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## Contents

**FACTA UNIVERSITATIS**
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**Original scientific paper**

# EVALUATION OF A LOW-COST-SENSOR-BASED PARTICULATE MATTER MONITOR: A COMPARATIVE STUDY

*UDC 502.3:504.3.054*

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**Abstract**. *Indoor air quality (IAQ) significantly affects health, productivity, and comfort, particularly in urban environments, where individuals spend over 90% of their time indoors. Indoor air is often more polluted than outdoor air due to various indoor pollution sources. Effective IAQ monitoring is essential but often constrained by the high cost and complexity of traditional gravimetric methods and high-end automatic monitors. Emerging low-cost sensors offer an affordable and scalable alternative.*
*This study examines the performance of the PM V1.0 device, equipped with a low-cost NOVA SDS011 particulate matter sensor ($PM_{10}$ and $PM_{2.5}$ fractions). The PM V1.0 was compared against two commercially available monitors: the high-precision Microdust PRO CEL-712 and the budget-friendly Dylos DC1100 PRO. Measurements conducted over 10 days through co-location of the monitors showed strong correlations between the PM V1.0 and the comparison devices, with coefficients of determination ($R^2$) values exceeding 0.93 for both PM fractions.*
*These findings validate the PM V1.0 as a reliable, cost-effective alternative for IAQ monitoring. The research highlights the potential of low-cost sensors to improve IAQ monitoring by providing affordable solutions.*

**Key words**: *Indoor Air Quality Monitoring, Particulate Matter ($PM_{10}$, $PM_{2.5}$), Low-Cost Sensors, NOVA SDS011, Microdust PRO CEL-712, Dylos DC1100 PRO*

## 1. Introduction

Urban residents spend more than 90% of their time indoors, making indoor air quality (IAQ) a critical factor for their comfort, productivity, and health [1]. The relationship between IAQ and overall quality of life is complex and can have both short-term and long-term effects. These effects may range from mild discomfort and reduced focus to

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respiratory tract irritation, headaches, and more severe conditions, such as respiratory infections and chronic diseases [2].

Indoor air quality is often worse than outdoor air quality, despite the influence of outdoor air on indoor environments. This is because indoor spaces frequently have additional sources of pollution directly linked to activities of the occupants. Given the limited natural purification mechanisms in enclosed spaces, the concentration of pollutants in such environments can be significantly higher, further complicating the issue of pollution [3].

In Serbia, air quality monitoring is primarily focused on outdoor environments and industrial workplaces, in accordance with existing regulations. Unlike industrial workplaces, there are no specific guidelines for monitoring IAQ in non-industrial buildings, such as residential buildings, public facilities, and administrative offices.

Particulate matter (PM), including $PM_{10}$, $PM_{2.5}$, and $PM_{0.1}$, is used worldwide as a key indicator of air quality due to its association with serious health issues, such as respiratory and cardiovascular diseases [4, 5].

Traditional methods for measuring PM concentrations, such as gravimetric methods, are considered the gold standard but are time-consuming and expensive, with results typically available days after sampling. In contrast, automatic stationary monitors enable real-time monitoring of PM concentrations but are too expensive to purchase and maintain, with prices reaching up to €20,000 [6].

Consequently, PM monitoring, which often involves filter collection and gravimetric analysis or the use of relatively expensive equipment, ultimately limits the spatial and temporal resolution of PM data [7, 8]. To address this, commercially available portable devices are increasingly used as an alternative to automatic stationary monitors. These devices mainly operate on an optical principle, counting particles and converting the count into mass concentrations. Portable PM monitors are significantly smaller than stationary ones, and their prices range from several hundred to several thousand euros, making them more accessible. Devices such as the Microdust PRO CEL-712 by Casella offer similar capabilities for no more than €6,000, while more affordable options (devices), such as the Dylos DC1100 PRO, are available for around €300. However, both types of devices require calibration and adaptation to specific conditions, and their accuracy can be further affected by relative humidity.

Recent technological advancements have led to the development of affordable low-cost sensors, such as the NOVA SDS011, which utilise the principle of laser scattering to detect particulate matter [9]. These sensors allow for high spatial and temporal resolution PM concentration measurements and are often priced below €100. Their small size, low power consumption, and ease of maintenance make them ideal for indoor air monitoring. However, the operation and key characteristics of these sensors have not been thoroughly examined, leaving room for further improvement in this field.

As part of this study, a new device, PM V1.0, was developed based on the NOVA SDS011 sensor to provide a cost-effective solution for monitoring $PM_{10}$ and $PM_{2.5}$ concentrations in indoor environments. Its measurement results were compared with those obtained from commercial devices in different price ranges, such as the Microdust PRO and the Dylos DC1100 PRO. The comparison involved regression and correlation analyses, with the coefficient of determination ($R^2$) used to assess the consistency of results. The aim of the study was to confirm the potential of low-cost sensors for broader application in proactive indoor air quality monitoring systems.

## 2. METHODOLOGY

The study was conducted in the Air Quality Management Laboratory at the Faculty of Occupational Safety, University of Niš (FOS). The experiment involved the co-location of three different PM concentration monitors: the tested PM V1.0 device, based on an Arduino platform with a NOVA SDS011 PM sensor, and two commercially available monitors in various price ranges – the Microdust PRO CEL-712 and the Dylos DC1100 PRO. All three devices are shown in Figure 1.

### 2.1. Description of measuring devices

- **Microdust PRO CEL-712**

The Microdust PRO CEL-712 is a real-time particle concentration monitoring device that utilises the proven forward light scattering principle, providing precise and reliable dust concentration measurements ranging from 0.001 mg/m³ to 250 g/m³ [10]. It was combined with a TUFF sampling pump, which provided a constant flow rate, and additional adapters for inserting polyurethane foam (PUF) filters. An AC/DC adapter powered the device, and a technical modification to the pump's battery charger allowed continuous operation beyond the factory limitation, which enabled continuous and uninterrupted monitoring. Additional adapters and PUF filters ($PM_{10}$ and $PM_{2.5}$ measurements can be made using a PUF size-selective inlet system) facilitated the measurement of $PM_{10}$ and $PM_{2.5}$ concentrations. The collected data were then uploaded to a computer using the Casella Insight Data Management software.

The Microdust PRO monitor was selected as the reference device for measuring $PM_{10}$ and $PM_{2.5}$ particle concentrations due to its calibration capabilities, which make it a reliable reference device for comparing results obtained from the low-cost NOVA SDS011 sensor and the Dylos DC1100 PRO. This device allows pre-measurement linearity adjustments, including ZERO calibration, which ensures a precise setup. It features a unique optical calibration insert, which establishes known instrument sensitivity or SPAN, providing highly accurate and reliable measurements. When inserted into the probe, the calibration insert creates a stable and fixed scattering effect. Similar to factory calibration (using Arizona Road Dust equivalent – ISO 12103-1 A2 (fine) test dust), the insert generates a light-scattering effect equivalent to the factory concentration level. This fixed reference value, indicated on the calibration insert's label, should be entered into the device to confirm the original factory calibration point.

- **Dylos DC1100 PRO**

The Dylos DC1100 PRO (with PC interface) is a low-cost laser particle counter designed to measure particle concentrations in indoor air. It features two particle size channels and measures (counts) and records in real time the numerical concentration of particles with diameters greater than 0.5 μm and 2.5 μm [11]. Continuous operation was achieved using a power adapter, and the device was connected to a personal computer via an RS-232 connector. The accompanying Data Logger software allowed for data acquisition. The particle number concentration (PNC) of $PM_{10}$ and $PM_{2.5}$ was subsequently converted to particle mass concentration (PMC) based on particle size, density, and count (number of particles) using the equation developed by Arling et al. [12].

