarski, 2012).

Basically, dust particles are classified as primary particles resulting from emissions from natural or artificial sources and secondary particles formed due to chemical and physical reactions once they are in the atmosphere. To facilitate the determination of the origin of the particles and the influence of the dust particles, we divide them into predetermined size classes. Particles can be quantitatively characterized by determining their geometry. After processing the image with the help of software, we get a set of geometric parameters that describe the size and shape of the particle (MDHS, 2014).

ISO standard 13322, entitled "Particle size analysis - Image analysis methods" (ISO 13322-1, 2014), consists of two parts, namely static image analysis and dynamic image analysis. For the purposes of the investigation work, the first part of the standard describing static analysis will be considered and will be presented below. The purpose of the first part of ISO 13322 is to recommend when captured images can be used for particle size analysis. The aim of this part of the standard is to give a standardized description of the technique used, whereby the obtained measurements correspond to the recommendations of the standard are traceable. This section does not describe the devices used to capture images, but the standard is limited to image sections that are relevant to the correctness of the results in the particle size analysis. The first part of the standard contains calibration verification methods and recommendations for using a certified standard as a reference. Throughout the analysis, errors are taken into account that contribute to the final uncertainty of the measurements. This part of ISO 13322 is useful for image analysis to determine the size distribution of stationary particles. The particles are arranged and fixed in the plane observed with the image capture device. The field of view changes by moving the support on which the particles are or by moving the camera, so it is necessary to ensure that there is no distortion of the captured images. The standard focuses on digital images generated by a light or electron detection system and considers only images that are analyzed using pixel counting methods (Gehr, 2022).

EXPERIMENTAL WORK

The experimental part of the work includes the measurement and analysis of particulate emissions produced by the cutting processes for tool steel S460 (Tables 1, 2) (Jocić, 2008).

Table 1. Chemical composition of steel S460

Element	C	Cr	Mn	Mo	V	Si	Fe
mas. %	1.00	8.00	0.30	2.30	0.30	1.10	balance

Table 2. Basic thermal and mechanical properties of steel S460 at ambient temperature

Thermal conductivity	17.6 W/mK
Specific heat	470 J/kgK
Density	7640 kg/m^3
Coefficient of thermal expansion	11.5 x10^{-6} m/mK
Young's modulus	210 GPa

Figure 1. Measuring instrument ZAMBELLI EGO PLUS TT.

All steel cutting operations were carried out for 1 minute, during which time the produced particulate emissions were recorded with the measuring instrument ZAMBELLI EGO PLUS TT (Figure 1), which had to be pre-calibrated (Malvern IL; 2015).
We first weighed the emitted particles that were trapped on the filter of the device and then evaporated them with carbon. With this, we prepared them for observation under field emission electron microscope (FEG SEM) ThermoFisher Scientific Quattro S (Figure 2), where we captured images of the particles on the filter and measured their chemical composition (Eriksen Hammer, 2022; Eun-Ji, 2021) . At the end we used the computer program ImageJ to process the captured images and determine the geometry and size of the particles.

Figure 2. Scanning electron field emission microscope Thermofischer Quattro S.

The flame cutting process of S460 steel was performed for 1 minute with a gk TIP200 / A flame cutter on acetylene and oxygen. Plasma cutting of S460 steel was also performed for 60 seconds (1 minute) with a Lincoln Electric INVERTEC PC100 plasma cutter connected to direct current and a three-phase voltage of 400 V (Table 3).

Table 3. Cutting process data

Heat source	Type	Time
Flame	Cutter gk TIP200/A	1 min
Plasma	Cutter Lincoln Electric INVERTEC PC100	1 min

Sampling with this meter can be done spatially or in person. In spatial sampling, the meter is fixed to a specific area in the room, which means that the average amount of dust particles in the measured area is measured. In personal sampling, the meter is located at the operator near his respiratory system. We decided to choose personal sampling as we were interested in the direct impact of particulate emissions on the operator performing the cutting or welding process. To achieve the desired effect, the mouthpiece of the meter was attached under the airway, approximately 25 to 30 cm away from the mouth as shown in Figure 3.

Figure 3. Operator with measuring instrument installed.

Before starting each measurement, it is necessary to calibrate the meter, determine the time of capture of particles and select the filter. Speed, temperature and relative humidity must also be measured during particle capture. The operation of the meter could be compared to the operation of a suction device, as the meter sucks air through a tube attached to a nozzle on which trapped dust particles accumulate that are large enough to trap on the filter.
The parameters with the corresponding units and values are shown below and had the same values in all processing operations.
Measured constant parameters during measurements:

- Room air temperature: 21 °C.
- Room air velocity: 0 m/s.
- Relative humidity in the room: 50%.

Selected parameters:

- Calibration of air flow through the filter: 3 l/min (simulates operators breathing).

- Filter: Mixed cellulose ester filter (MCE).
- Total particle capture time: 1 min.

RESULTS AND DISCUSSION

The results of dust particle emissions showed that the steel cutting process causes about 7 times more emissions than the manual arc welding process. The highest emission of dust particles is produced by the flame cutting process of S460 tool steel, namely 0.096 g/h.
In Figure 4 are presented results of dust analysis used field emission electron microscope (FEG SEM) ThermoFisher Scientific Quattro S. By analyzing the obtained images, we concluded that the individual particles have the correct spherical shape in both the cutting processes.

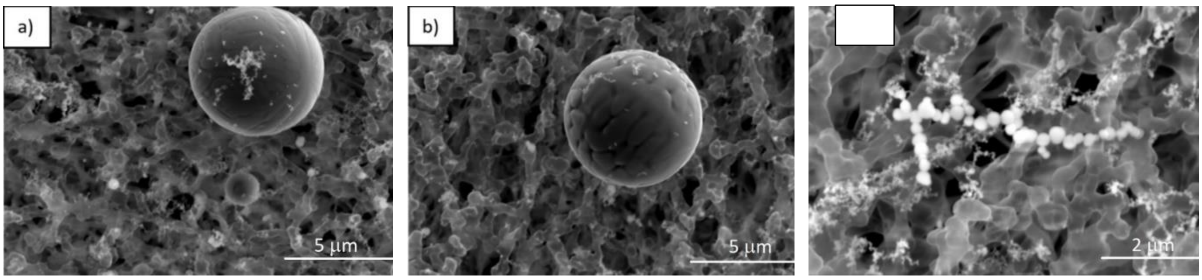

Figure 4. Only emitted dust particles through the use of ETD method, for example: a) Oxygen cutting of steel S460; b) Plasma cutting of steel S460; d) Clusters of nano dust particles

In all cases, clusters of particles or agglomerates were also present, which were composed of individual spherical particles and were clearly visible. Flame cutting produces more particles with an equivalent diameter of less than 1.75 µm than plasma cutting (Figure 4d).

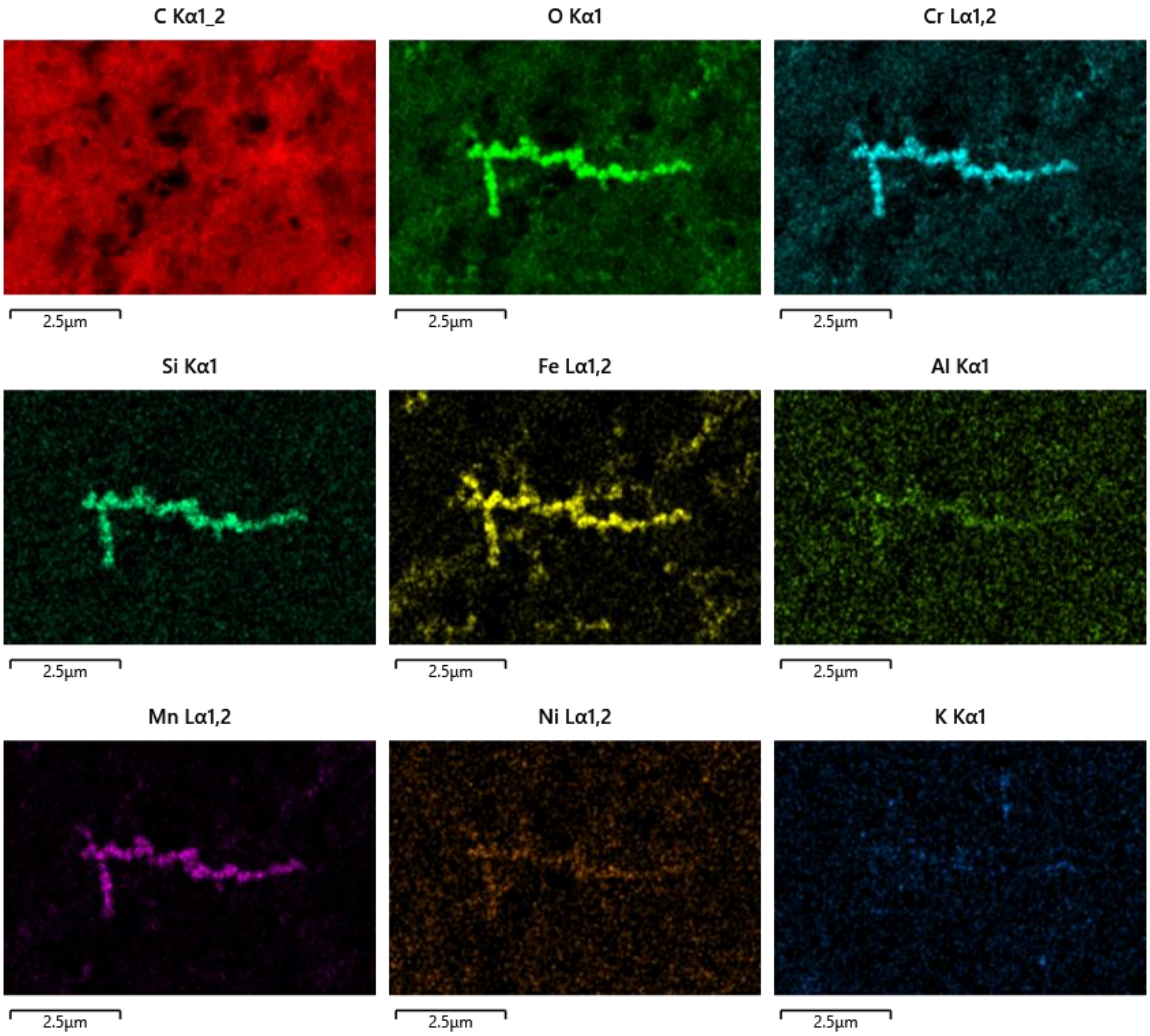

Figure 5. Elemental composition of nanoparticles captured on the filter – BOV.

Plasma cutting produces particles with a diameter greater than 5.5 µm, which cannot be detected during flame cutting. This means that, on average, smaller particles are obtained in flame cutting than in plasma cutting. All analyzed particles for both plasma and flame cutting are less than 10 µm, which means that they are classified as respiratory particles, as they reach the lower respiratory tract all the way to the alveoli.

Figure 5 shows the elemental composition of nano particles caught on the filter (Figure 5). The particles are seen to contain oxygen, carbon, chromium, silicon, aluminium, potassium, iron, nickel and manganese. The results suggest that these particles are oxide particles.

CONCLUSIONS

In the presented study, the emitted particles generated during flame cutting and plasma cutting of S460 grade tool steel have been analyzed.

The sampling of the particles was performed with the personal particle sampler, the weighting of the particles was performed on an electronic analytical balance, while particle size, their morphology and chemical composition were determined under a field emission scanning electron microscope.

Prior to sampling the emitted dust particles during the cutting processes, special attention must be taken to ensure that the mixed cellulose ester filter on which the particles are trapped is not moistened. Moisture affects the initial mass of the filter and causes a change in its properties.

Flame cutting of S460 steel produces more particles with an equivalent diameter of less than 1.75 μm than plasma cutting. Plasma cutting produces particles with a diameter greater than 5.50 μm that cannot be detected by flame cutting. This means that, on average, smaller particles are obtained in flame cutting than in plasma cutting. All analyzed particles for both flame and plasma cutting are less than 10 μm.

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STATIC MAGNETIC FIELDS IN INDUSTRY: NEW GUIDELINES FOR EXPOSURE CLASSIFICATION AND A SYSTEMATIC REVIEW OF HEALTH RISKS

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Abstract: This paper provides a comprehensive analysis of validated scientific studies examining the effects of static magnetic fields (SMFs) on occupational health in industrial and medical environments. The studies are systematically reviewed based on their findings regarding impacts on the nervous system, cardiovascular function, mental health, as well as physiological and cellular responses. Key findings are presented alongside quantitative data on field intensities. The paper introduces new guidelines for exposure limits and identifies occupational roles with elevated risk. The primary objective is to systematically present and critically evaluate scientific evidence on the presence and intensity of SMFs across various industrial sectors, as well as to assess the quality and conclusions of both epidemiological and experimental studies investigating their health implications. Through the analysis of sources and specific case studies, the paper aims to address whether current safety guidelines are adequate or whether they require revision in light of emerging evidence. The conclusions suggest that SMF-related health effects may occur even at intensities below the ICNIRP thresholds, particularly under prolonged exposure or in the presence of biomedical implants. The paper proposes an improved classification of exposure levels and enhanced safety control measures for industrial applications.
Keywords: *Static magnetic fields, industrial exposure, occupational health, neurological effects, MRI.*

STATIC MAGNETIC FIELDS IN INDUSTRY

Static magnetic fields (SMFs) are vector fields of constant magnitude and direction over time, with no oscillatory components. In industrial and medical environments, exposure to such fields has become increasingly common due to the widespread use of technologies such as magnets in electrolysis processes, material separation systems, direct current (DC) electric drives, and particularly magnetic resonance imaging (MRI) equipment used in diagnostics.

SMFs most frequently occur in the following domains.

1. Medical Diagnostics – MRI Systems:
   - MRI scanners employ extremely strong SMFs, typically ranging from 1.5 to 3 Tesla, with research-grade systems reaching up to 7 Tesla.
   - Personnel working with MRI equipment are frequently exposed to SMFs during operational tasks, especially while moving near the magnet bore.
2. Industrial Welding – Electric Arc Welding:
   - During arc welding, SMFs are generated around electrodes due to high electrical currents (100–1000 A).

   - Workers are locally exposed to magnetic fields in the milliTesla (mT) range.
3. Electrolytic Processes – Refining of Copper, Zinc, and Aluminum:
   - Electrolysis involves strong DC currents that produce SMFs within the electrolytic cells.
4. Reciclyng and Steel Industry – Magnetic Separators:
   - Devices utilize either permanent magnets or electromagnets to separate ferromagnetic materials from non-magnetic ones.
   - Field strengths may exceed 0.1 Tesla in operational zones.
5. Nuclear and Physical Research:
   - Laboratories employ superconducting magnets for experiments such as nuclear magnetic resonance (NMR) spectroscopy and controlled fusion in tokamak reactors.

In many of these sectors, workers spend a significant portion of their working hours near high-intensity SMF sources, with field strengths sometimes exceeding 1 Tesla. This raises critical concerns regarding both the short-term and long-term health impacts of occupational SMF exposure.

An increasing number of reports have documented the occurrence of symptoms such as dizziness, magnetophosphenes, spatial disorientation, and mental fatigue among personnel working in MRI environments and the electrical industry. These symptoms are increasingly being investigated in relation to underlying physiological mechanisms, including induced electrical currents in the vestibular system and alterations in microcirculatory function. Furthermore, prolonged occupational exposure to static magnetic fields in copper and aluminum electrolysis facilities has raised concerns about potential neuropsychiatric effects on workers, including mood disturbances, impaired attention, and sleep disorders.

Sources of Static Magnetic Fields

The modern application of strong magnetic fields in both industry and medicine has significantly increased the number and diversity of magnetic field sources to which humans are exposed. This section outlines the most common and significant sources, their basic characteristics, and potential effects on individuals working in their vicinity.

Medical Diagnostics – MRI Systems

One of the most frequent and intense sources of static magnetic fields (SMFs) in contemporary industry is medical imaging, particularly Magnetic Resonance Imaging (MRI) devices. These systems utilize extremely strong SMFs to generate detailed internal images of the human body by exploiting proton resonance in the presence of a magnetic field. Clinical MRI scanners commonly operate at field strengths of 1.5 to 3 Tesla, while research-grade units can reach 7 Tesla or even 11 Tesla in some experimental settings.

The SMF in an MRI scanner is continuously active — meaning the field is present even when no scanning is performed. While patients are exposed only briefly during imaging, technical personnel working around the MRI machine are frequently subject to chronic SMF exposure, especially when moving through the so-called "5-gauss" (0.5 mT) zone. Movement through this static field can induce electric currents in the body, leading to vestibular disturbances such as dizziness, metallic taste, visual light flashes (phosphenes), and nausea.

MRI systems generate SMFs through three types of magnets: permanent magnets (rare), resistive electromagnets (limited in power), and superconducting magnets (dominant technology), which are cooled with liquid helium to maintain low resistance and produce a strong, stable field. Additionally, MRI suites are equipped with ferromagnetic traps and detectors that prevent the entry of metallic objects into the magnetic zone, due to the strong attractive forces that SMFs exert on ferromagnetic materials.

Beyond immediate physiological symptoms in personnel, SMFs in MRI environments demand strict safety protocols due to the risk of interference with medical implants (e.g., pacemakers), insulin pumps, and other electronic devices. As a result, many countries have implemented standards that restrict time spent within high SMF zones, including mandatory dosimetry, staff education, and medical supervision.

This industrial application of SMFs underscores how advanced technologies inherently introduce occupational exposures that require specific health and safety protocols and continuous monitoring.