- **PM V1.0 Device**

The developed PM V1.0 device, based on the Arduino platform and the NOVA SDS011 sensor module [13], is primarily designed for measuring $PM_{10}$ and $PM_{2.5}$ concentrations within a range of 0-999.9 µg/m³, as well as ambient air temperature (-10 to +50 °C) and relative humidity (20–90% RH) by using the DHT22 sensor module [14]. Additional parameters (e.g. $CO_2$, VOCs, pressure) can be measured by integrating supplementary sensor modules into the device. Unlike most commercially available PM monitors, this device can be powered directly via an AC/DC adapter and it can operate independently for several days owing to an internal high-capacity battery. It allows adjustable measurement averaging intervals ranging from 5 seconds to 1 hour. Pre-determined correction factors can be set for specific environmental conditions, ensuring accurate real-time PM concentration readings displayed on the device. Lightweight, portable, and quiet, the PM V1.0 is well-suited for personal PM exposure monitoring in indoor environments.


**Fig. 1** (a) Casella Microdust Pro CEL-712, (b) Dylos DC1100 PRO (with PC interface), (c) PM V1.0 (with NOVA SDS011 sensor module) [10,11]

### 2.2. Co-location of the devices

All devices were placed on the same table, 10 cm apart (Figure 2), and exposed to identical air pollution conditions for a total duration of 10 days. Over the first five days, $PM_{2.5}$ concentrations were measured, followed by $PM_{10}$ concentrations over the subsequent 5 days, as the Microdust PRO CEL-712 can only measure one fraction at a time depending on the installed filter. Average 15-minute PM concentration values recorded by the devices were compared.

To assess the agreement between the measurements recorded by the low-cost device and the other two devices, the coefficient of determination ($R^2$) was calculated. The coefficient of determination is a useful metric for assessing the accuracy and reliability of low-cost devices, indicating whether the tested device replicates the measurements of the reference device and whether it can replace it in practice. A higher $R^2$ value indicates a stronger agreement between the two sets of results.

**Fig. 2** Co-location of PM measuring devices in the FOS laboratory

In the context of simple linear regression, the coefficient of determination ($R^2$) is equal to the square of Pearson's correlation coefficient between the dependent variable ($y$) and the independent variable ($x$). It is calculated using the following equation:

$$R^2 = \left( \frac{\sum (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \cdot \sum (y_i - \bar{y})^2}} \right), \tag{1}$$

where:

- $x_i$ is the measurement value obtained by the reference device;
- $y_i$ is the measurement value obtained by the tested device;
- $\bar{x}$ is the mean value of the reference device data;
- $\bar{y}$ is the mean value of the tested device data.

This calculation quantifies the degree of alignment between the results obtained by all three devices, providing a basis for determining the potential of the PM V1.0 device as a low-cost alternative for indoor air quality monitoring.

## 3. Results and Discussion

The results of this study reveal valuable insights into the performance and reliability of the tested PM V1.0 device compared to the commercially available Microdust PRO and Dylos DC1100 PRO monitors. The following sections provide a detailed comparison of the measurement results, emphasizing the correlation between the devices and discussing the implications of these findings for air quality monitoring.

The decision to use 15-minute mean values, despite all devices being capable of measuring 1-minute concentrations, was made for three important reasons. Firstly, averaging over 15 minutes helps facilitate the identification of meaningful trends and patterns that might be obscured by short-term fluctuations. Furthermore, using 15-minute means ensures consistency across the measurements from all devices, providing a fair comparison and reducing the influence of any transient anomalies. Lastly, handling 15-minute averages makes data management more efficient, simplifying the analysis process.

Figures 3 and 4 present the average 15-minute $PM_{10}$ and $PM_{2.5}$ concentrations recorded in the FOS laboratory. These line charts illustrate the consistency and variability in the measurements across the different devices over the test period.

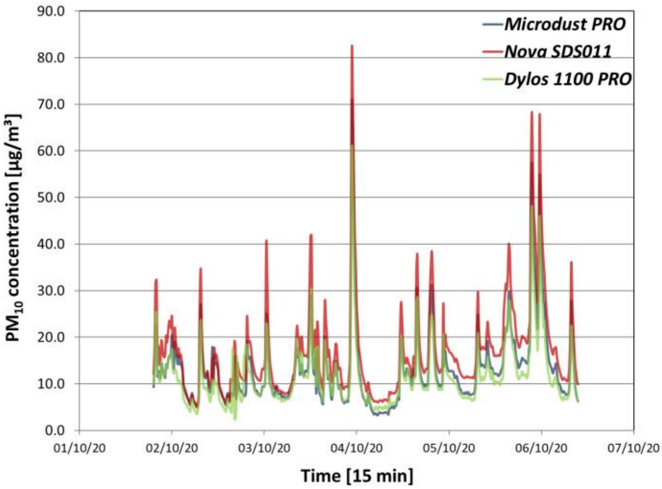


**Fig. 3** $PM_{10}$ concentration measurements in the FOS laboratory

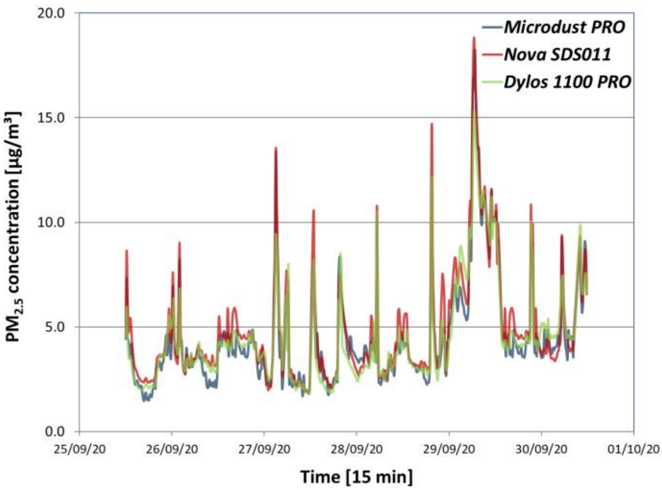


**Fig. 4** $PM_{2.5}$ concentration measurements in the FOS laboratory

Figures 5, 6, and 7 show scatter plots comparing $PM_{10}$ concentrations across all devices.

The coefficient of determination ($R^2 = 0.9757$) indicates a very strong linear dependence between $PM_{10}$ concentration measurements obtained using the Microdust PRO device and the NOVA SDS011 sensor.