Industrial Welding – Electric Arc Welding

Industrial welding, particularly electric arc welding (e.g., MMA, MIG/MAG, TIG techniques), represents a significant source of static magnetic fields (SMFs) within industrial environments. These welding processes employ either direct current (DC) or alternating current (AC), which flows through the electrode and the workpiece, forming an electric arc that melts the metal. When DC is used, a static magnetic field is generated in the welding zone, typically reaching several milliTesla (mT), which represents a considerable level of localized exposure.

Magnetic fields are formed according to Ampère's law around conductors carrying electrical current. In welding scenarios, the cables, electrode, and workpiece form a closed circuit, concentrating the magnetic field in areas where the welder's body — especially the head and torso — is closest to the arc. Moreover, if multiple machines are in use simultaneously or if cables are improperly arranged, the magnetic components may combine, resulting in higher overall SMF intensities.

Although SMF levels encountered in welding do not reach those observed near MRI scanners, continuous and long-term exposure (over 8 hours per day) may still have biological implications. Research has documented neurological disturbances, sleep disorders, headaches, and changes in the peripheral nervous system among professional welders. In addition to health concerns, SMFs may also interfere with sensitive electronic equipment used in welding environments — including detectors, robotic systems, and automation platforms. Consequently, modern facilities often incorporate magnetic field measurements and cable layout optimization, in combination with magnetic shielding and basic environmental controls (e.g., maintaining minimum distances between the body and high-current cables).

Numerous studies have demonstrated that SMFs — particularly in the context of transcranial static magnetic stimulation (tSMS) — can influence motor behavior through modulation of brain activity. European regulatory frameworks, such as Directive 2013/35/EU, mandate regular assessment of welder exposure to electromagnetic fields, including SMFs, and enforce mandatory technical and organizational protective measures.

Electrolytic Processes – Metal Refining

In the metallurgical industry, electrolysis is used for refining metals such as copper, aluminum, zinc, and nickel. These processes involve large direct currents passing through electrolytic cells between anodes and cathodes immersed in an electrolyte. Typical current levels are in the kiloampere (kA) range, with conductor lengths (e.g., busbars) extending over several meters — resulting in intense static magnetic fields throughout the work zone. Unlike in MRI systems, where SMFs serve a functional role, in electrolysis settings these fields are unintended byproducts of high direct currents. Nonetheless, their presence is continuous and spatially widespread.

Measurements have shown field strengths reaching up to 5 mT in the vicinity of anodes and busbars, and locally even higher (10–15 mT) near contact junctions. Workers stationed in electrolysis halls (e.g., copper refining) are subject to long-term exposure to SMFs during routine tasks such as electrode replacement, process monitoring, or maintenance. Chronic exposure has been associated with neurological symptoms, visual disturbances, fatigue, and even hormonal imbalance — effects documented in Russian studies from the 1980s and 1990s.

A significant challenge lies in the irregular spatial distribution of these fields, where sharp gradients are common. Worker movement through such non-uniform SMF zones may induce currents in bodily tissues. This can affect cardiovascular tissues, potentially leading to transient changes in heart rate, blood pressure, and autonomic function in sensitive individuals (Tenforde, 2005; Crozier, 2005). Technical mitigation strategies include optimized equipment placement, use of remote monitoring and automation, and limiting the time personnel spend in critical exposure zones. In some facilities, ferrite shielding is applied to cables and busbars to passively restrict the spatial spread of SMFs.

Recycling and Steel Industry – Magnetic Separators

Magnetic separation is employed not only in metallurgy, but also in numerous industrial sectors including recycling, waste processing, cement production, and logistics. The core principle involves using static magnetic fields to separate ferromagnetic materials (e.g., iron, steel, nickel) from non-magnetic bulk materials such as plastics, aluminum, glass, and rubber. These separators operate using either permanent magnets (e.g., neodymium) or electromagnets powered by DC currents. Permanent magnetic drum separators generate fields of 0.1 to 0.5 T at the drum surface. Electromagnetic separators can produce even higher field strengths — up to 1 T in localized zones — although field intensity decays rapidly with distance.

Operators who service these systems, replace conveyor belts, maintain magnets, or oversee sorting operations are frequently positioned in areas of significant SMF exposure. Inadequate shielding can result in extended exposure durations. Specific risks include the attraction of metal objects (e.g., tools, implants, belt buckles), which may lead to physical injury.

While these systems do not emit high-frequency fields, their intense and spatially concentrated SMFs can elicit acute physiological symptoms in susceptible individuals — such as dizziness or chest pressure. Rarely, sleep and concentration disturbances have also been reported. Preventive measures include marking high-field zones, installing physical barriers, routine maintenance and calibration of equipment, worker training, and prohibiting metal objects in proximity to the separator. Remote monitoring and process automation are increasingly employed to reduce worker presence in magnetically active zones.

Nuclear and Physical Research – Laboratory SMF Sources

Nuclear physics, experimental particle physics, and advanced quantum research frequently rely on strong static magnetic fields (SMFs) for laboratory experiments and particle detection. Sources of such fields include superconducting magnets, tokamaks, nuclear magnetic resonance (NMR) spectrometers, cyclotrons, synchrotrons, and mass spectrometers. In particle physics, SMFs are essential for beam steering, focusing, and charged particle detection. For instance, the Large Hadron Collider (LHC) uses massive superconducting magnets generating fields of 8 T (or more) to guide proton beams along its accelerator ring. These magnets are cryogenically cooled using liquid helium (<4 K) to maintain superconductivity and minimize electrical resistance.

Tokamaks — devices for controlled thermonuclear fusion — employ both static and pulsed fields to form magnetic "bottles" that confine high-energy plasma. In toroidal tokamaks, magnetic fields commonly exceed 5 T and in some configurations approach 12 T.

NMR spectroscopy, used for molecular structure analysis, typically operates at field strengths between 7 and 20 T. Unlike MRI, which is clinical, NMR is strictly laboratory-based and is used in material science, pharmaceuticals, and quantum measurements. Personnel in these environments may face intermittent exposure to intense SMFs during equipment servicing, experimental setup, or calibration. Despite access being tightly controlled and zones clearly marked, movement within strong SMF areas can provoke vestibular disturbances (e.g., dizziness, disorientation) and pose a significant risk to individuals with implanted medical devices.

Battery Industry and Lithium Processing

The development of electrochemical technologies, particularly lithium-ion (Li-ion) batteries, has led to the rapid expansion of battery manufacturing and recycling facilities worldwide. With increasing production capacity comes a growing number of workers exposed to various electromagnetic phenomena. Although radiofrequency and pulsed fields (e.g., from inductive welding) are more commonly discussed in this context, static magnetic fields (SMFs) are also present — particularly during lithium processing, electrode formation, magnetic separation, and quality control procedures.

Key sources of SMFs in lithium processing include:*Magnetic separation* during lithium extraction (from lithium carbonate and lithium hydroxide), which utilizes high-throughput permanent magnets. Fields reach 0.3 to 0.6 T in proximity to the separator, especially in enclosed units. *Electrochemical formation lines*, where battery cells undergo voltage cycling using multichannel DC power sources. These generate quasi-static currents, and SMFs of up to 50 mT are measured near DC bars and busbars. *Cell testing and classification* sometimes involve Hall effect sensors and high-voltage DC controls, with non-uniform SMFs observed in calibration rooms due to residual magnetization of components. *Transport and handling of battery modules* employ electromagnetic lifting and positioning systems, which combine static and dynamic fields. In static mode, field strengths typically range from 0.2 to 0.5 T.

The highest exposure risk exists for: operators working with magnetic separators (depending on shielding and distance), technicians servicing formation lines and busbars, laboratory personnel testing cells and sensors, and quality engineers stationed near automated lines. Measurements from Chinese, Japanese, and German facilities have shown that field strengths in close proximity to separators or cells may exceed 100 mT — a threshold associated with sensory effects such as dizziness during head rotation.

Although there is currently a lack of direct epidemiological studies on chronic SMF effects in this sector, exposure reports indicate symptoms including transient dizziness and disorientation (especially during rapid head movement in 100–400 mT zones, as defined by ICNIRP), metallic taste and nausea during prolonged calibration work, as well as occasional headaches and intracranial pressure sensations. Multi-hour exposures exceeding 50 mT may provoke sensory disturbances and subjective discomfort in sensitive individuals. Further measurements, longitudinal studies, and spatial exposure mapping are required to establish targeted health recommendations. When combined with the explosive and toxic risks inherent to lithium, SMF exposure presents an additional factor requiring integrated safety assessment in this industry.

HEALTH EFFECTS OF EXPOSURE TO STATIC MAGNETIC FIELDS

The health effects of static magnetic field (SMF) exposure depend on field intensity, duration of exposure, body position, and the speed at which individuals move through the magnetic field (Krstić, 2023). Studies have shown that personnel in MRI environments may experience a variety of subjective symptoms. For example, a Swedish pilot study found that 47% of MRI technicians frequently reported symptoms such as dizziness, motion illusions, and headaches while working near scanners.

Moreover, research has indicated that exposure to high-intensity SMFs may affect the nervous system. Alterations in electroencephalogram (EEG) and electrocardiogram (ECG) readings have been observed in individuals exposed to fields exceeding 1 Tesla.

There is also evidence that SMF exposure can induce oxidative stress at the cellular level (Krstić, 2025). Oxidative stress may damage cellular components including DNA, proteins, and lipids, potentially leading to long-term health consequences.

Biological effects of SMFs can be categorized by the affected level of biological organization:

Sensory System Effects: Movements within strong static fields (e.g., MRI environments) may induce dizziness, nausea, and metallic taste — typically due to interactions between the field and endolymph fluid in the inner ear.

Neurological and Cardiac Effects: At extremely high field strengths, studies have documented minor changes in EEG and ECG parameters, indicating potential influence on the nervous system and heart rhythm.

Cellular-Level Effects: Various studies suggest alterations in membrane permeability, enzyme activity, and increased oxidative stress. However, consistent evidence regarding genotoxicity or carcinogenicity remains limited, despite some isolated observations.

Interactions with Implants:SMFs can exert mechanical forces and induce voltages or currents in medical implants, potentially disrupting the function of pacemakers, insulin pumps, and metal-based implants.

Selected Symptoms from Literature

- Symptoms such as dizziness and motion perception have been reported at exposures between 0.2–0.4 T, especially when individuals are moving. This occurred even in zones below 1 T, suggesting that vestibular effects are not limited to extreme fields (Schaap et al., 2014).
- Subjects exposed to fields of 0.3–1 T (typically in 1.5 T MRI centers) reported significantly more neurological symptoms compared to administrative staff (Van Nierop et al., 2012).
- Human sperm (in vitro) exhibited significantly reduced motility after 2 hours of exposure to a 1 mT field (Muti et al., 2023).
- SMF increases the presence of reactive oxygen species, causing DNA damage and apoptosis in testicular and epididymal cells. Although antioxidants can mitigate these effects, overuse may result in counterproductive outcomes (Donnelly, 1999).
- Experimental studies have demonstrated behavioral changes and EEG alterations following exposures starting at 0.3 T in both animals and humans.
- Movement through static magnetic fields (≥0.2 T) may induce currents in the body (Valbonesi et al., 2012), trigger nerve impulses (Davids et al., 2017), and generate electrical currents in the aorta and other major arteries (Zilberti et al., 2015).
- Endocrine disturbances and oxidative stress at the cellular level have been reported even at SMFs below 5 mT.

ANALYSIS OF FINDINGS AND RECOMMENDATIONS FOR IMPROVEMENT

The reviewed studies and accumulated evidence demonstrate that even SMF intensities in the milliTesla (mT) range — below the exposure thresholds defined by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) — can result in biological effects. This highlights the need to reconsider the conventional thresholds that have so far guided occupational safety standards. A new classification system for SMF exposure is proposed in Table 1.

Table 1. Classification of Static Magnetic Field Exposure

Exposure Group	SMF Range [T]	Exposure Conditions	Recommended Duration	Observed Effects (from Literature)
A	< 0.1 mT	Ambient geomagnetic field. No significant industrial sources.	No restriction	No documented health effects
B−	0.1–10 mT	Near electrical infrastructure, cables, control panels	≤ 8 hours, low motion activity	Vestibular effects (Van Nierop, Schaap); blood viscosity changes (Krstić et al.); early oxidative stress
B	0.01–0.1 T	Final zones in power industry, magnetic separators	≤ 6 hours daily, with medical supervision	Documented vestibular dysfunction, EEG changes; neurological impacts
C	0.1–1 T	Work near electrochemical cells, low-field NMR labs	≤ 4 hours; medical screening every 6 months	Hormonal and vascular changes; effects on fertility; nystagmus, balance disorders (WHO, 2006)
D	1–2 T	MRI centers, industrial busbars, clearly marked 1 T zones	≤ 1 hour daily; restricted entry	Acute neurological symptoms, cardiac effects, short-term disorientation
E	> 2 T	Research-grade NMR, tokamaks, fields above 2 T	≤ 15 minutes under controlled conditions	Implant risk, potential neurological damage; strictly controlled access

Existing ICNIRP guidelines primarily account for acute toxicity under extreme conditions, whereas numerous scientific reports indicate that health effects occur within the 0.1–100 mT range, particularly affecting the nervous and vascular systems under prolonged exposure (6–8 hours daily) and movement through field gradients.

Analysis of magnetic field measurements in typical industrial settings shows that, aside from medical diagnostics and nuclear research laboratories, SMF values in most facilities are in the milliTesla range. Hence, a structured classification of exposure intensity levels is necessary to assess health risks and define appropriate safety measures.

Table 2 proposes a categorization of SMF exposure intensity levels specific to industrial environments, providing practical guidance for occupational health and safety professionals.

Table 2. Classification of Static Magnetic Field Exposure in Industrial Settings

Exposure Category	SMF Intensity (mT)	Typical Environment	Worker Exposure Type	Reported Effects
Low	< 0.5 mT	General population, offices, residential areas	Non-occupational, passive presence	No confirmed biological effects; within ICNIRP public limits
Moderate	0.5–3 mT	Low-current DC industries, magnetic sorting, near electrofilters	Intermittent exposure, near equipment	Mild subjective complaints (dizziness, nausea); no confirmed chronic effects
High	3–10 mT	Electrolytic plants, welding stations, DC drives	Extended professional exposure during work shift	Possible neurovegetative symptoms; sleep quality, anxiety, social functioning issues (Ghotbi et al., 2015)
Very High	>10 mT	MRI diagnostics, research magnets, aluminum industry	Technicians, engineers, MRI staff and patients	Induced currents in the body during movement; vestibular symptoms, magnetophosphenes (Crozier, Tenforde)

CONCLUSION

The proposed classification of static magnetic field exposure (Table 1) integrates the latest scientific findings regarding health effects on exposed workers and provides recommended exposure durations for each category, thus supporting the reduction of health risks.
The proposed exposure classification for industrial facilities (Table 2) enables effective monitoring and categorization of field intensity zones and can serve as a tool for health status tracking and strategic work planning aimed at minimizing negative effects during working hours.

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HARNESSING ARTIFICIAL INTELLIGENCE FOR REAL – TIME WATER QUALITY INSIGHTS

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Abstract: Impacted by climate change and human activities, the increasing contamination of water bodies poses a growing threat to environmental and public health. Real-time water quality assessment, particularly at the source, is essential for effective monitoring and ensuring safe, contaminant-free drinking water. Artificial Intelligence (AI) and Machine Learning (ML) technologies have transformed this field by enabling efficient data processing, accurate detection of pollutants, and early warning systems.

Developing high-accuracy AI-based models can significantly enhance water monitoring systems, reduce operational costs, support eco-friendly treatment practices, and promote sustainable resource management.

The evaluation of biological indicators, such as Chlorophyll-a, offers valuable insights into water quality due to its strong correlation with chemical status. When paired with appropriate data collection frequencies, ML models can be used for real-time forecasting. These models can analyze Chlorophyll-a trends from remote sensing data and serve as early warning systems for harmful algal blooms and related environmental issues.

Incorporating diverse data sources - such as satellite imagery, water temperature, nutrient concentrations, and meteorological data - can significantly improve predictive accuracy. Developing a robust methodology for these models will empower water utilities and decision-makers in Serbia, allowing them to respond proactively to water quality threats.

Keywords: Water quality, real-time monitoring, Artificial Intelligence-based performance

INTRODUCTION

Water bodies are complex and constantly evolving systems, increasingly affected by pollution and climate change. Hydromorphological changes make them more susceptible to extreme weather, amplifying the effects of contaminants (Inyinbor Adejumoke et al., 2018). One major consequence is eutrophication, caused by nutrients, primarily phosphates and nitrogen - which leads to excessive growth of cyanobacteria (Glibert et al., 2005). These blooms, known as "water blooms", often exceed 10,000 mL and release potent toxins like microcystin and saxitoxin, threatening aquatic life and human health through contaminated water, fish, and crops (Reynolds and Walsby, 1975).

Rising temperatures worsen eutrophication by disrupting chemical balances, accelerating algal growth, and lowering oxygen levels in water bodies. Monitoring Chlorophyll-a - a key indicator of algal biomass - helps assess eutrophication levels and guides ecological management. Since the 1990s, Eastern European countries have included Chlorophyll-an in national water quality monitoring programs (Boyer et al., 2009).

According to the UN's 2020 Water Scarcity Report, by 2025, 1.8 billion people will face water scarcity (Pointet, 2022). Innovative solutions, including real-time water quality prediction models powered by Machine Learning (ML), may significantly increase the supremacy of water quality monitoring. These models can analyze historical data and upstream measurements to forecast contamination risks, ensuring safer water supplies.