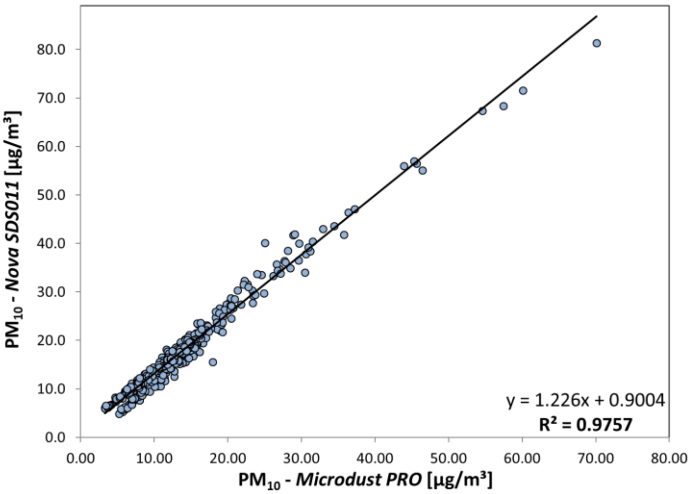


**Fig. 5** $PM_{10}$ concentrations – Microdust PRO vs. NOVA SDS011

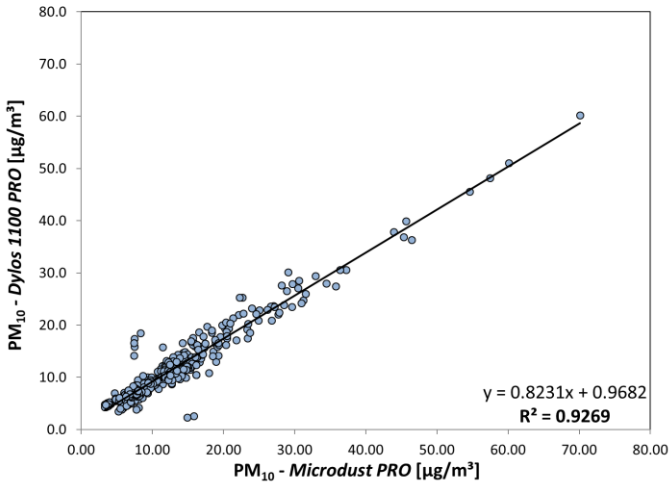


**Fig. 6** $PM_{10}$ concentrations – Microdust PRO vs. Dylos DC1100 PRO

The coefficient of determination ($R^2$ = 0.9269) also suggests a very strong linear dependence between $PM_{10}$ concentration measurements obtained using the Microdust PRO and Dylos DC1100 PRO devices.

The coefficient of determination ($R^2$ = 0.945) demonstrates that there is a very strong correlation between the $PM_{10}$ concentration measurements obtained using the low-cost NOVA SDS011 sensor and the Dylos DC1100 PRO device, which is also in the low-cost range.

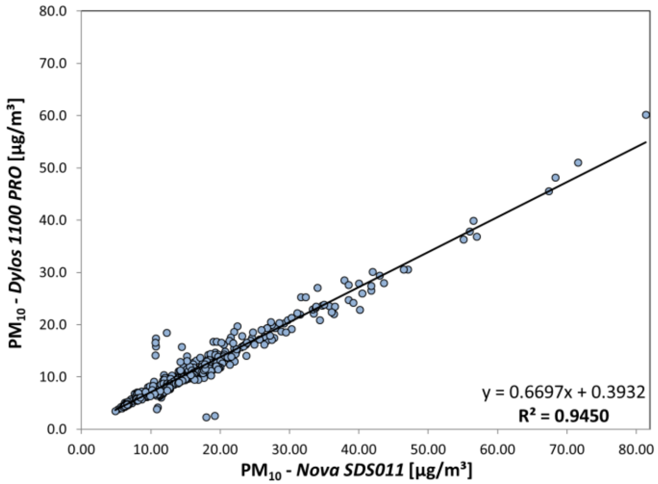


**Fig. 7** $PM_{10}$ concentrations – NOVA SDS011 vs. Dylos DC1100 PRO

Figures 8, 9, and 10 show scatter plots comparing $PM_{2.5}$ concentrations across all devices.

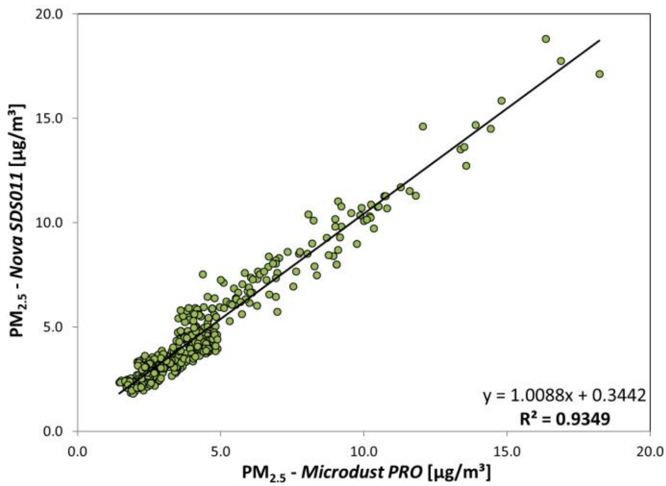


**Fig. 8** $PM_{2.5}$ concentrations – Microdust PRO vs. NOVA SDS011

The coefficient of determination ($R^2$ = 0.9349) indicates a very strong linear dependence between $PM_{2.5}$ concentration measurements obtained using the Microdust PRO device and the NOVA SDS011 sensor.

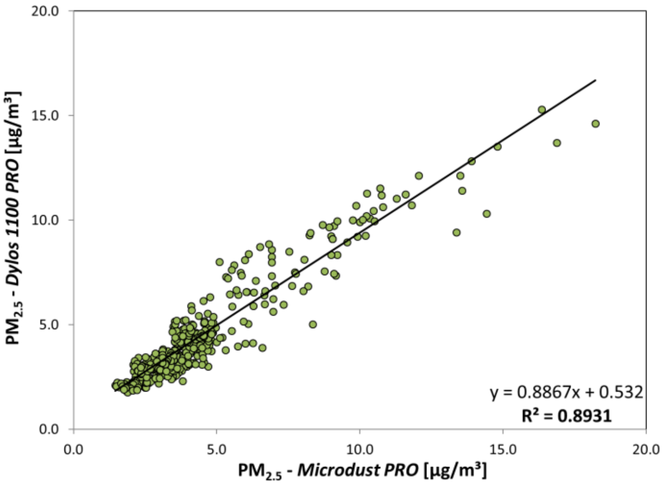


**Fig. 9** $PM_{2.5}$ concentrations – Microdust PRO vs. Dylos DC1100 PRO

The coefficient of determination ($R^2$ = 0.8931) shows a very strong linear dependence between $PM_{2.5}$ concentration measurements obtained using the Microdust PRO and Dylos DC1100 PRO devices, slightly weaker than the dependence observed for $PM_{10}$ concentrations.

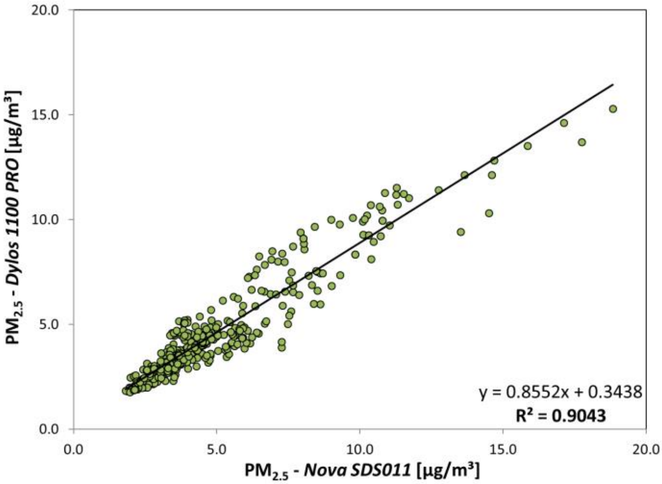


**Fig. 10** $PM_{2.5}$ concentrations – NOVA SDS011 vs. Dylos DC1100 PRO

The coefficient of determination ($R^2$ = 0.9043) reflects a very strong correlation between the $PM_{2.5}$ concentration measurements obtained using the low-cost NOVA SDS011 sensor and the Dylos DC1100 PRO device, albeit slightly weaker than the correlation observed for $PM_{10}$.

The comparison of $PM_{10}$ and $PM_{2.5}$ measurements between the commercially available Microdust PRO, which falls into a high price range, the more affordable, commercially available Dylos DC1100 PRO, and the NOVA SDS011-based PM V1.0 monitor revealed strong linear correlations, with $R^2$ values ranging from 0.8931 to 0.9757. The NOVA SDS011 sensor, in particular, showed excellent agreement with the Microdust PRO, especially for $PM_{10}$ concentrations, where the $R^2$ value was 0.9757. While the Dylos DC1100 PRO exhibited slightly weaker correlations, it still demonstrated reliable performance across both PM fractions, reflecting its consistent performance within its lower price range. Overall, while $PM_{10}$ measurements showed stronger correlations, the results confirm that the developed PM V1.0 monitor can be used as a reliable alternative for monitoring particulate matter, especially in budget-constrained applications. These findings validate the potential of low-cost sensors for air quality monitoring, highlighting their effectiveness, notably in indoor environments and cost-sensitive applications.