Chlorophyll-a levels, correlated with nitrate and phosphate concentrations, may serve as a basis for predictive ML models (Kim and Ahn, 2022). By integrating various environmental parameters, these tools can improve water management and mitigate the risks of eutrophication and harmful blooms. This approach supports water utilities, regulators, and public health systems in making informed decisions.

The main advantage of developing this kind of monitoring of surface water focuses on:

1. Real-time monitoring techniques,
2. ML-based simulation algorithms for continuous updates,
3. Real-time control strategies for pollution management.

These efforts align with the UN 2030 Agenda for Sustainable Development, aiming to boost Serbia's research capabilities and integrate it more fully into the European Research Area (Walsh et al., 2022).

METHODOLOGY

Machine Learning is a subset of Artificial Intelligence found on ability to learn from data (Kuhl et al., 2020). The main advantage of using a Machine Learning-based methodology, that includes predicting scenarios with available historical data is its ability to learn from past experiences and identify the underlying relationships among variables. The methodology for developing Machine Learning-based model for water quality prediction using Chlorophyll-a concentrations involves several key steps, designed to ensure scientific accuracy, practical relevance, and real-time applicability. The process begins with the collection of both historical and real-time data on Chlorophyll-a concentrations from monitoring stations across selected surface water bodies. This data is complemented with related environmental parameters such as water temperature, pH, turbidity, dissolved oxygen, nutrient levels (nitrates and phosphates), and meteorological data, which are all known to influence algal growth.

Once collected, the data undergoes thorough preprocessing to remove anomalies, handle missing values, and standardize formats. Exploratory data analysis (EDA) is conducted to identify patterns, trends, and correlations between Chlorophyll-a levels and other environmental variables (Data et al., 2016). Feature engineering follows, involving the selection and construction of relevant features that impact Chlorophyll-a variability, such as seasonal factors, rainfall events, and upstream pollution inputs. Statistical methods and expert knowledge are applied to refine the dataset and improve model interpretability.

The next phase involves selecting appropriate Machine Learning algorithms - such as Random Forest, Gradient Boosting, Support Vector Machines, or Long Short-Term Memory (LSTM) neural networks—and training these models on the prepared datasets (Mahesh, 2020). Chlorophyll-a concentration serves as the target variable, and supervised learning techniques are employed to build predictive models. Model performance is rigorously validated using cross-validation techniques and evaluated through standard metrics including root mean square error (RMSE), mean absolute error (MAE), R^2, and classification metrics for detecting harmful events like algal blooms (Tatachar, 2021).

After identifying the best-performing model, it is integrated with real-time data streams from monitoring stations, enabling live predictions of water quality. A visualization interface or alert system may be developed to communicate forecasts and issue early warnings when Chlorophyll-a levels exceed critical thresholds. To ensure long-term effectiveness, the model is continuously updated with new incoming data, either through online learning methods or periodic retraining. Feedback from environmental scientists and stakeholders is also incorporated to further refine the model, making it a dynamic and robust tool for managing surface water quality.

IMPLEMENTATION

Chlorophyll-a is an official chemical parameter used for water quality prediction proposed by the Water Frame Directive and there are series of measurements of that parameter during the Joint Danube Survey expeditions, organized by International Commission for the protection of the Danube River (Liška et al., 2015).

Real-time prediction of water quality based on Chlorophyll-a concentration data provides insight into nutrient levels in water bodies and enables the development of alert systems to signal elevated ecological risk. Using this parameter as input for provides a crucial foundation for developing AI-powered water quality forecasting models for Serbian water bodies, as it reflects nutrient presence and ecosystem health. This approach to surface water monitoring addresses challenges posed by pollution and climate-related hydrological stress through innovative and cost-effective solutions.

This type of monitoring showcases and promotes advanced systems tailored to local environmental conditions. Developing an AI-based model for real-time surface water prediction supports the creation of sustainable, cost-effective technologies for water quality assessment, aimed at enhancing ecological safety and ensuring a reliable water supply. Institutions such as the Institute for Biological Research and the Institute of Public Health possess valuable datasets on measured Chlorophyll-a concentrations, which can serve as an excellent starting point for training an Artificial Intelligence-based model. This model, designed to predict the trophic status of water bodies and serve as an early warning system for elevated nutrient concentrations, would rely on real-time Chlorophyll-a data. In this way, costly sampling procedures and laboratory analyses could be avoided. Developing a trophic state prediction model based on this methodology for at least one water body in Serbia would significantly enhance the overall water quality monitoring system. It would also enable prompt response by relevant authorities in cases of elevated nutrient concentrations, which are known to trigger “algal blooms” and eutrophication processes. Including temperature, conductivity and total dissolved solids, as input parameters, next to Chlorophyll-a, enhancing water quality monitoring and early detection of harmful “algal blooms”. Developing a similar methodology is described in many papers, proposing different modeling approaches (Zahir et al., 2024; Busari et al., 2023).

KEY BENEFITS OF USING AI FOR PREDICTING THE ECOLOGICAL STATE OF WATER BODIES

Using AI to predict the ecological status of water bodies offers several key advantages. It enables real-time analysis of complex environmental data, allowing for early detection of pollution and nutrient imbalances. AI models can identify patterns and trends that traditional methods may overlook, improving the accuracy of forecasts. This supports faster, data-driven decision-making, enhances monitoring efficiency, and reduces the need for costly manual sampling and laboratory testing (Miller et al., 2025). In addition, AI-based models can continuously learn and improve as new data become available, making them adaptable to changing environmental conditions. They facilitate the development of early warning systems for harmful algal blooms and other ecological risks, helping to prevent environmental degradation. By integrating various water quality parameters, AI enhances the understanding of ecosystem dynamics and supports the design of targeted, cost-effective management strategies (Geetha et al., 2023). This approach is especially valuable in regions with limited resources, where efficient monitoring and rapid response are essential. In accordance with the fact that Chlorophyll-a is collected continuously during Joint Danube Survey expeditions, monitoring system based on this described methodology is possible to develop for the whole length of

Danube River, the most international river in Europe, that flows through ten countries and serves as a vital waterway (ICPDR, 2020).

CONCLUSION

The integration of Artificial Intelligence (AI) and Machine Learning (ML) into the monitoring processes of water bodies can significantly enhance the accuracy of environmental assessments and enable the development of real-time prediction methodologies. Real-time water quality monitoring empowers authorities to respond promptly, thereby reducing ecological risks, preventing eutrophication, and ensuring the sustainable management of aquatic ecosystems. Enhancing the AI competencies of ecologists, chemists, and biologists not only strengthens the scientific community but also supports the country's sustainable development and technological progress. By equipping experts with advanced tools, it becomes possible to prevent ecological disasters more effectively and to develop modern, cost-efficient methodologies for environmental monitoring.

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BUILDING A RESILIENT AND SAFETY-CONSCIOUS WORKFORCE THROUGH INCLUSIVE OHS TRAINING

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Abstract: Occupational health and safety (OHS) training plays a crucial role in preventing workplace injuries and promoting a culture of safety, particularly among young and inexperienced workers entering vocational education and the labor market. This paper reviews recent studies (2022–2025) to examine how early engagement with OHS training influences risk awareness, hazard recognition, and safety behavior. The analysis is structured around three key themes: the effectiveness of experiential and early-stage training; the role of hazard recognition and risk perception in shaping worker behavior; and persistent gender-based differences in exposure, training access, and perceived preparedness. Findings show that standard compliance-focused training is often insufficient to meet the needs of new entrants to the workforce. More effective approaches include mentorship, peer-based learning, simulation exercises, and reflective practice following critical incidents. Technological tools such as virtual and augmented reality have shown promise in making safety training more engaging and relevant, particularly in high-risk sectors. Gender disparities remain a pressing concern. Women are often excluded from safety decision-making structures, receive less targeted training, and face design limitations in protective equipment that do not account for their needs. These gaps affect both confidence and actual safety outcomes. The paper highlights the need for more consistent and inclusive national frameworks for OHS training, starting from vocational education and extending into workplace practice. It calls for stronger policy support to encourage employer investment in adaptive and inclusive safety education.

Keywords: *VET; Hazard recognition; Risk perception; Gender disparities; Inclusive training.*

INTRODUCTION

Dual vocational education and training (VET) programs have been increasingly adopted across various countries as a strategic approach to preparing young people for the labor market. A core component of these programs is occupational health and safety (OHS) education, which plays a critical role in fostering early awareness of workplace risks and promoting long-term well-being among the future workforce (Rooney-Kron and Dymond, 2022). A growing body of literature underscores the positive effects of structured OHS training on students' knowledge acquisition, attitudes toward safety, and workplace behavior. Breslin et al. (2018) highlight that comprehensive OHS education improves young workers' hazard recognition and risk awareness, particularly among those with limited work experience or learning difficulties. Laberge et al. (2017a) and Dubeau et al. (2021) emphasize the role of contextualized training and on-site supervision in reinforcing safety knowledge and enabling behavior change. Moreover, Yanar et al. (2019) point to the challenges faced by students in dual training settings, including insufficient supervision and informal handling of safety concerns, which can undermine training effectiveness. Studies by Turner et al. (2022a) and Clarkson et al. (2018) further show that the impact of OHS education is mediated by gender, task assignment, and the perceived legitimacy of safety concerns in different occupational contexts. These findings are supported by constructivist learning theories and behaviorist approaches to safety training, which advocate for active, situated, and experiential learning as critical to developing lasting safety competencies in young workers.

Although OHS education is essential for all new entrants to the labor market, it holds particular importance for students with learning difficulties or additional support needs, as they may be more vulnerable to occupational risks and require differentiated instructional approaches to fully engage with and retain safety-related content (Breslin et al., 2018). The combination of youth, demanding work tasks and professional training, inexperience and atypical situations during the employment process increase the probability of working in an unsafe environment (Breslin et al., 2019). Additional risk factors include migrant status and disadvantaged socio-economic backgrounds, which may further heighten vulnerability to occupational injuries and health-related harm.

Dual vocational training environments pose significant risks to student safety, primarily due to their limited work experience and the often-inadequate supervision provided during placements (Yanar et al., 2019). In many cases, students are left without consistent support from colleagues or supervisors following initial task demonstrations, and safety-related concerns are frequently addressed in an informal or incidental manner. While some educators attempt to integrate theoretical instruction with practical supervision (Laberge et al., 2017b), the responsibility for occupational safety education is frequently delegated to workplace mentors. This approach often relies heavily on individual experience rather than structured pedagogical methods, leading to inconsistencies and gaps in safety instruction (Dubeau et al., 2021). The absence of a systematic and coordinated approach to OHS training within dual education programs remains a critical challenge.

Literature increasingly highlights the importance of gender as a critical factor in occupational health, safety training, and risk perception. Female-dominated occupations are often associated with less visible yet significant hazards such as musculoskeletal disorders, repetitive strain injuries, and psychosocial stressors that are frequently underrepresented in conventional training programs (Messing et al., 2003; EU-OSHA, 2014a). Occupational segregation and persistent gender stereotypes contribute to the limited participation of women in safety training and risk assessment processes (Walters and James, 2011). As a result, gender-neutral prevention strategies often fail to address the specific risks encountered in female professions. Messing and Östlin (2006) argue that such gender-blind approaches can perpetuate structural gaps in occupational health policies and practices, thereby reducing the overall effectiveness of safety interventions.

Previous research emphasized the importance of developing OHS tools that incorporate a gender-sensitive and inclusive approach, particularly in educational contexts involving students with disabilities (Dubeau et al., 2021; Rooney-Kron and Dymond, 2022). Studies have documented an initially low level of interest in OHS topics among students, which tends to increase once students engage in practical training. This shift is often accompanied by the perception that workplace injuries are a normal and expected aspect of certain jobs (Clarkson et al., 2018; Laberge et al., 2017a). A broader review of OHS literature further indicates that novice workers, especially youth and those in precarious positions, frequently lack awareness of their rights and of employers' legal responsibilities, which presents significant barriers to effective safety management and prevention (Breslin and Smith, 2006; EU-OSHA, 2014b).

This paper presents a systematic, literature-driven review of occupational health and safety (OHS) in dual vocational education and training (VET) programs, emphasizing the critical interplay between gender, practical work experience, and the effectiveness of safety training.

METHODOLOGY

The study is grounded in a secondary analysis of key research findings from existing peer-reviewed sources. The sources were identified through targeted database searches (e.g., Scopus, Web of Science, and ERIC) using keywords such as "occupational health and safety," "dual education," "VET," "gender," and "youth workplace safety." A total of 35 papers and reports were included based on inclusion criteria such as relevance, methodological rigor, and contribution to understanding student safety experiences in VET contexts.

A thematic analysis was applied to synthesize key findings from the selected studies. The core analytical categories included:

- Work experience and injury incidence;
- OHS training participation;
- Hazard recognition and risk perception and
- Gender-related disparities in safety knowledge and exposure.

These categories formed the basis for a comparative interpretation of findings across the reviewed studies, identifying both converging patterns and gaps in the current literature. The results and discussion sections of this paper are organized around these themes to provide a critical synthesis that supports future research and policy development in OHS education within dual VET contexts.

RESULTS AND DISCUSSION

Work experience and injury incidence

Recent evidence confirms a strong link between limited work experience and higher injury rates, especially among workers under 25. The University of Iowa (2024) found that individuals aged 15–24 are 2.3 times more likely to be injured at work, mainly due to poor training and low risk awareness (Berube et al., 2025). Sundstrup et al. (2024) emphasized that traditional safety education alone is insufficient and recommended fostering a safety culture and psychosocial support. Sector studies, such as those by Turner et al. (2022b), show that inexperience is a significant injury predictor. For example, 39% of healthcare workers reported injuries in one year, often due to low tenure and poor supervision (Mekonnen et al., 2024). In construction, high injury rates among apprentices led to stricter oversight by SafeWork SA (2024). Despite overall injury reductions (U.S. BLS, 2023), young workers remain disproportionately affected.

OHS training participation

OHS training is key to prevention, yet access and participation vary. Berube et al. (2025) and Amponsah-Tawaih and Appiah (2024) found that interactive training improves outcomes, but ILO (2024) reported that only 62% of enterprises regularly offer such programs. Young workers often receive only basic training, and female students have less access to hands-on instruction (Turner et al., 2022b). In healthcare and construction, refresher training improves safety outcomes (Mekonnen et al., 2024), but it must be updated and relevant. Digital tools like AR and mobile platforms boost access and retention (Fernandez-Muniz et al., 2023), though effectiveness depends on user readiness. To build a safer workforce, harmonized training standards, fiscal incentives, and early integration of OHS education are recommended.

Hazard recognition and risk perception

Hazard recognition and risk perception are key to occupational safety, shaping worker behavior and decision-making. Li et al. (2025) found that poor hazard recognition and flawed risk perception contribute to unsafe behaviors, especially in high-risk sectors like construction. Albert et al. (2016) showed that interactive training, such as simulation-based exercises, significantly improves these skills compared to traditional methods. Vercelli et al. (2024) reported that VR-based safety training enhances hazard recognition and risk assessment due to its immersive and engaging nature. To address industry-specific needs, Özbakır (2024) developed the Occupational Risk Perception Scale (ORPS) for construction workers, offering a standardized tool to assess risk perception and support targeted safety interventions. These studies highlight the importance of interactive, tech-enhanced training and tailored assessment tools in building a proactive, safety-aware workforce.

Gender-related disparities in safety knowledge and exposure

Studies show that men and women face different types and levels of occupational hazard exposure, even in the same job roles. Park and Kim (2024) found that women report significantly higher exposure to physical, ergonomic, and psychosocial hazards, often due to gendered task division rather than job nature. Physiological and ergonomic differences also lead to worse health outcomes for women, as equipment and PPE are typically designed for male body dimensions (Heub et al., 2024; Giammarioli, 2023). Women have less access to tailored OHS training and are underrepresented in safety committees, affecting the inclusivity of training and risk assessments (ILO, 2025). Turner et al. (2022b) noted that female students in dual VET programs felt less confident in hazard recognition and more vulnerable during practical training, partly due to unequal training access and task framing that underestimate risks for women (ILO, 2025). Psychosocial risks, such as stress and harassment, remain overlooked in male-dominated sectors despite disproportionately affecting women. The lack of gender-disaggregated data in risk assessments hinders the development of inclusive safety strategies (Heub et al., 2024).

CONCLUSION

This paper has reviewed recent literature addressing critical aspects of OHS training, with particular emphasis on early intervention, hazard recognition, risk perception, and gender-related disparities. The evidence highlights the need to integrate comprehensive safety training within early work experience and vocational education frameworks. Interventions that move beyond basic compliance, incorporating mentorship, peer learning, and critical incident analysis demonstrate greater efficacy in advancing safety competencies among less experienced workers.

The literature also highlights the urgency of harmonizing OHS training standards and promoting inclusive approaches that address gender-specific risks. Disaggregated data collection by gender is vital for evaluating and improving the impact of OHS strategies.

These findings call for coordinated policy actions and strong institutional commitment. Policymakers should incentivize employer investment in inclusive and equitable safety training and support the development of national competency frameworks that promote OHS literacy and foster a culture of inclusivity across all sectors of the workforce.

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CHEMICAL SOLUTION FOR FOR H_2S PROBLEM IN BIOGAS PLANT

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Abstract:. The presence of hydrogen sulphide (H_2S) in biogas is a significant operational problem due to its corrosive properties, potential inhibitory effect on microbial activity, and the necessity for its removal to ensure safe and efficient biogas utilization. In Serbia, H_2S removal is typically managed through the application of commercial chemical additives, commonly iron-based compounds. Aim of this manuscript is to analyse practise of one biogas plant in terms of addition of commercial chemical additive and its effect on reduction of H_2S. The results do not support a consistent or statistically significant impact of the additive on H_2S reduction. Instead, other factors such as feedstock composition, digestion conditions, or microbial dynamics may have a greater influence. The findings suggest the need for a more systematic, data-driven dosing approach and recommend further research using multivariate models to better understand the complex variables affecting H_2S levels in anaerobic digestion systems.