## 4. Conclusion

The results of this study demonstrate that low-cost sensors, such as the NOVA SDS011, can provide reliable measurements of particulate matter (PM) concentrations when compared to more expensive instruments. With high coefficients of determination indicating strong correlations, these sensors can be effectively used for monitoring indoor air quality (IAQ), which is crucial for the health and well-being of people who spend over 90% of their time indoors.

The study involved the co-location of low-cost and commercially available monitors, showing strong linear correlations between their measurements. The NOVA SDS011 sensor-based PM V1.0 device, in particular, demonstrated its ability to deliver accurate and consistent PM data at a fraction of the cost of traditional monitoring equipment. Therefore, it is a practical solution for applications where budget constraints limit the use of high-cost devices.

Despite their promising performance, low-cost PM sensors such as the NOVA SDS011 require thorough calibration and validation under various environmental conditions to ensure accuracy. Factors such as humidity, temperature, and the presence of other pollutants can affect sensor performance, and these variables need to be accounted for in future studies.

Moreover, the integration of these sensors into a wider air quality monitoring network could enhance the spatial and temporal resolution of air quality data. This could lead to better-informed public health policies and interventions aimed at reducing exposure to harmful particulate matter.

Ongoing research and development is essential to optimise their performance and expand their application in both indoor and outdoor air quality monitoring. Incorporating additional sensors for parameters such as $CO_2$, VOCs, and pressure could make devices like the PM V1.0 more versatile and comprehensive. In conclusion, low-cost sensors offer significant advantages in terms of affordability and ease of use, and with continued advancement, they could play a critical role in improving public health by providing detailed and accessible air quality data.

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# EVALUACIJA MONITORA KONCENTRACIJA SUSPENDOVANIH ČESTICA ZASNOVANOG NA NISKOBUDŽETNOM SENZORU: KOMPARATIVNA STUDIJA


*Kvalitet unutrašnjeg vazduha značajno utiče na zdravlje, produktivnost i udobnost, naročito u urbanim sredinama gde pojedinci provode više od 90% svog vremena u zatvorenom prostoru. Unutrašnji vazduh je često zagađeniji od spoljašnjeg zbog različitih izvora zagađenja u zatvorenim prostorima. Efikasno praćenje kvaliteta unutrašnjeg vazduha je od ključnog značaja, ali je često ograničeno visokim troškovima i složenošću tradicionalnih gravimetrijskih metoda i automatskih monitora visoke klase. Novi niskobudžetni senzori nude pristupačnu i skalabilnu alternativu.*

*U ovoj studiji ispitane su performanse uređaja PM V1.0, opremljenog niskobudžetnim NOVA SDS011 senzorom za merenje koncentracija suspendovanih čestica (frakcije $PM_{10}$ i $PM_{2.5}$). PM V1.0 je upoređen sa dva komercijalno dostupna monitora: visokopreciznim Microdust PRO CEL-712 i cenovno pristupačnijim Dylos DC1100 PRO. Merenja u trajanju od 10 dana, vršena kolokacijom sva 3 monitora, pokazala su jake korelacije između PM V1.0 i uporednih uređaja, sa vrednostima koeficijenata determinacije ($R^2$) većim od 0,93 za obe frakcije PM.*

*Rezultati su potvrdili da je PM V1.0 pouzdana i isplativa alternativa za praćenje kvaliteta unutrašnjeg vazduha. Istraživanje ističe potencijal niskobudžetnih senzora za unapređenje praćenja kvaliteta unutrašnjeg vazduha pružanjem cenovno pristupačnih rešenja.*



Ključne reči: *monitoring kvaliteta unutrašnjeg vazduha, suspendovane čestice ($PM_{10}$, $PM_{2,5}$), niskobudžetni senzori, NOVA SDS011, Microdust PRO CEL-712, Dylos DC1100 PRO*

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**Review Paper**

# MACHINE LEARNING IN ENVIRONMENTAL MONITORING

*UDC 004.8:504.06*

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**Abstract**. *Rapid advances in artificial intelligence and machine learning techniques, the availability of large-scale data and the increased computational capabilities of machines open the door to the development of sophisticated methods in environmental monitoring and management systems. Machine learning is becoming a powerful tool that is changing the way environmental data is collected, analyzed and interpreted. By going beyond conventional methods, it enables systems to learn from data, identify patterns and draw conclusions with minimal human intervention. Machine learning algorithms can process vast amounts of complex data from diverse sources to provide insight into environmental changes, predict future trends and support decision-making. Using machine learning in the fight for a better and healthier ecosystem has a number of potential long-term benefits. This paper will outline how machine learning can be put to use in environmental monitoring.*

**Key words**: *machine learning, environmental monitoring*

## 1. INTRODUCTION

The role of artificial intelligence in environmental monitoring systems has grown exponentially in recent years, fueled by the increasing availability of large amounts of data, advances in computing, and the urgent need to address global environmental challenges. Environmental monitoring involves systematic data collection, analysis and interpretation to assess the state of natural resources and ecosystems. Also, environmental management focuses on using this information to make decisions and take actions to mitigate environmental risks. Because they can analyze vast amounts of data and identify complicated patterns that may not be clearly discernible using existing methods, machine learning techniques can be particularly successful for environmental monitoring and management.

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Traditional environmental monitoring systems are characterized by disadvantages such as limited coverage, expensive infrastructure, high energy consumption, limited scalability, as well as limited real-time data. In recent years, machine learning has emerged as a game-changing technology in the field of environmental monitoring. It represents enormous potential in environmental monitoring and management, allowing us to gain accurate insight, increase efficiency and detect environmental problems early. The application of machine learning in environmental monitoring can significantly improve our understanding and conservation of natural resources, as well as more effective response to environmental challenges.

Machine learning is suitable for implementation in situations where a large amount of data is available that in some way illustrates solutions to individual parts of the problem. With incredible speed, machine learning algorithms can detect anomalies or deviations in data that signal unusual events or potential hazards in the environment.

This sophisticated branch of artificial intelligence has contributed to revolutionary changes in environmental monitoring and management, empowering scientists, politicians and activists to gain deeper insight, make more accurate predictions and implement more effective strategies.

## 2. Basic of Artificial Neural Networks and Machine Learning

Artificial intelligence represents the development of software that includes the intelligent behavior of computers: acquisition, memory and processing of certain knowledge. It is based on computer science, information technology, mathematics, statistics, psychology, linguistics and many other fields. Artificial intelligence implies a way of reasoning and acting on derived conclusions, with complete reliance on logic, whereby analysis and reasoning are carried out by software applications that do not have to be physically visible. They are often not located in one place, but are active at a large number of virtual addresses and can perform tasks at the same time at billions of different spatial points.

Machine learning is a specific and very narrow branch of artificial intelligence that is the process of discovering patterns in massive data sets, and then making predictions based on decisions made from those patterns. It is based on the idea that systems can learn from the data, identify patterns and draw conclusions independently, without explicit participation i.e. human programming. This approach gives computers the power to learn from experience, which has so far resulted in the surprising performance of computer systems, surpassing the success of human experts in some fields.

Machine learning methods are tasked with identifying relevant regularities in the provided data and defining a mathematical model based on them. Such a mathematical model is applied in situations that were not described within the basic, available database. A good mathematical model that is useful for making inferences in solving future problem instances is the main goal of machine learning. Although errors are always to be expected in solutions based on machine learning, this approach in many fields produces great results that far surpass other approaches.