Keywords: *Biogas; Hydrogen sulphide; Chemical treatment.*

INTRODUCTION

Biogas is produced in process of anaerobic fermentation where are complex biomolecules degraded to the level of methane and carbon-dioxide. In this process, there are other gaseous compounds next to the stated two gases that are result of degradation, for example ammonia and hydrogen sulphide – H_2S. H_2S is specifically important or to be more precise, problematic. H_2S formation in anaerobic fermentation is primarily attributed to the microbial reduction of sulphate (SO_4^{2-}) under anaerobic conditions. Sulphate-reducing bacteria (SRBs), which thrive in anaerobic conditions, play a central role in this process. These bacteria utilize sulphate as an electron acceptor, reducing it to hydrogen sulphide. This occurs during the degradation of organic matter, particularly in the presence of sulphur-rich compounds such as proteins, amino acids (especially cysteine and methionine), and other sulphur-containing organic molecules. The sulphur in these organic substrates, when metabolized by SRBs, is reduced to H_2S, which then accumulates in the biogas.

The concentration of H_2S in biogas can vary depending on several factors, including the composition of the feedstock, temperature, pH, and the microbial community present in the digester (FNR, 2016). High levels of H_2S in biogas are problematic, as they can lead to corrosion of equipment, inhibit the performance of the microbial processes, and require treatment technologies to ensure the safe use of the produced biogas.

Various technologies have been developed to effectively treat and remove H_2S from biogas, each with its advantages and limitations. Some of the most appropriate and conventional are use of iron salts, addition of air (oxygen), biofilters etc. There are also unconventional techniques such as bio desulphurisation, adsorption techniques etc. These unconventional techniques are currently in focus of scientific research. For example, (Dada et al., 2025) state that bio desulphurization is a promising biological method for H_2S removal, utilizing sulphur-oxidizing bacteria to convert H_2S into elemental sulphur or sulfuric acid. This process is environmentally friendly and sustainable, offering a low-cost alternative to chemical treatments. Adsorption techniques are also widely used, with materials such as zeolites demonstrating high efficiency in removing H_2S from biogas (Kulawong et al., 2022). These adsorbents are often regenerated and reused, enhancing their cost-effectiveness. Membrane separation technology is gaining attention for its potential in H_2S removal, offering selective permeation that allows for efficient separation of H_2S from other biogas components. This method is particularly advantageous for large-scale biogas plants (Jusoh et al., 2025). These technologies, whether biological or physical, offer various solutions for optimizing biogas quality and minimizing the environmental impacts of H_2S.

Scientific research of the H_2S removal techniques in Serbia has not been performed. Most dominant technique in biogas sector in Serbia is application of commercial additives for removal of H_2S. They are probably based iron salts and removal of H_2S happens by reaction and formation of insoluble iron sulphide (FeS).

Aim of this manuscript is to analyse practise of a biogas plant in terms of addition of commercial chemical additive and its effect on reduction of H_2S.

MATERIAL AND METHOD

The practise of additive addition that was analysed was from a biogas plant in Sremska Mitrovica, Serbia. This biogas plant utilises produced biogas to generate electricity that delivers to the public grid under subsidized conditions. During analysed period app. 15 different substrates were used for biogas production. Biogas is produced in two fermenters, stored in gas storages above these fermenters and used in combined heat and power unit. The biogas plant has 1 MWe of installed capacity.

As a technique used for H_2S treatment was used a commercial chemical additive. The practice of the additive addition was completely based on readings of gas analyser: if H_2S concentration starts to rise, more of the additive was used and vice versa. Additives were added in quantities between 0 to 60 kg/day, and general condition was that H_2S concentration must remain below 100 ppm. This practice was based on the recommended practice of the additive production company.

Data about H_2S concentration and dosage of chemical additive were collected on daily basis during period of two years in 2023 and 2024. H_2S was measured by biogas plant's gas analyser Awite that simultaneously measures methane, oxygen and H_2S level.

To evaluate the relationship between H_2S concentration and the application of a chemical additive intended to reduce it, a statistical correlation analysis was conducted. The Pearson correlation coefficient was used to quantify the linear association between the daily dosage of the additive and the measured H_2S levels in biogas. To assess possible delayed effects of the additive, a **lag analysis** was performed by shifting the H_2S concentration data forward by one and two days and recalculating the correlation coefficients.

RESULTS AND DISCUSION

The resulting parameters of the analysis of operational data are presented in Table 1. Operational data are presented at the Figure 1. Over the two-year period several important patterns in the management of material inputs (chemical additive) and biogas quality output (measured as H_2S concentration) are observed:

1. Significant Reduction in Additive Use:

In 2024, the total quantity of chemical additive used decreased by approximately 31%, from 16,260 kg in 2023 to 11,220 kg. Similarly, the average daily dosage fell from 44.5 kg/day to 30.7 kg/day. This indicates a clear change in dosing policy, possibly aimed at cost reduction or optimization.

2. Stable H_2S Concentrations Despite Reduced Additive Input:

Despite the reduction in additive use, the average H_2S concentration remained relatively stable, decreasing only slightly from 47 ppm in 2023 to 44 ppm in 2024. The minimum H_2S value remained 0 ppm in both years, while the maximum dropped from 169 ppm in 2023 to 103 ppm in 2024, suggesting improved control or less severe peaks.

3. Possible Influence of Non-Chemical Factors:

The data suggest that the reduction in additive use did not result in a corresponding increase in average H_2S levels, which implies that other operational or biological factors—such as substrate composition, digestion conditions, or microbial balance—may have contributed to H_2S control.

4. Implications for Process Optimization:

These results highlight a potential opportunity to optimize chemical usage without compromising biogas quality. A more targeted or predictive dosing strategy could lead to cost savings and improved environmental efficiency, especially if coupled with better process monitoring and substrate management.

Table 1. The resulting parameters of the H_2S reduction strategy.

Year	Additive		H_2S concentration		
	Total amount, kg	Average amount, kg/day	Average, ppm	Lowest, ppm	Highest, ppm
2023	16260	44.5	47	0	169
2024	11220	30.7	44	0	103

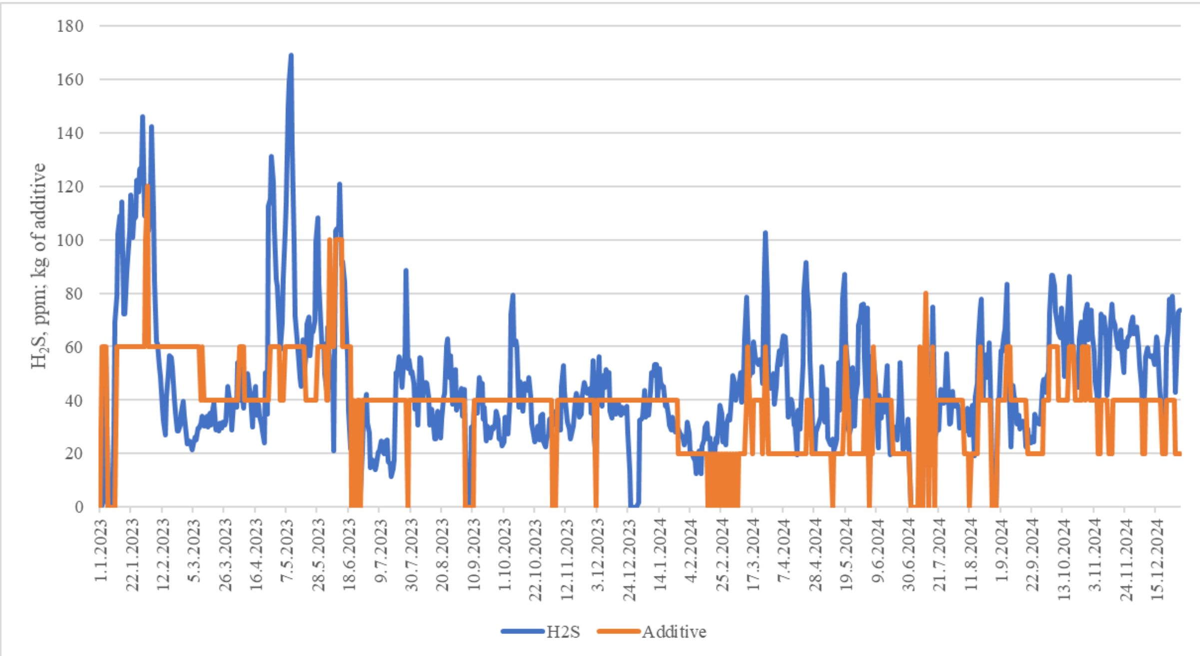

Figure 1. Measured concentrations of H_2S during two year period and dosage of the chemical additive.

In Table 2. Are presented results of the statistical analysis.

Table 2. The results of the correlation analysis.

Lag (days)	Correlation coefficient (r)
0	0.511
1	0.424
2	0.364

The initial Pearson correlation analysis between the chemical additive dosage and H_2S concentration yielded a moderate positive coefficient ($r = 0.511$), suggesting that higher additive inputs corresponded with higher H_2S levels. Rather than confirming additive effectiveness, this result implies a reactive dosing strategy, where operators increase the additive in response to rising H_2S levels.

To explore potential delayed effects, the analysis was extended by introducing time lags. The correlation coefficients decreased to 0.424 with a 1-day lag and 0.364 with a 2-day lag, Table 2, indicating a partial but weak delayed relationship. However, the persistent positive direction of the correlation across all lags suggests that the additive's effect is neither immediate nor clearly suppressive in nature.

Annual data, Table 1, further supports this interpretation. Despite a 31% reduction in the total additive usage from 2023 to 2024, the average H_2S concentrations remained similar (47 ppm in 2023 vs. 44 ppm in 2024), while the peak values decreased substantially. This may point to improvements in process stability or substrate quality, rather than to changes in additive efficiency.

Overall, the results indicate that while the additive is used in response to increased H_2S, its actual impact on lowering concentrations is not statistically supported. Other operational variables such as feedstock type, retention time, and microbial activity likely play a more influential role and should be further investigated through multivariate models.

CONCLUSION

Based on the conducted statistical analysis, no clear evidence was found to support the hypothesis that the applied chemical additive as a consistent and statistically measurable effect in reducing H_2S concentrations in biogas under the current dosing strategy. Although the additive is applied with the intention of mitigating elevated H_2S levels, the observed positive correlation between additive dosage and H_2S concentration suggests that the dosing is likely performed as a reactive measure in response to rising H_2S, rather than as a preventive action.

Furthermore, the lag analysis, which examined possible delayed effects by comparing additive dosages to H_2S concentrations one and two days later, revealed only a slight reduction in correlation values. This marginal decrease does not indicate a strong delayed effect and is insufficient to confirm a causal relationship. Importantly, at no point did the correlation become negative, which would have supported the intended purpose of the additive.

These results imply that variations in H_2S concentrations may be predominantly governed by other operational factors, such as the type and quality of feedstock, fluctuations in organic loading rate, temperature conditions, or microbial community dynamics. The current approach to chemical dosing, while well-intentioned, may not be achieving optimal results due to its reactive nature and potential misalignment with the underlying causes of H_2S formation.

It is recommended that future operational strategies include a more systematic and data-driven approach to additive application. Additionally, further research should incorporate multivariate regression or time-series modelling to evaluate the combined impact of chemical additives and other key process variables. Such methods may provide deeper insights into the root causes of

H_2S variability and support the development of more effective control measures in anaerobic digestion systems.

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VIDEO GAMES AS AN EDUCATIONAL TOOL IN OCCUPATIONAL HEALTH AND SAFETY

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Abstract: The paper explores possibility for video games to replace traditional educational tools in the field of occupational health and safety. Portraying the research across cognitive science, pedagogy, and occupational health and safety training, the analysis highlights the strengths and limitations of Game Based Learning. Traditional presentations, while structured and content-rich, often struggle to maintain learner attention, especially over extended periods. In contrast, video games offer a dynamic and immersive experience that fosters stronger engagement and creates a more meaningful connection between the educational material and the learner. While games significantly enhance engagement and learning outcomes, especially in applied fields, the paper considers whether they can be used to complement or to completely replace traditional presentations, particularly in compliance-heavy sectors like education and occupational safety.

Key words: *Video Games; Occupational Health; Safety Training.*

INTRODUCTION

Traditional education in the field of occupational health and safety (OHS) is mostly focused on lectures, while nowadays there is some small intakes of practical education implemented, there is a lot of issues following its effectiveness. The field of occupational health and safety is predominantly heavy regulatory structured, with a lot of different legislations defining the domain (Ncube & Kanda, 2018; Salguero-Caparrós et al., 2020). The existing learning environment often emphasizes memorization over practical application, leaving learners underprepared for real-world challenges. As a result, many professionals enter the workforce with limited hands-on experience, struggling to translate theoretical knowledge into effective safety practices. The gap between academic instruction and workplace reality highlights the urgent need for more engaging, interactive, and context-driven educational approaches (Dorman & Dorman, 2023; Llewellyn & Frame, 2012; Qu & Purvis, 2018).

The existing methods offer a reliable and controlled means of disseminating standardized information to a wide audience. Presentations are efficient in delivering structured content and are especially suited to scenarios where information must be uniformly conveyed and retained. Slide-based instruction enables the repetition of key compliance elements and aligns well with regulatory standards, making them a staple in workplace training sessions, certifications, and academic modules (David, 2015; Mayer, 2024). Many researches have shown that traditional lecture methods are often associated with low learner engagement and poor retention (Loughlin & Lindberg-Sand, 2023), and are increasingly criticized for promoting passive learning and disengagement, especially among learners accustomed to interactive and multimedia-rich environments.

In recent years, educational systems worldwide have seen a pedagogical shift fueled by advancements in digital technology and an evolving understanding of how people learn (Nadeem et al., 2023). Game-based learning (GBL), a pedagogical approach that incorporates principles of game design into educational contexts, has emerged as a promising alternative (Wang et al., 2023; Zheng et al., 2024). It seeks not only to improve engagement but also to enhance retention, motivation, and the development of higher-order cognitive skills. The interactive nature of games contrasts sharply with the often static and one-directional format of traditional presentations.

Video games introduce interactivity, challenge, and immediate feedback, which are all known to enhance cognitive engagement (Kefalis et al., 2020). They also support experiential learning by placing learners in simulated environments where decision-making and critical thinking are encouraged. This makes them particularly suitable for training in occupational health and safety, where learners must not only memorize protocols but also understand how to apply them under pressure. Games often require players to solve problems, collaborate, and adapt strategies—skills that are directly transferable to real-world scenarios. Despite the strengths, there are valid concerns about the scalability, accessibility, and consistency of game-based learning. Implementation often demands significant investment in technology and instructor training. There is also a risk that educational games may prioritize entertainment over educational value, especially if poorly designed (Choi et al., 2020).

Generation gap

The process of learning and adopting new educational methods often differs significantly between young professionals and older individuals, particularly when it comes to the use of new technologies (Andreoletti & Howard, 2018; Josephine & Jones, 2022). Younger professionals, having grown up in a digital environment, tend to be more adaptable and confident in using modern tools such as e-learning platforms, mobile apps, and interactive simulations. These technologies align with their everyday experiences, making it easier for them to engage with and absorb new information. Typically, younger professionals are more open to multimedia content, gamified learning environments, and self-paced modules that allow for flexibility and personalization—features that enhance retention and motivation.

In contrast, older individuals may face challenges due to limited exposure to digital tools, a preference for traditional learning methods, or discomfort with fast-evolving technology (Fischer et al., 2021; Heredia Sánchez, 2023). Many have spent the majority of their careers relying on face-to-face instruction, printed manuals, and structured classroom settings, which can make the transition to digital learning environments feel overwhelming or less intuitive. This can lead to resistance or slower adaptation, ultimately affecting the overall learning outcomes.

Cognitive and physical factors such as reduced memory retention or difficulties with fine motor skills may further complicate interactions with digital interfaces for some older learners. As a result, they may require additional support, including guided tutorials, simplified user interfaces, and more time for familiarization with new platforms.

The generational gap can impact the effectiveness of training programs, especially in fields like occupational health and safety where up-to-date knowledge and skills are crucial to preventing workplace incidents. Therefore, educational strategies must consider these differences, offering tailored approaches that support digital literacy among older learners while maximizing the tech-savvy strengths of younger ones. A blended learning approach—combining traditional methods with gradual technological integration—may help bridge this gap, ensuring that all professionals, regardless of age, can engage meaningfully with educational content and continue to develop their competencies in a rapidly changing work environment.

Age structure

The age structure within a company can significantly influence how educational methods, especially those involving new technology, are adopted and utilized. In general, larger and more modern organizations tend to have a younger workforce, often due to higher turnover rates, active graduate recruitment programs, and a greater emphasis on innovation and adaptability (Lolo Ramma & Gunawan, 2023). These companies frequently prioritize digital transformation and are more likely to invest in cutting-edge training platforms that appeal to tech-savvy employees. As a result, their workforce is typically more receptive to e-learning tools, mobile applications, virtual reality training, and other forms of technology-enhanced education.

Younger workers in such environments are not only more comfortable with these tools but also expect their employers to provide engaging, flexible, and digitally accessible learning opportunities. This expectation aligns with the broader workplace culture in newer or rapidly growing organizations, where continuous upskilling and agile learning are key priorities. In contrast, smaller or more traditional companies often have an older age profile, with employees who may have been with the company for decades. In these settings, educational practices tend to be more conventional, and the adoption of new technologies can be slower due to resistance to change, limited resources, or a lack of digital fluency.

Defining the age composition of a company's workforce is essential when designing and implementing training programs. A younger workforce might thrive with app-based microlearning or gamified simulations, while an older workforce may benefit more from a gradual transition that incorporates familiar elements, such as in-person support or printed guides, alongside digital tools. Recognizing and accommodating these differences can help ensure that educational initiatives are inclusive, effective, and aligned with the technological readiness of the workforce.

TRADITIONAL PRESENTATIONS IN EDUCATION

Presentations, particularly through slides and lectures, offer a linear and controlled method of delivering information (He et al., 2021; Oda Abunamous et al., 2022; Pakdaman et al., 2019; Uyal et al., 2017). They allow for structured dissemination of critical content and are especially effective in environments where compliance and accuracy are essential (Mayer, 2024). They provide educators and trainers with the ability to present large volumes of information in a systematic and timely manner, making them an ideal tool for covering mandatory safety protocols, regulatory updates, and policy frameworks.

In occupational health and safety education, traditional presentations remain a dominant instructional strategy due to their ability to standardize learning outcomes across diverse learner populations. For instance, compliance training modules often utilize PowerPoint presentations to ensure that every employee receives the same core message, reducing the likelihood of knowledge discrepancies. Presentations also make it easier to track instructional progress, facilitate structured testing, and meet audit requirements from regulatory bodies such as OSHA or HSE.

Another advantage of presentations is their scalability. One instructor can deliver a presentation to hundreds of learners simultaneously, whether in a physical classroom or through online platforms like Zoom or Microsoft Teams. This efficiency is especially valuable in large organizations or institutions with limited instructional resources. Also, recorded presentations can be reused for future associates, adding to their cost-effectiveness.

The very structure that makes presentations efficient also contributes to their pedagogical limitations. Traditional presentations often follow a didactic model in which the instructor speaks and learners passively receive information. This model, rooted in behaviorist learning theory, does not account for the diverse ways in which individuals process and internalize knowledge (He et al., 2021). Learners may become disengaged, particularly if the content is abstract, overly technical, or delivered without opportunities for interaction.

Numerous studies have found that lecture-based teaching, while beneficial for transmitting factual information, is less effective for developing critical thinking skills or fostering long-term knowledge retention (Mayer, 2024). In occupational safety education, where learners are expected not just to know procedures but to apply them in dynamic and potentially hazardous environments, the passive absorption of facts may be insufficient.

Presentations may unintentionally promote a superficial approach to learning. The heavy reliance on bullet points, charts, and condensed content can lead to cognitive overload or shallow processing(He et al., 2021). Without reinforcement through discussion, application, or hands-on practice, learners may forget critical content soon after the training concludes.

Despite drawbacks, the value of presentations cannot be entirely dismissed. When used effectively—paired with visual aids, real-world examples, and brief interactive segments—they can form a solid foundation for knowledge dissemination. The challenge lies in optimizing their design and delivery to make them more engaging and learner-centered. Techniques such as incorporating storytelling, using multimedia content, and including frequent knowledge checks can enhance their instructional impact.

VIDEO GAMES IN OHS

Video games have long been excluded from occupational health and safety education due to a combination of economic, technological, and practical challenges (Chodan et al., 2017; Junaini et al., 2022; Murwonugroho & Syaifudin, 2020). Historically, the development of educational video games was prohibitively expensive, requiring substantial investment in both time and money. Unlike traditional training methods—such as lectures or printed manuals—video games demanded a multidisciplinary team including programmers, graphic designers, instructional designers, and OHS experts. For companies already operating under tight training budgets, the high upfront cost and ongoing maintenance were often seen as unjustifiable. Furthermore, OHS education is highly specific to each company's industry, operations, and regulatory context. A generic game would fail to reflect the distinctions of different work environments, while a tailored solution significantly increased development complexity and cost. The lack of scalability made video games an impractical choice for most organizations, especially smaller ones.

In addition to financial and customization barriers, early technological limitations also contributed to the exclusion of video games from the OHS training landscape. In the early years of gaming, platforms lacked the graphical power, realism, and interactivity required to simulate real-life hazards effectively. Hardware was expensive, and few companies had the digital infrastructure to support immersive media. Moreover, cultural perceptions of video games as purely recreational further impeded their acceptance as serious learning tools in professional settings.

In contrast, the current technological landscape has drastically shifted. Modern game engines like Unity and Unreal Engine offer cost-effective development options, while no-code platforms allow for faster prototyping and iteration. Games can now be delivered through mobile devices, web browsers, and VR headsets, making them more accessible across diverse workplaces. Artificial intelligence and data analytics can also be integrated to track progress and personalize the learning experience. Customization, once a barrier, has become more feasible through modular game design, allowing core content to be adapted to different industries without starting from scratch. Additionally, the rising presence of digital-native employees in the workforce has increased the demand for interactive, self-directed learning experiences.

The evolution and current state, not only makes video games a viable tool for OHS education but positions them as a superior method in many aspects, capable of simulating dangerous scenarios in a safe environment, reinforcing knowledge through active participation, and increasing retention through gamified incentives. What was once considered an expensive novelty is now emerging as a powerful, cost-effective, and scalable solution for training in occupational health and safety.

Contemporary Usage of Video Games OHS

Video games are increasingly being utilized in safety education across various industries, including healthcare, construction, manufacturing, and emergency services. The ability to simulate real-world scenarios, promote active engagement, and provide instant feedback makes them particularly effective for teaching critical safety protocols and decision-making skills. Game-based learning in safety contexts not only enhances the acquisition of knowledge but also helps in developing practical competencies that are essential in high-risk environments.

Prominent example is “Hazard Spotting,” a digital game developed to train workers in identifying workplace hazards in industrial settings. This game immerses users in a simulated construction site or factory where they must identify and respond to various hazards under time constraints. A study by Patel et al. (2020) found that learners using Hazard Spotting demonstrated significantly better hazard recognition skills compared to those trained with conventional slide-based instruction. The interactive nature of the game helped reinforce memory and situational awareness.

In the healthcare sector, simulation-based games such as “Code Blue” allow nurses and emergency medical technicians to practice responding to medical emergencies in a controlled virtual environment. The game includes various modules for CPR, triage, and patient communication. According to the research (Malti et al., 2017), these types of simulations improve clinical decision-making skills and reduce error rates in high-pressure scenarios. Learners can make decisions, observe the outcomes, and receive targeted feedback—all without risk to real patients.

Another compelling case is "VR Mine Rescue Training," a virtual reality platform used in mining industries in countries like Australia and Canada. This game replicates underground mining conditions and simulates emergency scenarios such as gas leaks or cave-ins. It allows trainees to practice evacuation protocols, equipment usage, and communication strategies. A report by the International Council on Mining and Metals highlighted the platform's success in improving both individual readiness and team coordination, aspects that traditional classroom instruction often struggles to address (Pedram et al., 2017).

Even outside high-risk sectors, game-based safety training has gained traction in general workplace environments. "Workplace Adventure," a gamified e-learning module developed by SafetyCulture, integrates real-world safety scenarios with role-playing elements. Employees navigate through virtual office spaces, responding to safety violations and performing audits. The game incorporates scoreboards, badges, and levels to increase motivation and participation. Studies have shown that gamified modules like this result in higher completion rates and better post-training assessments (Landers et al., 2017).

Educational institutions have also adopted game-based tools for safety education. For example, "ChemLab" is a digital simulation used in high school and university science courses to teach lab safety procedures. Students must identify appropriate personal protective equipment (PPE), follow correct protocols, and manage hazardous materials safely. It provides a hands-on experience that would be too dangerous or costly to replicate in real life. The research (Vogel et al., 2006) supports the effectiveness of such simulations in increasing learner confidence and knowledge retention.

Mobile apps like "OSH Quiz" and "SafeTech" provide microlearning opportunities for on-the-go training in occupational health and safety. These apps feature short quizzes, scenarios, and games that reinforce compliance knowledge and workplace standards. They allow for just-in-time learning and are especially useful for remote or field-based workers. The gamification of safety training via mobile platforms has been linked to increased user engagement and long-term knowledge retention (Boyle et al., 2016; Connolly et al., 2012).

Measuring learning outcomes in game-based environments can be complex. Traditional tests may not fully capture the competencies developed through interactive scenarios. As a result, some organizations use blended assessment strategies, combining digital performance analytics with conventional exams or peer reviews (Connolly et al., 2012).

Nevertheless, the trajectory of game-based safety education is promising. As technology becomes more accessible and instructional design continues to evolve, more sectors are likely to adopt games as part of their training regimes. Partnerships between educational institutions, government bodies, and private developers are producing increasingly sophisticated educational games tailored to specific industries.

CONCLUSION

The evolution of digital technology and pedagogical strategies has brought video games to the forefront of occupational health and safety (OHS) education, challenging long-standing reliance on traditional presentations. While historically excluded due to high development costs, limited technological infrastructure, and the need for highly tailored content, video games have become increasingly viable with advancements in modular design, affordable development tools, and widespread digital literacy—particularly among younger workers. Today's game-based learning environments offer immersive, engaging, and realistic simulations that enhance retention, critical thinking, and situational awareness, particularly in high-risk industries where practical application is essential. Although traditional methods retain value in standardizing content and meeting regulatory requirements, their limitations in fostering engagement and active learning make them less suitable as standalone tools. As the workforce continues to diversify in age and digital fluency, a blended educational model that integrates the interactivity of games with the reliability of conventional instruction offers the most promising path forward. By embracing game-based learning, OHS education can become more dynamic, effective, and aligned with the needs of both modern industries and their evolving workforces.

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CIRCULAR BIOECONOMY IN SERBIA: OPPORTUNITIES AND CHALLENGES

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Abstract: Circular bioeconomy integrates sustainability, resource efficiency, and innovation to create an economic system that simultaneously advances environmental goals and supports socio-economic development. This paper explores the current state, challenges, and opportunities of circular bioeconomy in Serbia, drawing insights from the EU-funded RIBES project results. Through theoretical analysis, available data, and practical examples such as biogas production from agricultural residues and transforming of food waste into beer, this study highlights strategies for improving biomass utilization and enabling socially inclusive bioeconomic transition in Serbia. Recommendations are made for developing value chains and supporting frameworks that leverage Serbia's existing potentials.

Keywords: *Circular bioeconomy; Social innovation; Value chains; Serbia.*

INTRODUCTION

The increasing global pressure to transition towards more sustainable and resilient economic systems has prompted a search for solutions that harmonize environmental preservation with socio-economic development. One such integrative concept is the circular bioeconomy - a model that merges the renewable potential of biological resources with circular economy principles, aiming to reduce waste, enhance resource efficiency, and decouple economic growth from environmental degradation (EC, 2018; 2020; 2021).

In the European Union (EU), the circular bioeconomy has gained strategic significance, supported by the European Green Deal, the Bioeconomy Strategy, and the Circular Economy Action Plan. This framework emphasizes innovation, regional development, and climate neutrality through sustainable use of biological resources. As a country in the EU accession process, Serbia is encouraged to align its development strategies with these broader goals, yet faces unique challenges due to structural, institutional, and economic constraints.

Serbia's opportunity for the development of circular bioeconomic lies in its abundant but unused biomass potential, including crop residues, manure, food waste, and forestry by-products. However, the realization of this potential is slow by a lack of coherent policy and capacities, limited public awareness, weak innovation ecosystems, and insufficient investment.

The objective of this paper is to analyse the opportunities and challenges related to implementing a circular bioeconomy in Serbia, using case studies and insights from the EU-funded RIBES project (RIBES, 2025).

The analysis is structured as follows: the next section provides a theoretical framework linking definitions of circular bioeconomy and social innovation. This is followed by two case studies that illustrate good practices in biomass valorization. Section four explores Serbia's biomass potential and value chain development. Section five discusses systemic barriers and offers recommendations. The final section draws conclusions and outlines future research directions.

THEORETICAL FRAMEWORK: CIRCULAR BIOECONOMY AND SOCIAL INNOVATION

The circular bioeconomy is an evolving concept at the intersection of ecological economics, biotechnology, and innovation policy. It is defined by the European Commission (2018) as an economy that uses biological resources from land and sea, as well as biological waste, to produce food, materials, and energy in a sustainable way. Unlike traditional bioeconomy, circular bioeconomy explicitly incorporates the principles of circularity - extending product life cycles, designing out waste, and regenerating natural systems.

The circular bioeconomy has three main dimensions (EC, 2018):

- Technological – involving bio-based innovations such as fermentation, anaerobic digestion, bio-refineries, and synthetic biology.
- Environmental – focusing on emission savings, land use efficiency, and biodiversity preservation.
- Social and institutional – promoting inclusive development, rural development, and participatory governance.

A related and increasingly important concept is social innovation. Social innovation refers to new ideas, practices, and institutions that meet social needs more effectively than existing solutions. Within the context of circular bioeconomy, social innovation facilitates behavioral change, institutional transformation, and value chain inclusivity. For example, cooperative models for biomass collection or community-led food waste recycling initiatives are forms of social innovation that enhance circularity (Solidarna kuhinja, 2025).

The interplay between circular bioeconomy and social innovation is particularly critical in transitioning economies like Serbia. Here, established economic connections, institutional inertia, and limited capacities for investment hinder technological adoption. However, grassroots entrepreneurship, public-private partnerships, and EU-funded initiatives are gradually fostering a more resilient and participatory bioeconomic landscape.

EXAMPLES OF GOOD PRACTICE

Biogas from Agricultural Waste (Pilze-Nagy Kft, 2024)

Biogas production from agricultural residues represents a key component of the circular bioeconomy anywhere. It enables the conversion of biomass that would otherwise be wasted into valuable energy (electricity, heat) and digestate that can be applied back to the soil. A

notable example is the biogas facility operated by Pilze-Nagy Kft in Kecskemét, Hungary. The company, primarily engaged in cultivating oyster mushrooms (*Pleurotus ostreatus*), utilizes agricultural residues such as wheat straw-based mushroom substrate 3,500 t/year (thus pre-treated, otherwise restricted for use as a substrate), pig slurry 3,000 t/year, and maize silage for anaerobic digestion 4,000 t/year. This combination provides a balanced substrate for anaerobic digestion while reducing reliance on energy crops and contributing to cost savings.
The plant has been operational since 2008, has a capacity of 330 kW of electrical power and 400 kW of thermal power. What makes this example distinctive is the integration of the biogas facility with the company's primary production activities. The heat produced is used to heat greenhouses for mushroom cultivation, located just a few hundred meters from the plant. Moreover, the digestate produced in the process is distributed to local agricultural fields where wheat and other crops are grown - thus completing a local nutrient and energy loop. The system exemplifies the principles of circular bioeconomy by minimizing waste, closing resource loops, and enhancing farm resilience through diversified income streams.

Brewing beer from bread waste (Biova Srl, 2023)
Food waste valorization is another field where circular bioeconomy can have significant environmental and social benefits. The start-up company Biova, based in Italy, has pioneered a business model centered on converting unsold bread into craft beer. This innovative approach was motivated by the statistic that approximately one-third of all food produced globally is wasted. In Italy alone, around 46,000 t of bread are discarded annually.
Biova collects leftover bread from local bakeries and repurposes it in the brewing process, replacing up to 30% of the barley malt usually required. The substitution not only reduces raw material costs but also decrease CO_2 emissions associated with barley cultivation and processing. The process results in a unique craft beer with a lower environmental footprint. Additionally, the residual malt is used to create high-protein, low-sugar snacks rich in fibre and minerals - extending the value chain and appealing to health-conscious consumers. Products are distributed via the same bakeries that provide the raw material, reinforcing local circularity and consumer awareness.
By combining circular food production with social engagement, Biova demonstrates the potential of small-scale social entrepreneurship to tackle food waste, promote sustainable consumption, and foster local economies.

BIOMASS POTENTIAL AND VALUE CHAINS IN SERBIA

Serbia possesses considerable untapped potential in biomass resources that could serve as the foundation for developing a circular bioeconomy. The most prominent types of biomass in the country include crop residues (straw, livestock manure, food processing waste, used cooking oil, green municipal waste, pruning residues, and forest biomass. Despite this diversity, biomass exploitation remains relatively inefficient due to infrastructural, logistical, and regulatory challenges.

According to Eurostat (Eurostat, 2024) data and national estimates, Serbia's total biomass potential for 2030 includes millions of tons of dry matter annually, table 1. This biomass is often scattered across rural households and small farms, which complicates collection and transport. Additionally, a lack of cooperative structures, insufficient investment in pre-treatment technologies, and limited market demand further restrict the development of biomass-based value chains.

Table 1. Total biomass potential for 2030 in Serbia (Nesterovic et al., 2025).

Biomass type	Serbia (kt of dry matter)	Vojvodina (kt of dry matter)
Crop residues	1,040	830
Manure	653	464
Food processing waste	16	10
HORECA (Hotels, Restaurants, Caffes)	8	2
Used cooking oil	5	4
Organic Fraction of Municipal Solid Waste (OFMSW)	68	27
Green municipal waste	9	2
Forest biomass	367	–
Pruning residues from agriculture	150	18
Total	2,316	1,357

Several promising value chains for Serbia have been identified within the RIBES project framework:

- Biomethane production – Biogas upgrading into biomethane offers an opportunity to replace natural gas in households, industry, and transport.
- Advanced biofuels – Lignocellulosic ethanol (LCB) and hydrotreated vegetable oil (HVO) from waste oils represent feasible alternatives to fossil fuels.
- Hydrogen from biomass – Via thermochemical (gasification, pyrolysis) or biochemical (dark/photo-fermentation) routes, enabling low-emission fuel.