Although the machine learning method itself can be created by combining several techniques, there is a basic division of machine learning types:

- Supervised learning: a type of machine learning where a model is trained on labeled data, meaning that the correct output (also known as a label) is provided for each example in the training data. The goal of supervised learning is to build a model that can make predictions or take actions based on new, unseen input data, generalizing from the patterns it has learned in the training data. If the model performs well on test data, then it can be used to make predictions or take action on new data in the future. For example, a supervised learning algorithm could be trained on a dataset of species identification, land use classification and pollution level prediction.
- Unsupervised learning: involves training a model on unlabeled data and learning to identify patterns and relationships in the data on its own, without any guidance from a human supervisor. This type of learning is useful for tasks such as clustering and dimensionality reduction, where the goal is to discover the underlying structure in the data without providing explicit labels for different classes or groups. For example, an unsupervised learning algorithm could be used to identify ecosystem types from remote sensing data, as well as to cluster climate zones.
- Semi-supervised learning: is a combination of supervised and unsupervised learning, where the model is trained on a dataset that includes both labeled and unlabeled data. It can be useful when a large amount of unlabeled data is available, but only a small amount of labeled data.

### 2.1. Types of machine learning algorithms

Machine learning algorithms are great for analyzing large amounts of environmental data, such as air quality measurements, water quality readings, and satellite imagery. By processing this data, machine learning models can uncover hidden patterns, correlations and trends, providing a comprehensive understanding of environmental dynamics.

There are many different machine learning algorithms, which, among other things, continue to be developed and improved to minimize the value of the error. The choice of the specific algorithm to be used for a particular set of data primarily depends on the type of machine learning being performed, as well as the nature of the data and the goals of the model.

Using supervised machine learning regression algorithms on a dataset that includes the height and weight of a group of wild animals, a model could be trained to predict an individual's weight based on their height. During training, the model would use input features (heights) and target values (weights) to learn the relationship between them. Once the model is trained, it can be used to predict new data by providing the model with input features (height) and the model predicts the corresponding target value (weight). Some of the more important types of regression methods in machine learning are linear regression, K nearest neighbors (kNN), decision trees, random forests, and neural network.

Supervised machine learning classification algorithms are used to categorize data into one of several predefined classes. Suppose that in a certain set, there is data that includes the height and weight of a group of individuals, along with their gender (male or female). Using supervised learning classification, a model could be trained to predict an individual's gender based on their height and weight. Such a model can show great efficiency in capturing and classifying wild animals caught on camera. It has also been successfully used to classify land cover types from satellite images, helping to track deforestation and urban expansion. There are several types of classification methods in machine learning, such as logistic regression, naive Bayes classifier, K nearest neighbors (kNN), support vector machine (SVM), decision tree, random forest, and neural networks.

The goal of unsupervised learning algorithms is to find the underlying structure of a data set, group that data according to similarities, and present that data set in an appropriate format. Suppose an unsupervised learning algorithm is given an input dataset containing images of different types of cats and dogs. The algorithm is never trained on a given set of data, which means it does not know its characteristics, but instead independently identifies common features in the data and reacts based on the presence or absence of such common features in each new piece of data. This approach helps detect anomalous data points that do not fit into any group. Thus, it shows great efficiency in the detection and classification of species in the animal and plant world, as well as in the detection of anomalies in environmental time series data. Some common unsupervised machine learning models are:

- Clustering algorithms that group similar data points together based on their proximity in feature space: K-means clustering, hierarchical clustering, Density-based spatial clustering of applications with noise (DBSCAN).
- Dimensionality reduction algorithms that reduce the dimensionality of data by projecting it onto a lower dimensional space while preserving the most important information: Principal Component Analysis (PSA), t-Distributed Stochastic Neighbor Embedding (t-SNE)
- Generative models used to generate new data similar to training data, such as Autoencoder and Generative adversarial networks (GAN).

## 3. Application of Machine Learning in Environmental Monitoring

Environmental monitoring refers to the strategy of monitoring and assessing the state of both natural and built environments. Its purpose is to collect, identify and quantify information that can be used to spot patterns and hazards, but also to assess the effectiveness of environmental protection policies and check the impact of human activity on the environment. Machine learning has ushered in a new era in environmental monitoring and management, improving our ability to understand complex ecosystems and develop sustainable practices. The applications of machine learning in environmental monitoring are diverse and constantly expanding.

- Air Quality Monitoring: Machine learning algorithms by analyzing measurement data, above all, can help expand the air pollution monitoring network around the world, predict pollution levels, identify pollution sources and monitor changes over time. They offer the possibility of pairing data from various modern sources that are becoming more and more available and cheaper. Air quality sensors, satellite imagery and meteorological data provide information that can be comprehensively analyzed by machine learning algorithms to predict air quality conditions, as well as identify the main contributors to air pollution in different locations. Pattern prediction, offered by machine learning, enables authorities to take proactive measures to mitigate pollution and protect public health.
- Water Quality Monitoring: Using algorithms to analyze data from water systems, water quality can be monitored, including levels of toxic substances or changes in chemical composition. These insights enable timely action to be taken to prevent contamination, ensure safe drinking water and protect aquatic ecosystems. In water

resource management, machine learning offers help in limiting costs and minimizing environmental impact while reducing or eliminating waste. Excessive water use can be reduced with the help of localized weather forecasts driven by artificial intelligence.

- Soil Quality Monitoring: The application of machine learning in this area is promising and can contribute to a more sustainable management of natural resources. Data collection, data analysis, soil quality prediction, problem identification as well as optimization of agricultural practices are just some of the items that machine learning algorithms can improve. Using sensors, drones and satellites to collect data on the physical, chemical and biological properties of the soil, machine learning algorithms integrate the data and process it to identify patterns and trends in soil quality. Automated analysis can detect problem areas, such as pollution or land degradation, enabling rapid response. By generating maps of soil quality, machine learning makes it possible to predict soil erosion and identify optimal conditions for crop growth.
- Biodiversity Conservation: In biodiversity monitoring, machine learning is transforming the way we monitor and understand ecosystems. Automatic identification and classification of species based on photographs and acoustic recordings is one of the most interesting applications in this field. By predicting threatened species based on trends in their populations and changes in the environment, as well as early identification of invasive species, machine learning contributes to biodiversity conservation. Species monitoring, optimization of conservation measures, training and education are just some of the techniques that can be improved by analyzing complex ecosystem data, including climate data, soil properties and human activities, provided by machine learning algorithms.
- Prediction of Natural Disasters: Using data from the past, machine learning can help predict extreme natural events such as hurricanes, floods, wildfires or droughts. By monitoring and analyzing parameters such as temperature, precipitation, sea level, and concentration of greenhouse gases, this branch of artificial intelligence offers great help for effective planning, response, prevention of natural disasters, as well as assistance for recovery in emergency situations.

In addition to environmental monitoring, machine learning can be applied to climate modeling and prediction, energy efficiency and resource management, natural disaster management, waste and recycling management, ecosystem restoration and biodiversity conservation. Using the power of machine learning algorithms and data analysis, we can gain valuable insights, make informed decisions and take proactive measures to protect our environment and ensure a sustainable future.

## 4. Conclusion

The application of applications based on machine learning algorithms is represented in a wide range of numerous fields. Its influence only continues to grow within all spheres of life. Also, it achieves results that greatly exceed previous achievements and predictions. Together with the Internet, machine learning is changing the way we experience the world and has the potential to be a new driver in solving global environmental challenges.

Environmental monitoring is becoming an increasingly important issue today when considering climate and land cover changes and their environmental consequences. Conventional monitoring methods often struggle to keep up with the scale and complexity of environmental change occurring on a global scale. All this has led to a significant evolution of the technology behind environmental monitoring in the last few decades. Modern technical innovations provide data with advanced spatial and temporal detail that increase the potential for automatic detection of patterns and trends. In such situations, machine learning algorithms have proven to be a powerful method for relating remote sensing information to relevant environmental variables taking into account the complexity and nonlinearity found in nature.