- Biochar – Carbon-rich material obtained through pyrolysis, useful for soil improvement and carbon sequestration.

Among these, biomethane stands out due to its technological maturity, higher decarbonization potential and lower production costs than other renewable gases or liquid biofuels, compatibility with existing infrastructure, and contribution to energy independence. Moreover, co-digestion strategies (e.g., combining manure with food waste) improve digestion efficiency while addressing multiple waste streams.

However, several structural bottlenecks must be addressed:

- Lack of feedstock contracts and fragmented land ownership.
- Underdeveloped logistics for biomass collection.
- Policy and subsidy gaps in comparison to EU incentives.
- Public awareness and resistance to technology adoption.

To unlock Serbia's biomass potential, an integrated approach is required - combining technological support, policy reform, stakeholder coordination, and targeted investment. Creating bioeconomy strategies and regional innovation hubs could catalyze locally adapted, influential projects (Scarlat et al., 2015).

DISCUSSION AND RECOMMENDATIONS

The development of a circular bioeconomy in Serbia presents both significant opportunity and considerable challenge. The findings from this analysis suggest that although the country possesses vast biomass resources and examples of innovative practices, systemic issues hinder full-scale implementation. This section outlines key discussion points and provides strategic recommendations.

Institutional Fragmentation and Policy Gaps

The bioeconomy in Serbia is currently not governed by an integrated national strategy. Responsibilities are dispersed across ministries dealing with agriculture, environment, energy, and education, leading to a lack of coordination and strategic coherence. Without a dedicated bioeconomy roadmap or legal framework (it is under development), efforts remain isolated and insufficiently funded. Aligning with the EU Bioeconomy Strategy would offer Serbia a structured path forward, particularly regarding sustainability standards, funding instruments, and innovation ecosystems.

Knowledge Transfer and Innovation Deficit

One of the major barriers in transitioning to a circular bioeconomy is the limited capacity for research and innovation. Public R&D institutions often operate isolated and have weak linkages with the private sector. Moreover, SMEs in rural areas have minimal access to bio-based technology or expertise. Regional innovation platforms, living labs, and public-private partnerships can serve as vehicles for knowledge co-creation, scaling, and adaptation to local contexts.

Social Acceptance and Behavioral Change
Public awareness of bioeconomy principles remains low. Behavioral resistance to new practices, especially in agricultural and municipal sectors, hinder adoption of bio-waste valorization technologies. Campaigns targeting consumer awareness, as well as training programs for farmers and municipal workers, are necessary to foster a culture of circularity and community-based resource management.

Investment and Financial Mechanisms
Circular bioeconomy projects often require significant investment capital, which is a major barrier for rural and peri-urban actors. Targeted finance schemes, green bonds, and EU funding instruments (e.g., Horizon Europe) can make such investments less risky. Establishing a bioeconomy investment platform or guarantee fund could help mobilize private sector participation.

Territorial Approaches and Regional Tailoring
Given the diversity of biomass sources, socio-economic conditions, and industrial capacities across Serbian regions, a one-size-fits-all approach is unlikely to succeed. Instead, territorial bioeconomy strategies should be developed, focusing on regional strengths - e.g., livestock farming in Vojvodina or forestry in central Serbia. Such localization enables adaptive governance and stakeholder ownership.

Recommendations

- Formulate and adopt a national strategy for circular bioeconomy with interministerial coordination.
- Foster innovation through living labs and public-private partnerships.
- Establish regional biomass hubs for aggregation, pre-treatment, and logistics.
- Integrate circular bioeconomy into rural development and education policies.
- Expand financing schemes and advisory support for small-scale entrepreneurs.

Serbia's transition toward a circular bioeconomy depends not only on resource availability and technological potential, but also on systemic policy reform, institutional capacity building, and public engagement. Only through holistic and participatory approaches can circularity become embedded in the country's economic and ecological systems.

CONCLUSION

Serbia faces an important crossroad in its pursuit of a sustainable and inclusive economic future. The circular bioeconomy presents a powerful framework for addressing the interconnected challenges of environmental pollution, rural decline, and economic vulnerability. As demonstrated through the examples of biogas production and food waste valorization, practical pathways for transformation already exist and can be scaled with appropriate support.
However, to unlock the full potential of its bio-based resources, Serbia must adopt an integrated strategy that combines technological innovation, institutional reform, territorial planning, and social engagement. The recommendations presented in this paper offer a roadmap for building resilient regional bioeconomy systems that contribute to both climate objectives and local prosperity.
Future research should focus on developing multiscale bioeconomy models, assessing life cycle impacts of proposed solutions, and designing participatory governance mechanisms that ensure equitable benefit distribution (RIBES, 2005). By joining circularity and innovation as important part of its development agenda, Serbia can become a country with successful and sustainable bioeconomic transition.

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EMPOWERING OCCUPATIONAL SAFETY AND HEALTH FOR SUSTAINABLE DEVELOPMENT IN THE WESTERN BALKANS – PROJECT OVERVIEW

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Abstract: The empowering occupational safety and health for sustainable development in the Western Balkans (GREEN4OHS) project addresses shared occupational health and safety (OHS) challenges in the Western Balkans through an integrated strategy focused on regional cooperation, inclusive education, policy harmonization, and sustainable development. As countries in the region continue to face high rates of occupational injuries, limited enforcement capacity, and inconsistent alignment with EU directives, this initiative provides a coordinated response that transcends national boundaries. Through the development and piloting of modular blended learning programs, the facilitation of regionally hosted workshops, and the establishment of a comprehensive digital knowledge platform, the project empowers key stakeholders including academic institutions, policymakers, civil society actors, and industry professionals to advance common OHS goals. It places particular emphasis on equipping vulnerable and underrepresented groups with the tools needed to participate in safe and sustainable working environments. Aligned with the EU Strategic Framework on Health and Safety at Work and the Green Agenda for the Western Balkans, the project represents a forward-looking model for transnational collaboration in addressing systemic occupational risks. This paper outlines the project's underlying rationale, research methodology, implementation phases, and its anticipated contribution to regional resilience and long-term institutional transformation.

Keywords: *occupational health and safety; Western Balkans; sustainable development; blended learning; regional cooperation.*

INTRODUCTION

Occupational health and safety (OHS) is a cornerstone of equitable and sustainable development, directly contributing to the goals of decent work, human rights protection, and economic resilience. Globally, the International Labor Organization (ILO) estimates that more than 2.9 million workers die annually from occupational accidents and work-related diseases, while over 395 million suffer non-fatal work-related injuries (ILO, 2023a). In the Western

Balkans, these figures are exacerbated by structural inefficiencies, under-resourced labor inspectorates and the prevalence of informal work, particularly in high-risk sectors such as construction, agriculture and processing industries (EU-OSHA, 2023; ILO, 2023a).

Although each Western Balkan country has established national OHS legislation and maintains well-developed academic and vocational (VET) training systems, alignment with the EU legal framework remains partial. Furthermore, these education and training frameworks diverge from EU best practices across six critical dimensions: (1) no harmonized, certified curriculum framework (e.g. EQF/NQF alignment) leads to wide variability in content quality; (2) limited collaboration between universities, VET schools, industry and labour inspectorates restricts hands-on internships and practical skill acquisition; (3) predominant reliance on traditional, lecture-based delivery with minimal e-learning, simulation or blended-learning formats; (4) scarce opportunities for continuous professional development (CPD) and mandatory recertification weaken long-term competency maintenance; (5) negligible integration of "green" and digital competencies such as carbon-footprint assessment or data-driven risk analysis leaves graduates unprepared for sustainability and Industry 4.0 challenges; and (6) a shortage of internationally accredited OHS instructors (e.g. ISO 45001 lead auditors or European OHS educator certifications) limits the transfer of best practices. Closing these gaps is essential to equip regional OHS professionals with EU-comparable competencies, enhance cross-border mobility and accelerate the uptake of advanced safety and sustainability measures.

The 2024 European Commission Enlargement Reports document persistent implementation gaps in Serbia, Bosnia and Herzegovina and North Macedonia, including limited enforcement capacity, outdated inspection methodologies and insufficient intersectoral coordination (European Commission, 2024). Concurrently, psychosocial risks such as work-related stress, burnout and musculoskeletal disorders are on the rise. Surveys indicate that nearly one in four workers in the region reports chronic stress symptoms, correlating with weakened mental health support structures at enterprises (Stanković et al., 2022).

Vulnerable populations including women, youth and informal workers face disproportionate hazards stemming from limited access to training, under-representation in safety committees and lack of inclusive policy design. Informal sector employees face injury rates up to 30% higher due to irregular oversight and inadequate protective equipment, and this gap is compounded by the absence of formal safety protocols and social protections (Benach et al., 2014; ILO, 2022). Migrant and informal workers report 40% lower access to employer-provided safety briefings compared to formal employees, reflecting systemic barriers to hazard awareness in precarious employment contexts (De Lange et al., 2018; WHO, 2021). Female workers experience a 20% higher incidence of musculoskeletal disorders and chemical-exposure complaints, driven in part by poorly fitted personal protective equipment and risk communication materials that fail to account for gender differences in body morphology and language (Gochfeld, 2018; Smith and Jones, 2019). Moreover, psychosocial hazards such as work life conflict and harassment disproportionately affect women, with studies linking these stressors to a 25% increase in absenteeism and long-term health impacts (Eurofound, 2020). Workers under 25 face a 50 % greater risk of acute workplace injury, with youth particularly susceptible to falls, machinery incidents and overexertion when training is generic rather than age-adapted (Leijten et al., 2020; Eurofound, 2021). Early-career employees report occupational stress and anxiety rates up to 35 % higher than those of older cohorts, highlighting the need for targeted psychosocial risk management in training curricula (Stanković et al., 2022; ILO, 2023b). Finally, individuals with lower literacy or digital skills often overlapping with informal, female and young demographics report 45% lower engagement with e-learning modules, highlighting the necessity for multimodal instructional design that accommodates diverse learning needs (European Commission, 2021; WHO, 2021). Together, this body of evidence demonstrates the urgent need for inclusive, tailored OHS interventions that address the intersecting vulnerabilities of these groups.

Despite EU-mandated drives toward a green transition, sustainable practices within OHS systems remain limited. Recent surveys indicate that fewer than 15% of enterprises formally evaluate the environmental co-benefits of safety measures (Smith and Taylor, 2022). Only 22% of OHS professionals receive training on eco-risk management, and just 18% of companies have formal ties between their OHS and environmental management teams (EU-OSHA, 2021b).

The GREEN4OHS project was launched to address these interlinked challenges through regional cooperation and a multi-stakeholder approach. It aligns fully with the EU Strategic Framework on Health and Safety at Work 2021–2027, which emphasizes proactive risk management, digitalization and the integration of OHS within the green transition (European Commission, 2021). Initial surveys and focus groups with practitioners from higher education, government, industry, and civil society identified three critical intervention areas: 1) harmonizing national regulations with EU directives, 2) expanding training opportunities and 3) embedding sustainable practices within workplace safety systems. These findings underscored the necessity of developing modular blended-learning programs and establishing a regional OHS Knowledge Hub to drive long-term capacity building and systemic enhancement of health and safety practices across the Western Balkans.

METHODOLOGY

The GREEN4OHS methodological framework advances through three interdependent stages, each firmly grounded in current European Union policy guidance. In the diagnostic assessment stage, extensive online surveys of occupational health and safety, environmental management, and labor policy professionals will be combined with semi-structured focus-group discussions among cross-sector stakeholders to map exact needs, identify policy gaps, and inform the design of targeted interventions. This approach fulfills the EU-OSHA Strategic Framework on Health and Safety at Work 2021 to 2027 requirement for evidence-based needs assessments (EU-

OSHA, 2021a).

Building on this robust evidence base, the instructional development stage will employ iterative regional workshop to co-create training curricula that reflect both fundamental OHS legislation and emerging sustainability priorities. Interactive e-learning units and practical case studies will be produced and subjected to pilot testing with representative cohorts. Validated pre- and post-assessment measures will confirm knowledge gains, guide any necessary content refinements, and ensure alignment with the New Skills Agenda for Europe's focus on green-competency upskilling (European Commission, 2020).

In the dissemination stage, all educational resources will be consolidated within an open-access regional OHS Knowledge Hub, in line with the Digital Education Action Plan 2021 to 2027 vision for inclusive lifelong learning. Complementary outreach through practitioner interviews, social-media infographics and policy recommendations will promote outputs, legislative proposals and will sustain dynamic stakeholder dialogue (European Commission, 2020).

RESULTS AND DISCUSSION

The GREEN4OHS project aims to establish a regional foundation for advancing occupational health and safety (OHS) through the integration of environmental sustainability and inclusive workforce development. As the region faces increasing pressures from the twin transitions, green and digital, there is a growing need to reinforce OHS frameworks with competencies that reflect not only traditional safety concerns but also emerging ecological and social dimensions. In response, GREEN4OHS proposes a multilayered intervention designed to build institutional capacity, support policy alignment with European and international standards, and foster long-term cooperation among academic, public, and private sector actors.

A core output of the project will be the establishment of a Regional OHS Knowledge Hub. This digital platform will function as a central repository for training materials, regulatory and policy analyses, and interactive peer-to-peer exchanges. The Hub is projected to serve over one hundred unique users, facilitating continuous knowledge transfer and professional networking across borders. Its architecture will support open-access learning while also promoting modular, competency-based training aligned with EU-level frameworks such as the 2021–2027 Strategic Framework on Health and Safety at Work (European Commission, 2021).

Complementing this digital infrastructure is the curricular integration of green-safety principles into higher education. Three partner universities will incorporate at least 30% of the project-developed teaching modules into existing bachelor's and master's programs, thereby embedding key competencies related to sustainable and inclusive OHS. This process is aligned with Directive 89/391/EEC, the foundational EU Framework Directive on Occupational Safety and Health, which underscores the need for structured training, risk prevention, and participatory engagement at all levels of the workforce (European Council, 1989). The project's pedagogical innovations further contribute to the European Skills Agenda by addressing green skill gaps and promoting lifelong learning.

Institutional commitment to sustained regional collaboration will be formalized through a trilateral Memorandum of Agreement among the participating universities. This document will outline responsibilities for long-term maintenance of the Knowledge Hub, coordination of academic exchange, and mutual support in policy advocacy. Such cross-border cooperation resonates with the ILO's Promotional Framework for Occupational Safety and Health (Convention No. 187), which emphasizes systems-based approaches to improving OSH performance (ILO, 2006).

To ensure wide stakeholder engagement, GREEN4OHS will launch a multifaceted outreach campaign targeting policymakers, labor inspectors, industry representatives, and civil society organizations. Through a mix of digital communication (including infographics and targeted content) and in-person events (such as regional events and workshops), the project aims to raise awareness, foster dialogue, and build a constituency for reform. These efforts directly support the dissemination mandates outlined by EU-OSHA and reinforce principles set forth in ILO Convention No. 155 on occupational safety and health and the working environment (ILO, 1981).

Another critical deliverable is a consolidated regulatory gap analysis, comparing existing national legislation across the Western Balkans with core EU directives (e.g., Directive 92/58/EEC on safety and health signage; Directive 2004/37/EC on carcinogens or mutagens at work). The analysis will be complemented by actionable policy recommendations to support national alignment with EU law and ILO instruments, notably Convention No. 170 concerning safety in the use of chemicals at work (ILO, 1990). These recommendations will serve as a roadmap for regulatory convergence, ensuring the protection of workers in sectors undergoing rapid ecological and technological transformation.

The project's impact will be evaluated through a mixed-method framework encompassing assessments of knowledge retention, monitoring of platform engagement metrics, and tracking of policy uptake. In doing so, GREEN4OHS aims not only to meet its immediate objectives but also to establish a replicable model for sustainable and inclusive occupational safety governance in the Western Balkans and beyond.

CONCLUSION

The GREEN4OHS initiative aims to demonstrate how a coordinated, policy-aligned framework can effectively address deeply rooted occupational health and safety deficiencies in the Western Balkans. By integrating comprehensive needs assessment with co-creative curriculum development, the project aligns its activities with EU mandates for proactive occupational risk management, green transition and lifelong learning. The establishment of a cross-border platform, modular blended-learning program, regulatory alignment workshops and a dynamic Knowledge Hub creates a robust ecosystem for sustained capacity building and policy coherence. Pilot implementations and stakeholder feedback loops will ensure that training materials remain responsive to the diverse needs of workers including vulnerable groups such as informal workers, women and youth. Moreover, the emphasis on eco-friendly safety practices in the context of occupational safety and health not only mitigates workplace hazards but also advances broader environmental objectives.

As GREEN4OHS transitions from pilot to scale-up, its methodologies and tools offer a replicable blueprint for other regions seeking to harmonize OHS standards with sustainability imperatives. Ultimately, the project's multi-stakeholder, data-driven approach lays the groundwork for safer, more resilient workplaces and strengthened regional cooperation across the Western Balkans.

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READINESS OF THE OSH SYSTEM FOR THE CHALLENGES OF INDUSTRY I4.0

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Abstract: Industry 4.0 - implies industrial automation and robotic production, based on the integration of digital technology, information technology and communication in production processes, with the aim of optimizing the process, increasing productivity and efficiency. The networking of these systems has led to the emergence of "cyber-physical production systems" and thus to "smart factories", which use the network to connect production systems, products and people. This trend will inevitably affect the way work is organized and performed and may also affect the health and safety of workers.

Widespread automation in the manufacturing operations of Industry 4.0 will inevitably lead to a reduction in manual work and heavy physical work, as well as an increase in the demand for complex management functions, abstraction and problem solving for all available workforce in case of unforeseen events.

The focus in risk assessment is on identifying operational risks related to all stages of the production process, from data management to maintenance information, work methods and used tools, materials, human errors, machines and production technologies. The fact that it is quite a challenging task in an emerging and flexible factory system of this type where the procedures of occupational health and safety risk assessment and management will change and be continuously assessed, improved and verified so that risk information takes on an increasingly important role. Therefore, in the current, early stage of knowledge on this topic, a new precautionary risk management approach should be adopted in order to achieve sustainable development of Industry 4.0 innovations.

Keywords: *Industry 4.0; smart factories; health and safety; risk assessment; risk management*

INTRODUCTION

Industrial development has experienced significant evolutionary transformations since its beginnings in the 18th century. The replacement of manufacturing production is associated with the local production of steam, which separated production from the limitations of human manual effort (Industrial Revolution 1.0), the next paradigm shift came in the 19th century with the introduction of electricity in productive processes, which enabled a wide distribution of energy from a central facility. Thanks to electricity, machines became smaller, worked faster and more efficiently (Industry 2.0). In the 20th century, power assembly lines, machining centres were developed, and with the development of electronics, production became increasingly automated (Industry 3.0) and focused on performance. With automation, opportunities are created to optimize production processes and improve productivity through the design of more flexible systems, ergonomically adaptive and safe machines that ensure process safety. Finally, in the 21st century, more precisely in 2011, we meet the term "Industry 4.0" coined in a highly developed industrial environment, picture 01. In 2011, the term Industry 4.0 was coined by the German Academy of Science and Engineering. Industry 4.0 and its many synonyms, such as smart manufacturing, "intelligent industry" and smart manufacturing, describe a strategic approach to digitization in manufacturing. As could be expected, it refers to the convergence of production with the digital revolution, artificial intelligence, the Internet of Things, as well as with any device whose structure is based on the prefix "smart".

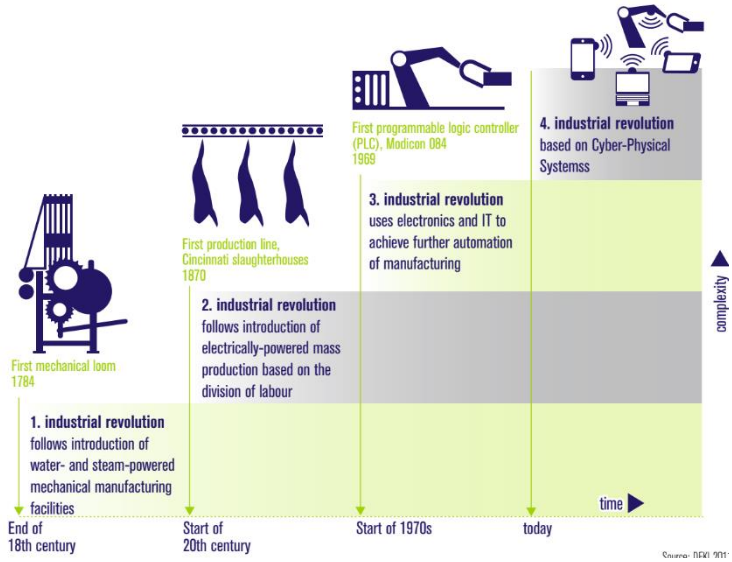

Figure 1. Characteristic features of industrial revolutions [1]

The technical systems around us are becoming more and more complex. Production lines can order spare parts when they run out. What makes this all possible are increasingly powerful mechanical elements, microprocessors and intelligent software. Today, many machines and devices are also connected via the Internet and mobile communications to each other, as well as to service operations and control centres. These complex technical systems represent enormous opportunities. However, the growing complexity makes it an increasingly difficult task for developers to design and create solutions for machines and devices, as they are intertwined in a way that is difficult to understand. Are engineering and engineers professionally qualified to respond to the challenges of SMS - Safety Management System or Occupational health and safety (OH&S) management, based on the principles of good international practice in the context of the challenges of Industry 4.0? This dilemma becomes a reality, if it is known that an increasing number of experts from different disciplines are involved in the development of increasingly complex production systems, and there is a need for these experts to communicate with each other. Until now, there has not been a common "technical language" that integrates more and more represented disciplines. It is expected that in the future, Advanced Systems Engineering (ASE) aims to devise a common language that can deal with this growing complexity, allowing future engineers to continue to create safe, reliable technical systems in a realistic time frame.

When it comes to safety at work, it should be emphasized that the evolution in this specific area has always followed revolutionary developments in the industry. The reaction to technological progress, changes in work methods and the real consequences of these on health and occupational health have given impetus to the implementation of reliable and sustainable solutions to the problem. In most industrialized countries, reactivity is now yielding to proactivity, which has advanced considerably over recent decades, but has also benefited from legislation, regulation and standards that have prioritized both occupational risk and the duty to eliminate hazard at source. Prevention is no longer just a word. Industrial companies today understand that the health and safety of their workers is a major component of financial success, as is overall quality, productivity and cost reduction. A healthy business is now one where OHS is considered imperative. Considering that the development trend of Industry 4.0 is gaining momentum, we have to ask ourselves whether we have thought enough about the new imperatives in the field of occupational safety. Have we evaluated the consequences of this industrial revolution on the safety and health of employees (positive and negative)? Are there valid reasons for concern? By raising such questions, our intention in this paper is to initiate thinking regarding the integration of OHS into the Industry 4.0 system.

DEVELOPMENT OF INDUSTRY 4.0 AND CHALLENGES FOR SAFETY AND HEALTH AT WORK

Industry 4.0 represents the fourth technological revolution in industry, characterized by the introduction of advanced technologies such as intelligent systems, artificial intelligence, the Internet of Things (IoT), robotics, automation and digitization of production processes. This development brings great benefits in efficiency and quality, but at the same time it also poses new challenges in the field of occupational safety and health.

There are many examples in the literature about the benefits offered by Industry 4.0. They are very numerous and diverse. Among other advantages, they stand out: reducing the number of required processes, improving the work environment, reducing processing time, required resources and tools, improving operations management, facilitating decision-making, facilitating mass customization, reducing delivery time, increasing productivity, helping to control information, enabling real-time measurement, improving information transfer, facilitating stakeholder collaboration, virtually supporting customer support and training.

There are significant opportunities for workplace advancement and productivity growth by integrating artificial intelligence (AI) applications and tools into Industry 4.0 workplaces. However, there are also important occupational safety and health (OSH) issues that arise when AI is integrated into the workplace. Stress, discrimination, increased insecurity, musculoskeletal disorders and the possibility of work intensification and job loss have already shown to represent psychosocial risks, including physical violence in digitized workplaces.

These risks are exacerbated when AI augments already existing technological tools or new ones are introduced for workplace management and design. Indeed, AI increases OSH risks in digitized workplaces, as it can enable increased micro-management oversight, which is a major cause of stress and anxiety. AI highlights the imperative to give greater credibility and potentially authority to predictive machines, robotics and algorithmic processes at work. At the same time, it is worth emphasizing that it is not technology in itself that creates benefits or risks in terms of OSH. Instead, the implementation of technologies creates both positive and negative conditions. Productivity discussions include direct implications for workers and working conditions, of course, but there is still little discussion of how the introduction of artificial intelligence into the workplace will benefit or create occupational safety and health (OSH) risks for workers themselves.

In general, there is no production process without risk, but decisive actions should be taken in order to realize the intention of the owner of the process who has available technical, organizational and human resources for identification, detection, monitoring and continuous sustainable management of relative risks to health and safety at work.

Opportunities for occupational health and safety in the context of Industry 4.0

The fourth industrial revolution brings full automation and digitization of production to workplaces by adopting automatically controlled, knowledge-based and sensor-equipped machines and equipment that improve processes through self-optimization and autonomous decision-making. In such a work organization, employees will retain a key function in knowledge work, including decentralized decision-making activities and quality assessment of production processes. This may mean that workers will be involved in more creative, interesting activities with added value, and will have the opportunity to qualitatively enrich their work, abandon routine tasks and achieve greater autonomy and self-development (Figure 2) [2]. Importantly, the greater organizational complexity involved in Industry 4.0 will require flexible working conditions that can offer employees greater compatibility between their work demands and private life, as well as between personal and ongoing professional development. Furthermore, the flow of information along the production line can make industrial management more transparent and organized, thereby reducing hierarchical pressure on the workforce [3].

Industry 4.0 could make work safer and healthier through early and continuous analysis and risk management based on intelligent safety technologies and virtual engineering (Figure 2). Monitoring technologies, on personal protective equipment and devices (eg, sensor helmets and gloves), have the potential to help employees stay safe in hazardous work environments where they may be exposed to extreme heat, toxic gases, open flames, or harmful elements and chemicals (Figure 2). They enable continuous monitoring of the condition of employees (eg sudden anomalies, such as a heart attack, fall or gradual changes in stress level), as well as the condition of equipment, machines and facilities. [4]

Viewed from the perspective of modern technology, such monitoring can provide real-time alerts that indicate the need to adopt preventive measures designed to stop dangerous behaviors, restore safety procedures, avoid injuries, and allow the injured worker to reach for help. [5] By interpreting what is observed and subsequently choosing the appropriate action, self-aware and self-learning machines, equipped with advanced analytics, may be able to predict dangerous situations during work in the workplace and use predictive safety management algorithms in unexpected conditions, with the aim of avoiding accidents and injuries at work. The technological capabilities of Industry 4.0 together with cognitive analytics could improve the ability of employees by making them smarter and supporting their safety. According to its concept, Industry 4.0 will use functional, industrial robots for an ever-increasing number of tasks, with which the production benefit will be in the robot's strength, durability and precision

(Figure 2). In this way, productivity and quality would be increased, while at the same time musculoskeletal disorders, traumatic or fatal injuries, as well as product and service costs would be avoided or reduced. Ultimately, the health and safety of employees could be protected, for example, by using professional robots to replace human workers during hazardous operations in hazardous areas. This type of "Collaborative Robots", abbreviated as "cobots", are designed to safely interact and work together with humans in shared workspaces. The cobot communicates one-way with its human operator who controls the robot, feeding it information about its environment and its tasks. Unlike traditional industrial robots that work autonomously behind a cage, cobots are built with advanced sensors, artificial intelligence and control algorithms that allow them to work in close proximity to humans. In such a human-robot symbiosis, human dexterity, agility and problem-solving skills are combined with advantageous, mechanical robotic characteristics. This type of advanced automation will make the workplace environment more ergonomic and comfortable. The human-robot combination enables more flexible and socially inclusive jobs for a workforce that is increasingly diverse in terms of age, gender and cultural background, as well as for injured workers during rehabilitation.

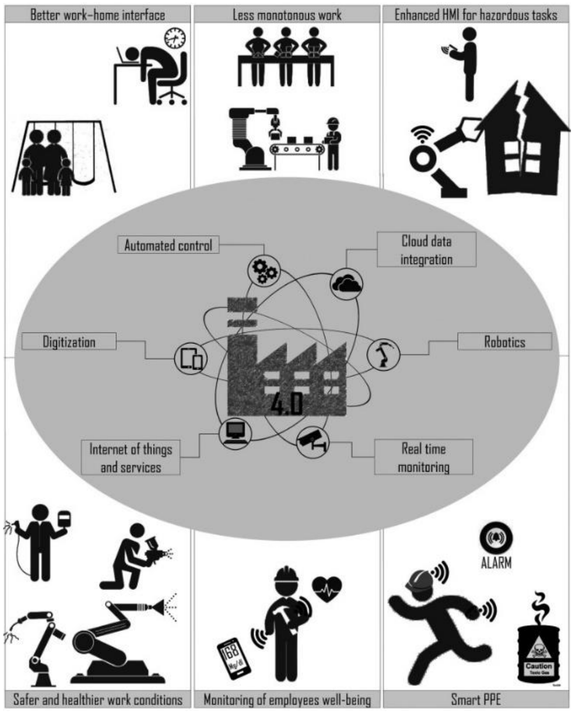

Figure 2. Main opportunities and benefits arising from the context of Industry 4.0 in workplaces [2].

Challenges of the occupational safety and health system in the context of Industry 4.0

Widespread automation in Industry 4.0 manufacturing jobs inevitably leads to a reduction in manual labor and heavy physical tasks, as well as an increase in complex management, abstraction and problem-solving requirements for the entire workforce in the event of unforeseen events. Psychological risks will become more apparent than physical risks in the workplace due to mental overload and work density caused by even more flexible and dynamic smart manufacturing activities (Figure 3). Workers employed in monitoring automated equipment or engaged in decentralized decision-making, as well as in engineering activities from start to finish, are expected to be able to work much more on their own initiative, and to possess excellent communication skills and the ability to organize their own work and maintain greater responsibility [6].

Industry 4.0 needs skilled rather than unskilled workers, as employees will be required to use and operate machines and intervene when necessary. Industrial automation also makes lifelong learning a prerequisite for work engagement, and that can be a big challenge, especially for older workers who don't have instinctive, natural access to digital tools. Certainly, these issues can play a role in changing the demographic picture of Industry 4.0 factories, which would be considered unacceptable from a socially inclusive occupational perspective. At the same time, the use of digital tools to continuously monitor employee behavior, performance, and productivity could create an atmosphere of professional insecurity, invasion of privacy, and psychological pressure. Ultimately, it could reduce contact between employees and supervisors, as well as among colleagues, thus worsening the workplace atmosphere by increasing work-related stress, as well as long-term negative health effects [7]. The greater mobility, flexibility and availability of machines can also enable working anywhere at any time, potentially disrupting an individual's work-life balance. The stress associated with changing jobs, displacement of workers and possible unemployment due to the replacement of human workers by robots could become apparent. In general, the changes brought about by I4.0 are associated with the increase in the technological level of companies, and it is accompanied by contributions to changes in the working conditions of employees. However, in the end, companies and the academic community focused on the impact of I40T implementation on competitiveness rather than on occupational safety and health issues.

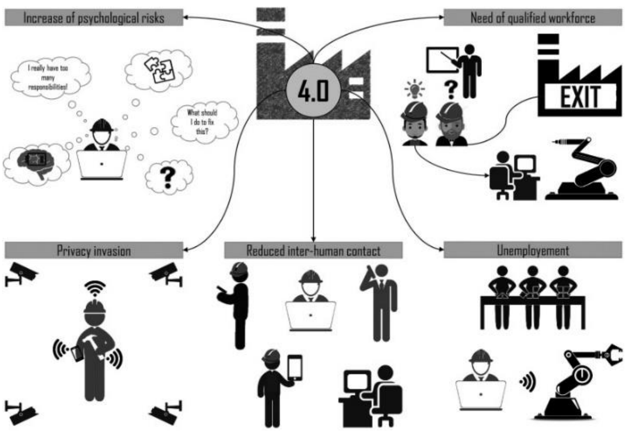

Figure 3. Basic issues and concerns arising from the application of Industry 4.0 in the workplace [2].

ESSENTIAL ASPECTS OF SAFETY AND HEALTH AT WORK IN INDUSTRY 4.0

In the digital era of Industry 4.0, workplaces have been transformed, new risks associated with working on automated and connected systems are emerging. Workers are increasingly facing the dangers of electric shock, injuries from robotic systems, cyber attacks and other new threats.

By analyzing the impact of Industry 4.0 on health and safety at work, and taking into account very specific risks, vision-related disorders, mental fatigue, disorders arising from static work positions, exposure to unknown dangerous particles as a result of cooperation with robots and psychological pressure were observed. Despite this, there are few studies in the literature that, taking into account the same parameters, provide quantitative comparisons of the impact of different Industry 4.0 on occupational health and safety risks in the industrial sector.

In general, some important aspects of occupational safety related to Industry 4.0 can be distinguished:

a. Developing safety standards and protocols: In this industrial evolution, the classic risk assessment methodology should be used to analyze traditional risks, but it may not be suitable for assessing some of the numerical risks [8]. For this reason, the new international standard for the management of safety at work (OSH) ISO 45001:2018 [9] includes in the annexes some requirements for managing the risks associated with the integration of new technologies. In particular, the standard highlights the need to understand new threats and opportunities that affect or may affect an organization's OSH performance, such as those arising from the integration of new technologies. In particular, the standard emphasizes that OSH hazards and risks should be minimized and opportunities for improvement maximized. Taking into account the rapid integration of Industry 4.0 into business processes, the transformation of working conditions that directly affect OSH risks and the need to introduce new assessment methodologies.

b. Training of working personnel: Workers should be adequately trained to work with advanced technologies, including familiarization with safety procedures and rules for working with robots and other devices. To thrive in the fourth industrial revolution I4.0, companies must ensure that their workers are adequately equipped through training and retraining, and then hire new people when necessary. Upskilling means that employees learn new skills that will help them in their current positions while developing the skills they need. Retraining is a real challenge; workers are being retrained with new skills that will enable them to fill different positions in their companies. This is increasingly important as "disruptive" technologies transform job demands, but views on reskilling vary geographically. In Europe, 94% of executives surveyed believe that the balance between hiring and retraining for I4.0 needs should be equal or should be geared toward retraining, compared to only 62% of respondents in the US. End-to-end skill transformation has three phases:

c. Application of smart sensors and systems A wide range of sensors are used to monitor working conditions (temperature, vibrations, electromagnetic field) in order to detect potential hazards in a timely manner.
   - Smart protective helmets with impact detection sensors
   - Advanced glasses and visors with anti-fog and anti-scratch technologies
   - Ergonomically designed cut and chemical resistant gloves
   - Work suits with integrated sensors for monitoring vital parameters
   - Protective footwear resistant to extreme conditions and electrostatics

Figure 4. Personal protective equipment with integrated sensors [Balkan Security Expo 2025].

d. Cyber security: Given the digital character of Industry 4.0, it is particularly important to strengthen protection against cyber attacks that can threaten the security of systems and workers. As more and more devices are connected to the production process, cyber security is becoming an increasingly important topic. Manufacturers must ensure that their networks and devices are protected from cyber attacks that could disrupt operations, steal valuable data or cause physical damage. Cyber security is a key topic for Industry 4.0, and manufacturers must be proactive in implementing security measures to protect their operations.