Machine learning offers the potential to improve accuracy, efficiency and speed, as well as cost savings. It can detect subtle changes in an ecosystem, predict environmental risks, and even suggest mitigation strategies. All this at a scale and speed that would be impossible for human analysts. Overall, machine learning has the power to completely transform environmental management by providing data-driven insights and predictive capabilities for well-informed decision-making and proactive environmental conservation. The combination of mobile survey data and machine learning methods offers great, but still not fully exploited opportunities for monitoring environmental components in different disciplines.

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# MAŠINSKO UČENJE U MONITORINGU ŽIVOTNE SREDINE

*Brzi napredak u tehnikama veštačke inteligencije i mašinskog učenja, dostupnost podataka velikih razmera i povećane računarske mogućnosti mašina otvaraju vrata za razvoj sofisticiranih metoda u sistemu za praćenje i upravljanje životnom sredinom. Mašinsko učenje postaje moćno sredstvo koje menja način prikupljanja, analiziranja i tumačenja podataka o životnoj sredini. Prevazilazeći konvencionalne metode, omogućava sistemima da uče iz podataka, identifikuju obrasce i donose zaključke uz minimalnu ljudsku intervenciju. Algoritmi mašinskog učenja mogu da obrađuju ogromne količine složenih podataka iz različitih izvora da bi pružili uvid u promene životne sredine, predvideli buduće trendove i podržali donošenje odluka. Upotreba mašinskog učenja u borbi za boljim i zdravijim ekosistemom ima niz mogućih dugoročnih prednosti. U ovom radu biće izloženo kako se mašinsko učenje može staviti u korist nadzoru životne sredine.*

Ključne reči: *mašinsko učenje, monitoring životne sredine*

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**Original scientific paper**

# ESTIMATION OF THE PENETRATED ELECTRIC FIELD INSIDE A HUMAN HEAD DUE TO EXPOSURE TO ELECTROMAGNETIC RADIATION OF A MOBILE PHONE

*UDC 537.531:611.91*

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**Abstract.** *The main aim of this study is the estimation of electric field strength induced inside a human head due to exposure to the electromagnetic radiation of a mobile phone. Numerical calculations are performed using a frequency of 2600 MHz, characteristic of 4G mobile communication networks. Realistic 3D models of the mobile phone, the user's head and an actual smart phone have been created. The head is modeled as a highly non-homogeneous structure containing sixteen homogeneous domains of electromagnetic parameters taken from literature. Our results show that the values of the electric field strength are the highest in the layer nearest to the outer surface of the head.*

**Key words**: *electric field, electromagnetic radiation, human head, mobile phone.*

## 1. INTRODUCTION

The number of mobile phones and broadband wireless communication devices has grown rapidly over the past few decades, making them an integral part of modern everyday life. This causes a significant increase in exposure of people to radio frequency (RF) radiation. A human population is directly or indirectly exposed to the RF electromagnetic fields of base stations, mobile phones and other wireless communication devices. Nowadays the total number of mobile phones in use in the world is larger than the total number of its inhabitants. In 2019, the global population was approximately 7.54 billion, while the number of mobile devices exceeded 8.93 billion [1]. Currently, 5.1 billion inhabitants are subscribed to mobile telephone services, which is 67% of the

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world's population. Furthermore, 710 million of new users are expected in the next few years [2].

The previously disclosed data justify the increasing concern of the public that exposure to electromagnetic (EM) waves emitted by the mobile phones can lead to adverse health effects. The impact of electromagnetic fields on living organisms has been the focus of numerous studies conducted over the past several decades. Based on this, standards, recommendations and legal solutions that deal with the permissible levels of exposure to RF radiation have been established. Electromagnetic fields in the frequency range from 30kHz to 300GHz mainly appear in telecommunications technologies, including mobile phones, televisions and radio transmissions.

Analyses and results presented in a large number of publications indicate that exposure to even lower values of the electromagnetic field than permitted can cause various biological and health effects. Thus, in 2011, the World Health Organization's International Agency for Research on Cancer classified electromagnetic radiation from mobile phones as a class 2B carcinogen [3] and recommended the continuation of intensive research.

Many studies aimed to determine the impact of RF radiation from mobile phones on the human body. Corresponding results are published in the form of epidemiological studies based on information from multiple sources, including questionnaires filled out by respondents and data obtained from mobile phone operators. The emphasis was on the following data:

- How regularly the study participants use mobile phones (number of calls per week or month);
- User's age and when they first started using a mobile phone;
- Average number of calls during the day, week or month (frequency);
- Average call duration and
- The total number of hours of mobile phone use, determined by the length of a call, the frequency of use, and the duration of the mobile phone use.

Epidemiological studies [4 - 13] investigate the connection between the frequency of mobile phone use and the increased risk of malignant and benign diseases (glioma, acoustic neuroma-tumors of the nerve cells responsible for hearing, meningioma-tumors in the membranes that protect the brain and spinal cord, salivary gland tumors, etc.). Some of these studies have shown an increased risk of tumor formation due to the excessive use of mobile phones, while the results of another group did not indicate a connection between health problems and exposure to RF radiation.

Recent publications present results of glucose metabolism tests in the brains of users after using mobile phones [14, 15]. Some studies conclude that glucose metabolism is higher in the region of the brain near the mobile phone antenna compared to the opposite side. In contrast, another study suggests that glucose metabolism decreases in the brain area closer to the mobile phone. This experimental research raises new questions regarding possible changes in the organism at the cellular level caused by exposure to electromagnetic radiation. Due to the great diversity of the mentioned studies, in terms of methodology and conditions of exposure to radiation, it is very difficult to make a general conclusion about the potential biological effects of electromagnetic radiation from mobile phones.

Since experimental procedures cannot be carried out on humans due to ethical reasons, numerical calculations offer a convenient way to assess the impact of RF radiation from mobile phones. This assessment is based on the calculation of the penetrating electromagnetic field i.e. the amount of absorbed energy within the user's head. A continuous development of numerical methods and the constant improvement in computer performance allow for consideration of high-resolution models including a lot of compartments of possibly anisotropic electromagnetic parameters. Detailed models and their frequency-dependent characteristics are essential for understanding the interaction of electromagnetic radiation with a specific biological structure. Some studies that use simplified head models [16 - 18] cannot be considered accurate because these models do not take into account boundary conditions on interfaces separating different head tissues. Besides that, the type of antenna, the shape and the model of a device, and also the position of a source related to the observed biological structure enormously influence the amount of electromagnetic energy induced into the human head.

The primary goal of this study is an estimation of the penetrated electromagnetic field, absorbed electromagnetic energy, and potential biological effects due to exposure to electromagnetic radiation of mobile phones. We use the 3D realistic human head model containing several compartments of electromagnetic parameters reported in the literature. A Computer Simulation Technology (CST) [19] software package is used to perform numerical calculations of the electric field at the frequency of 2600 MHz, typical for 4G mobile networks.

## 2. Models and Method

### 2.1. Model of a human head

The 3D realistic head model of a mobile phone user is created to contain the following biological tissues and organs: skin, fat, muscle, skull, mandible, tongue, teeth, vertebrae, cartilage, thyroid gland, eyes, cerebrospinal fluid, cerebrum, cerebellum, brain stem and pituitary gland. The head model is presented in Fig. 1, while its sagittal and coronal cross-sections are presented in Fig. 2.