There are three models of cyber attacks:

- Physical attack - an attack against computer facilities and/or transmission lines, and can be achieved using conventional weapons with the aim of destroying or seriously damaging their computers and terminals.
- Electronic attack - an attack achieved by the use of electromagnetic high energy or an electromagnetic pulse, resulting in an overload of the computer circuit or microwave radio transmission.
- Computer network attack. This is usually achieved by using malicious code to exploit software weaknesses.

e. Smart Maintenance: Introduces intelligent maintenance based on learning. It is based on proactive maintenance that includes continuous or periodic monitoring of physical changes in the condition of machines and processes (Condition Monitoring), as well as analysis of the obtained data using machine learning methods, i.e. artificial intelligence. The main goal is to prevent or minimize production downtime. Basic condition monitoring techniques: Vibration analysis and diagnostics, Acoustic emission, Thermal behavior analysis, Infrared thermography, Ultrasonic testing, Energy consumption analysis, Abrasive and particle analysis, SHP analysis**.**

CONCLUSION

The highest level of industrial development Industry 4.0 (I4.0), also known as the fourth industrial revolution, introduced new paradigms in the work environment, changing the way companies organize work processes, changing the procedures by which workers communicate with machines and their work environment. I4.0 by improving traditional work systems towards high levels of automation and integration of cybernetic and physical worlds.

Automated machines and robots can either replace workers or sustain them by making their tasks more flexible, safer and socially inclusive. On the other hand, workers will be engaged in tasks that require decision-making, responsibility and management, as well as human-machine interaction that will expose them to health and safety risks intrinsically associated with automated tools and greater psychosocial stress.

Specifics of Industry 4.0: The application of smart machines, robotic systems and digital platforms enables dynamic process management. However, the complexity of the system increases the risk of breakdowns, errors and overloading of the working staff. The risks in the new industrial era are:

- Injuries caused by human-robot interaction (crashes or accidents with robots)
- Electronic and software malfunctions that can lead to accidents
- Stress and mental strain due to information complexity
- Exposure to electromagnetic fields and other factors caused by digital devices
- Technological solutions for protection:
- Integration of sensors to monitor the condition of the equipment and the workplace, enabling the prevention of accidents
- Automation and robotics for safety tasks reduce the risk of direct contact with hazardous materials or machinery
- Digital platforms for training workers and monitoring their safety
- System of detection and quick intervention in case of failure or error

Industry 4.0 brings great advantages in production and resource management, but at the same time introduces new risks for the safety and health of workers. Establishing safety systems, continuous education and primary innovative technology are key to preserving worker health and safety in a digitalized work environment.

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HOW TO GO FROM REACTIVE TO PROACTIVE OHS - SUSTAINABILITY OF A LAW-BASED SYSTEM

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Abstract: Real-time communication, large databases, human-machine cooperation, remote detection, process monitoring and control, autonomous equipment and interconnection are becoming the main advantage of modern Industry 4.0. As the fourth industrial revolution or Industry 4.0 becomes a dominant reality, it will bring new paradigm changes, which will have an impact on the management of the occupational health and safety system.

Occupational health and safety legislation is an essential part of the management process of organizations and companies. However, there are valid criticisms that a law-based system limits the contributions that innovation and industrial development bring to the system. In the procedures for editing the Safety and Health at Work system, there is no indication of the SMS - Safety Management System or Occupational health and safety (OH&S) management, which must instil in every legal entity, as well as the responsible social community, the belief that safety performance must be improved, and that the MS - Management System is actually a tool that ensures that the organization achieves its business goals in a safe manner.

The proactive approach recommended by the ISO 45001 standard appears for the first time in some of the documents that regulate the occupational safety system in the national professional public. The goal of proactive protection is timely detection and elimination of defects before they turn into a serious incident and threaten the process or the entire production system.

Our intention in this paper is to initiate thinking regarding the integration of the OSH System into Industry 4.0.

Keywords: *Management; Proactive approach; By integrating the OSH System*

INTRODUCTION

It should be emphasized that the evolution of occupational safety and health has always followed revolutionary developments in industry. The response to technological advances, changes in working methods and the real consequences of these on health and safety at work have given impetus to the implementation of reliable and sustainable solutions to the problem. In most industrialized countries, reactivity is now giving way to proactivity, which has advanced considerably over the last decades, but has also benefited from legislation, regulations and standards that have put both occupational risk and the duty to eliminate hazards at source at the forefront. Industrial companies today understand that the health and safety of their workers is a major component of financial success, as is overall quality, productivity and cost reduction. Healthy working activity is one in which OHS is considered imperative.

The International Organization for Standardization (ISO) has announced the first global standard for occupational health and safety, ISO 45001 2018, Occupational health and safety management system – Requirements with guidance for use, citing statistics from the International Labor Organization (ILO) report for 2017.

Global work activity resulted in 2.78 million deaths as a result of occupational accidents or work-related diseases, and 374 million non-fatal injuries and illnesses.[1] The standard is expected to provide a framework for increasing safety, reducing workplace risks and improving health and well-being at work, enabling organizations to proactively improve their OH&S performance.

The proactive approach recommended by the standard appears for the first time in one of the national documents regulating the occupational safety and health system. In the last 50 years of the institutional process of development of higher education, the scientific and professional community has profiled the professional essence of the Occupational Safety and Health system, through processes that:

- applies activities, measures and means in the processes of creating safe working conditions, by integrating modern technical, organizational, health, social, repressive, educational and other procedures;
- promote a preventive character with the unique goal of eliminating hazards as causes of injuries and health damage.
- develop a proactive structure, which in a defined time frame controls the elements of the system and, if necessary, implements corrective actions and/or fine-tuning of individual elements of the system. Develops new services and checks: Is there a possibility that safety and health may be endangered? Who or what may be endangered? How can a hazard occur? as well as other actions to maintain and improve good practice endangered? me.

Achieving the achievements of a proactive relationship and the implementation of functional requirements implies a built and documented system. Proactive support defines in advance and controls all elements of the system in the time domain, and if necessary, corrective actions and/or fine-tuning of individual elements and parameters are carried out in order to improve them. The goal of proactive protection is to timely detect and eliminate deficiencies before they become serious incidents and endanger the process or the entire production system. Incident resolution is the primary goal for ensuring normal system operation, so that in unplanned situations (outages, slowdowns or other anomalies in operation) - the business process can be maintained as quickly as possible and with minimal disruption. Risk assessment is certainly a process that creates a platform for achieving organizational goals, which imperatively implies a documented and organized system.

Occupational accidents and diseases are events that can and must be controlled preventively by planning, organizing and evaluating the results of the controls carried out. Excellence in occupational health and safety (OHS) depends on models that enable the adoption of preventive measures to reduce risks at work by proactively acting to improve the health, safety and satisfaction of workers. Finally, one can feel professional satisfaction that the "occupational health and safety" system has the chance to change current practice, which is abundant in four typical models ranked by prevalence:

- pathological model: promotes the attitude "who cares about Occupational Safety and

Health, work until you get caught"
- reactive model: implemented by employers who believe that Occupational Safety and Health is important but take concrete measures only when an accident has already occurred.
- calculative model: implemented by employers who appreciate the importance of process safety and employee health and implement a system of monitoring hazards and hazards
- proactive model: is represented in entities that recognize business interests and the importance of process safety and employee health and implement continuous improvements to the process safety system.
- LAW-based model: The original model, out of competition in the national space.

For many years, in this and the previous century, occupational safety and health and the importance of this organizational form in legal entities have been discussed through the prism of the Report on Accidents and Injuries, the number of inspection supervision and data on the number of undeclared workers. The only tool that is absolutely present in the system in question is the Law on Occupational Safety and Health, which is constantly being cosmetically innovated and supplemented, because how else can we explain the fact that in the last decade of this century, almost every year, there has been talk of a new Law, while some of the current Rulebooks as the basic levers of the management mechanism date back to the time of the SFRY, or rather the FNRJ.

This statement is supported by the campaign activity for the adoption of a new law on Occupational Safety and Health. In explaining the goals of improving the efficiency of the occupational safety and health system, the proponents impose three groups of reasons why it is necessary to adopt, or amend, the Law.

What stands out as the first and most important reason for the adoption of the Law is defined in terms of incorporating all relevant secondary sources of Community law into domestic legislation, thereby achieving 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 improvements in the safety and health of employees at work, which have not yet been transposed, are being incorporated into domestic legislation.
- We note that the Framework Directive 89/391/EEC of 12 June 1989 (Official Journal of the European Union) on the introduction of measures to encourage improvements in safety and health at work was implemented for the first time in the national legal system in the Law on Safety at Work of 18 July 1991 (Official Gazette of the Republic of Serbia, No. 42), which means that thirty years is not enough to harmonize only one document in the national legal system
- The second reason is, among other things, to harmonize the Law on Safety and Health at Work with the provisions of other laws.
- The third reason is to regulate certain issues that have not been regulated or that have been identified as problems in implementation and whose solution requires finding better legal solutions. It is necessary to specify certain provisions of this law, or to carry out legal and technical harmonization of certain provisions of the Law on Safety and Health at Work, in order to implement this law with as few interpretations as possible and thus contribute to faster implementation, as well as greater consistency in the application of the law.

Finally, the Law on Occupational Safety and Health, through the process of harmonization with the provisions of other laws and in order to ensure that the organization achieves its business goals in a safe manner, ignores the fact that in 2017, the Project Committee ISO/PC 283, Occupational health and safety management systems, published the ISO 45001:2018 standard, and that on April 5, 2018, the Director of the Serbian Institute for Standardization, by Decision No. 1986/2-51-02/2018, adopted SRPS ISO 45001:2018, which is identical to the international standard ISO 45001:2018, Occupational health and safety management systems – Requirements with guidance for use.

ISO 45001:2018 specifies requirements for an occupational health and safety (OH&S) management system and provides guidance for its use, to enable organizations to provide safe and healthy workplaces by preventing work-related injuries and illnesses, and by proactively improving their OH&S performance. [2]

The common denominator of the management process in such a designed environment is the risk assessment act as a tool for managing and conducting operations to a level that can be characterized as a "risk-free process". Unfortunately, experience gained in Serbian business practice shows that this tool does not have any management mechanisms, nor can it be considered a reliable document in determining responsibility and adjudicating in disputes that may arise between the process owner and employees. The reasons for such an attitude are contained primarily in the fact that the safety management mechanisms of employers have remained at the hypothetical level, with personnel values that lack professional capacity and a supervisory function that is subordinate to the interests of the process owner.

Our objective reality recognizes: Pathological and Reactive models, Based on the principles of the Law on Occupational Safety and Health. Domestic companies: small and medium-sized enterprises, (especially the construction sector) represent the pathological model, while Foreign companies - combine the law-based model and the reactive model

- We meet the minimum requirements prescribed by the Law on Occupational Safety and Health, and
- We implement the models represented in the domicile country (Lafarge - France; Leoni - Germany; China; Italy; Turkey; Russia ...)

The conclusion is that we cannot speak of a model that belongs to any of the classified groups, which are recognized by modern theory and practice.

OHS MANAGEMENT MODELS

Reactive Occupational Health and Safety Model

When organizations use a REACTIVE approach to health and safety management, they respond to incidents as soon as they occur and take action to prevent similar incidents from occurring in the future. In this process, standard procedures are applied that promote a reactive approach to incident management, including:

- Incident reporting.
- Incident investigations.
- Health and safety training after an incident occurs;
- Correction of the Risk Assessment Act.

The reactive model of occupational health and safety process management is referred to in professional circles as “nuclear”. This term derives from the fact of “waiting for a reaction”, in fact, process owners do not take any action regarding safety until an incident or injury occurs in order to move towards prevention. Being reactive means hoping for a positive outcome that will avoid fatal or catastrophic consequences. The positive message of the reactive approach is learning from mistakes, which are sometimes very expensive and irreparable.

Effective safety management requires the ability to learn from the past and anticipate the future. Yet what we can learn from the past (accident investigation) and what we can envision for the future (risk assessment) critically depend on how we think about it, i.e. on the models and methods at our disposal. Accident investigations have long been dominated by the search for causes, whether root causes or human error. Risk assessment has similarly been dominated by static representations such as event and fault trees. In both cases, the commonly used models and methods have reached their limits as the reality of our self-created socio-technical environments has become too complex. The alternative is to understand how the variability of human actions is a resource, not a threat, and to define safety as the resilience of a system, its ability to adapt and adapt, rather than as the absence of adverse outcomes.

Events that we are not prepared for will inevitably occur, some with positive outcomes and some with negative outcomes. Although there are very few situations in which things go wrong compared to the many situations in which things work well, and the outcomes are as expected – or at least acceptable under the circumstances – positive cases tend to go unnoticed. When the outcome of a task or activity is acceptable, there is little motivation to ask why it happened; it is simply taken for granted – and even considered normal – that things are going well.

Conversely, when something goes wrong, a relentless reactive search for the causes begins, to ensure that such an event never happens again. Unless we are prepared to treat accidents with optimism, we must, of course, find a way to reduce uncertainty, especially about things that can go wrong. One way to do this is to create processes, systems and organizations so that hazards are eliminated or to ensure that the probability of adverse events is reduced to an acceptable level. A hazard is defined as an event that may result in a known loss. In order to achieve this, it is necessary that the system is monitored and that the processes develop in a predictable manner. However, since an increasing number of socio-technical systems are functionally connected, in practice it is impossible to achieve an acceptable level of security only with precautionary measures, i.e. by eliminating hazards, preventing unexpected events or protecting against unwanted outcomes. Security by design (analytical security) must therefore be complemented by management security (operational security). As resilience engineering makes clear, security is something a system does, not something a system has [3].

Proactive model of safety and health at work

Being proactive means showing courage and self-initiative in solving problems before they appear. When organizations take a proactive approach to health and safety management, they aim to reduce the number of incidents by identifying and addressing workplace hazards before they occur. Unlike reactive management, proactive safety management is a continuous process. A proactive approach to health and safety is basically about taking action to spot hazards and implementing preventative measures to prevent accidents. Organizations with a proactive approach do not wait for an incident to occur before making changes; they are continuously looking for ways to improve health and safety in every workplace.

Standard OHS procedures that use a proactive approach to incident prevention include:

- Pre-incident investigations
- Predictive training and analytics review
- Proactive audits and inspections
- Risk assessments
- Safety training
- Procedure reviews
- Spotting danger

Real-time communication, Big Data, human-machine collaboration, remote sensing, process monitoring and control, autonomous equipment, and interconnection are becoming major assets in modern industry. Technological reality requires abandoning the traditional attitude towards safety and health at work and imposes procedures based on generally recognized rules (standards) and good practice. As the fourth industrial revolution or Industry 4.0 becomes a dominant reality, it will bring new paradigm shifts, which will have an impact on occupational health and safety (OHS) management. In this sense, the SRPS ISO 45001 standard specifies requirements for an occupational health and safety (OH&S) management system.

Standardization of management procedures helps the organization achieve the desired results of its OH&S (Occupational Health and Safety System) management system. According to the organization's OH&S policy, the desired results of the OH&S management system include:

- continuous improvement of OH&S performance.
- fulfilling legal and other requirements.
- achievement of OH&S objectives.

It provides a framework for organizations to manage risks and improve OH&S performance. The standard establishes the criteria for the construction of an occupational safety policy, goals, planning, implementation, work, audit and review. Key elements include management commitment, worker participation, hazard identification and risk assessment, legal and regulatory compliance, emergency planning, incident investigation and continuous improvement. The standard requires compliance with occupational health and safety regulations, ensuring legal compliance and promoting proactive risk management, potentially reducing insurance premiums, improving worker reputation, morale and employer trust, improving long-term worker health and safety performance.

The management standard ISO 45001 can significantly improve the image of occupational safety and improve the environment in favor of the health of employees, if the key management levers are adapted to move from the form of "voluntary" to the form of "mandatory". This approach can easily also be criticized, but as a transitional phase of raising awareness of the importance of the risk management process, it would have a significant contribution to the development of the Occupational Safety and Health system. 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[4]:

- 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

CONCLUSION

Management in the system of safety and health at work in order to eliminate dangers or harms that contribute to damage to the health of the employee, based on legal regulations, did not 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 draw up a risk assessment act formally represents a strategic decision that can be understood as a position that he will manage the risks arising from the legal frameworks that legally regulate Occupational Safety and Health in an organized manner. The implementation of that decision and the improvement of the processes that lead to the risk to an acceptable level also include the procedure of auditing the risk management process. However, formal risk assessment processes can lead to significant losses in the organization or to unnecessary costs for the implementation of security measures, without their effect being justified by anything. The omission of any procedure documenting the control over the process, risk assessment and the act on risk assessment itself as a document has no significance in the validation of the resulting disorders of the employee's health condition.

In support of this statement, there are many other reasons for implementing an effective OH&S system to create a framework for increasing safety, reducing risks in the workplace and improving health and well-being at work, enabling the organization to proactively improve its OH&S performance.

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