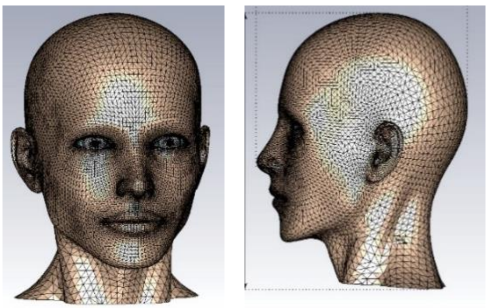


**Fig. 1** Front and side view of the head model

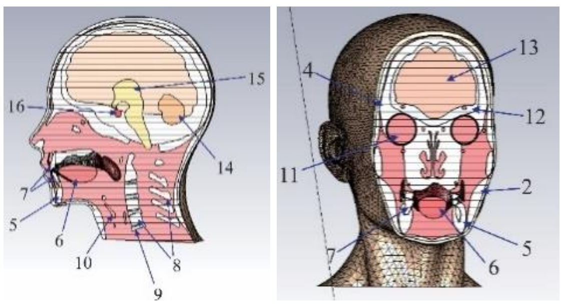



**Fig. 2** Sagittal and coronal cross-sections of the head model

Each tissue and biological organ of the head model was created separately using appropriate 3D modeling software. Electromagnetic parameters from the literature were assigned to each organ and tissue inside the model, Fig. 2, and imported into CST. These parameters are: relative dielectric permittivity ($\varepsilon_r$), specific electrical conductivity ($\sigma$) and tissue density ($\rho$). These parameters strongly affect a propagation, reflection and attenuation of electromagnetic waves. For the frequency of 2600 MHz, at which the numerical simulations have been performed, the above mentioned parameters are presented in Table 1 [20]. When connecting the head compartments, it is essential to ensure that the separating surfaces do not overlap. Only in this way, it is possible to satisfy the boundary conditions correctly.

**Table 1** Electromagnetic properties of biological tissues and organs at 2600 MHz

| | Biological tissue | $\varepsilon_r$ | $\sigma$[S/m] | $\rho$[kg/m$^3$] |
|---|---|---|---|---|
| 1. | Skin | 37.8 | 1.54 | 1109 |
| 2. | Fat | 10.8 | 0.29 | 911 |
| 3. | Muscle | 52.5 | 1.84 | 1090 |
| 4. | Skull | 14.8 | 0.64 | 1543 |
| 5. | Mandible | 11.3 | 0.42 | 1908 |
| 6. | Tongue | 52.4 | 1.92 | 1090 |
| 7. | Teeth | 11.3 | 0.42 | 2180 |
| 8. | Vertebrae | 11.3 | 0.42 | 1908 |
| 9. | Cartilage | 38.4 | 1.87 | 1100 |
| 10. | Thyroid gland | 57.0 | 2.09 | 1050 |
| 11. | Eyes* | 47.55 | 2.08 | 1060 |
| 12. | Cerebrospinal fluid | 66.0 | 3.60 | 1007 |
| 13. | Cerebrum | 44.5 | 2.20 | 1046 |
| 14. | Cerebellum | 44.5 | 2.20 | 1045 |
| 15. | Brain stem | 44.5 | 2.20 | 1046 |
| 16. | Pituitary gland | 57.0 | 2.09 | 1053 |

### 2.2. Model of a mobile phone

An actual smart phone is modeled in CST as a source of EM field (Fig. 3). The model contains the following parts: the planar inverted F antenna (PIFA), a display and mobile housing. The PIFA, as a source of EM radiation, was modeled for the frequency of 2600 MHz, with the output power of $P$ = 1 W [21] and the impedance of $Z$ = 50 Ohm. In general, the construction of the PIFA depends on the producer. One PIFA model considering its performance, construction and radiation pattern at certain frequencies can be found in [22].

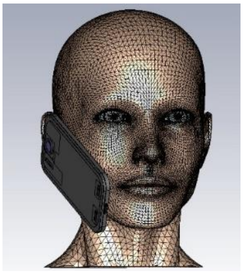


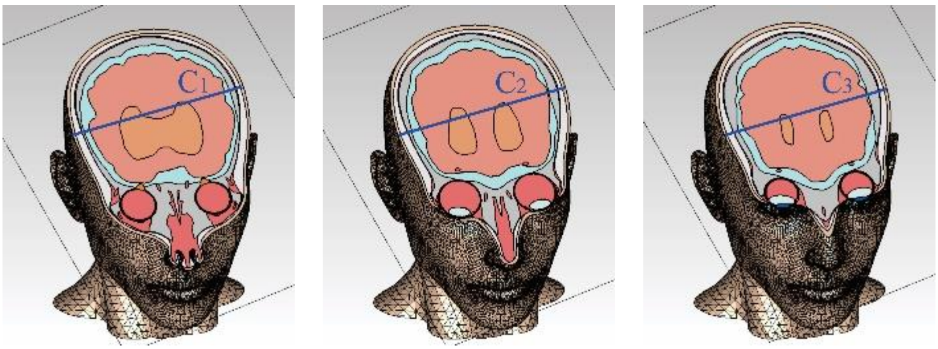
**Fig. 3** External view of 3D numerical models of the user's head and a mobile phone in the vicinity of the head

### 2.3. CST Studio Suite

In order to simulate the propagation of electromagnetic waves of a mobile phone inside biological tissues, the CST Studio Suite software package based on the numerical method known as Finite Integral Technique (FIT) [23] was used. This software for the analysis of 3D electromagnetic problems offers a very good CAD interface for the construction and editing of the models, while the tools for importing and exporting 3D models allow the use of models created with different software for 3D modeling.

### 2.4. Presentation of results

For a previously described model, electric field distribution inside the human head due to exposure to mobile phone electromagnetic radiation is determined. These values are calculated at different planes (cross-section A, cross-section B and cross-section C) relative to the position of the mobile phone antenna (Fig. 4). Additionally, the values are determined along the lines C1, C2 and C3 perpendicular to the mobile phone and belonging to the cross-sections A, B and C, respectively (Fig. 4).




a) b) c)

**Fig. 4** Cross-sections of the user's head model for the presentations of numerical results: a) cross-section A, b) cross-section B and c) cross-section C

## 3. Results

### 3.1. Electric field distribution

Distributions of electric field strength inside the human head at the planes A, B and C are presented in Figs. 5-7. Fig. 8 shows electric field strength along the lines C1, C2 and C3 defined in section 2.4.

Figs 5-7 show that the electric field strength is higher in the layers close to the outer boundary of the head (skin, fatty tissue and muscle) at all the observed planes A, B and C.

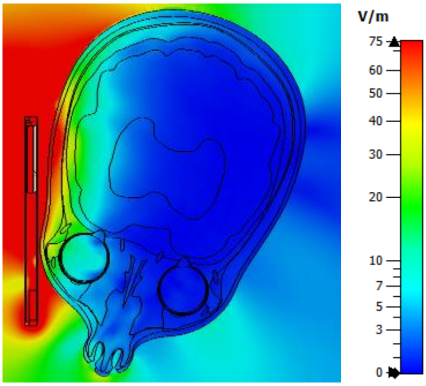



**Fig. 5** Electric field distribution within the user's head model – cross-section A

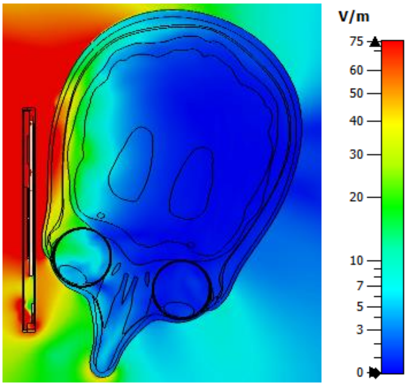



**Fig. 6** Electric field distribution within the user's head model – cross-section B

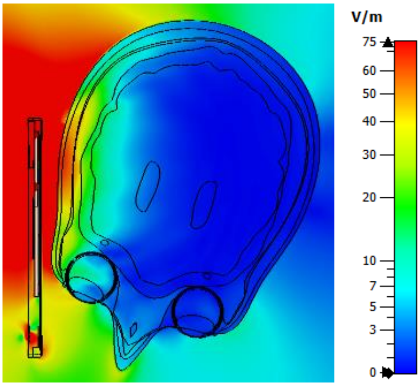



**Fig. 7** Electric field distribution within the user's head model – cross-section C

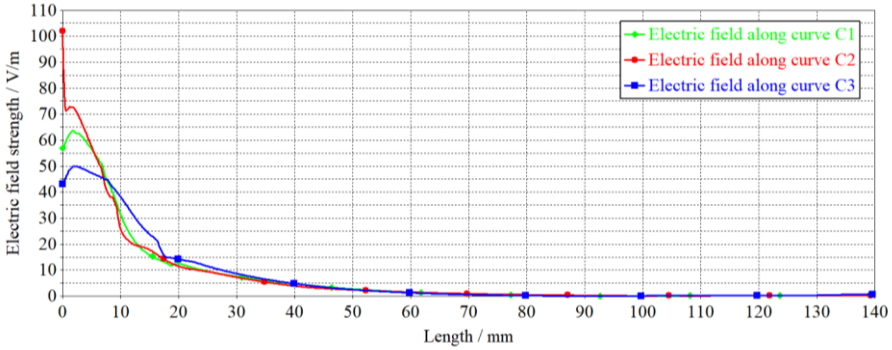



**Fig. 8** Electric field strengths along the lines C1, C2 and C3

Maximal induced electric field strengths along line C1 (Fig. 8) in the skin, fat and muscle are 64.93 V/m, 63.40 V/m and 59.30 V/m, respectively. Skull, cerebrospinal fluid and brain experience much lower field strengths equal to 42.20 V/m, 29.15 V/m and 12.32 V/m, respectively. Electric field strengths at line C2 are the largest compared to other lines (and planes) and they are equal to 101.94 V/m, 72.40 V/m and 60.30 V/m in the skin, fat and muscle, respectively. Similar to the line C1, lower electric field are induced inside the inner positioned head compartments, i.e. the strengths of 41.20 V/m inside the skull, 26.15 V/m inside the cerebrospinal fluid and 12.55 V/m inside the brain. The electric field strengths at the line C3 are also much higher in the outer tissues (48.16 V/m in the skin, 48.84 V/m in the fat and 47.23 V/m in the muscle), compared to the more centrally positioned compartments: 43.20 V/m inside the skull, 36.15 V/m inside the cerebrospinal fluid and 14.42 V/m inside the brain tissue.

## 4. Discussion and Conclusion

This study deals with the electric field distribution within biological tissues inside the human head exposed to the electromagnetic radiation produced by a mobile phone. Numerical calculations are performed for a real head model, consisting of sixteen tissues of electromagnetic parameters taken from the literature. A commercial software package CST Studio Suite is used for numerical calculations at the frequency of 2.6 GHz.

In our simulations, we had three observation planes, one below, one above and one equal to the vertical position of a mobile phone. Additionally, we have observed the induced fields along three lines belonging to the above mentioned planes and perpendicular to the area of a phone. Our results show that the induced electric field strength is higher in the layers close to the outer boundary of the head (skin, fatty tissue and muscle) compared to the inner, more centrally positioned compartments. The largest electric field is within a plane at the same vertical position as the source of radiation, equal to 101.94 V/m, 72.40 V/m and 60.30 V/m in the skin, fat and muscle, respectively. The skin right next to the phone experiences the largest electric field of all calculated values in the model. The observation plane positioned at the highest height experiences the smallest fields in every tissue compared to the other two planes.

Many studies have examined the impact of mobile phone use on human health. In [24], a significant risk of brain cancer has been pointed out in children and adolescents of an average

age of 13 years. Similarly, in [25], Hardell and Carlberg have shown a significant risk of brain cancer in young people due to the use of mobile phones. This leads to the conclusion that excessive exposure to the electromagnetic field of a mobile phone can affect human health. Therefore, our future work will be based on the estimation of the penetrated electric field inside a human head at the frequency of 5G, the newest generation of mobile networks.

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# RASPODELA PRODRLOG ELEKTRIČNOG POLJA UNUTAR GLAVE ČOVEKA IZLOŽENOG ELEKTROMAGNETNOM ZRAČENJU MOBILNOG TELEFONA

*Glavni cilj ove studije je određivanje jačine električnog polja indukovanog unutar ljudske glave usled izlaganja elektromagnetnom zračenju mobilnog telefona. U numeričkim proračunima se koristi frekvencija 4G mobilne komunikacione mreže, odnosno 2600 MHz. Kreirani su realistični 3D modeli mobilnog telefona, glave korisnika i stvarnog pametnog telefona. Glava je modelovana kao visoko nehomogena struktura koja sadrži šesnaest homogenih domena elektromagnetnih parametara preuzetih iz literature. Naši rezultati pokazuju da su vrednosti jačine električnog polja najveće u sloju najbližem spoljašnjoj površini glave.*

Ključne reči: *električno polje, elektromagnetno zračenje, ljudska glava, mobilni telefon.*

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**Review paper**

# HUMAN ERROR ANALYSIS – A CASE STUDY

*UDC 356.13:614.841.26*

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**Abstract**. *Due to the high risk and unpredictability of situations that firefighters encounter during fire-rescue interventions, assessing human reliability is crucial, as any mistake can have serious consequences for the safety of firefighters, vulnerable individuals, as well as natural and material assets. In this paper, the Success Likelihood Index Method (SLIM) was applied to analyze human errors in fire rescue interventions. A scenario involving a fire on the 7th floor of a student dormitory near the Faculty of Electronics in Niš was used for the human error analysis.*
*In this paper, typical performance shaping factors (PSFs) were analyzed, and 10 characteristic errors of firefighters-rescuers were identified, for which the human error probability (HEP) was determined. The analysis revealed that "errors in routine operations" have the highest probability of occurrence, with the most significant contributing PSFs being teamwork and procedures. The results show that SLIM enables the identification of critical points where errors most often occur and provides good guidelines for defining corrective measures and reducing the likelihood of errors occurring among firefighters-rescuers.*

**Key words**: *human error (HE), Success Likelihood Index Method (SLIM), human error probability (HEP), Performance Shaping Factors (PSFs), fire-rescue interventions.*

## 1. INTRODUCTION

Human errors (HEs) in the workplace often lead to unforeseeable consequences. The causes of these errors vary, but they become particularly problematic in emergency situations. In such cases, the time available for a person to respond is limited, which increases stress and, consequently, the probability of making an error [1].

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Human error is often the result of a complicated series of events, so a comprehensive definition of human error is very difficult to formulate. Human error can be defined as the failure of planned actions to achieve desired goals without the intervention of external or unpredictable events. This definition was provided by Reason [2]. In addition, Swain's [3] definition is frequently cited in the literature, which states that human error occurs when any procedural step within a set of activities exceeds a certain threshold of acceptability – whether through actions or omissions by the operator or team – that cannot be tolerated, whereby acceptable performance limits of the operator are defined within the performance of the system in which the operator works.

According to the traditional approach, human error is the cause of failure in the functioning of the system and the cause of accidents, while according to the modern approach, human error reflects deeper problems that exist in the system and is the result of systemic relationships between people, tools, tasks and the work environment [4, 5]. That is why the majority of researchers who deal with the issue of human reliability assessment agree that errors made by a person (operator) are a specific result of his performance, actions, or characteristics.

Fire and rescue units carry out a wide range of tasks, from extinguishing fires and performing technical interventions to mitigating the consequences of disasters. They are organized to ensure a prompt response at all times, with minimal preparation time required before deploying to interventions. The goal of this paper is to apply the Success Likelihood Index Method (SLIM) to analyze human errors during fire-rescue interventions, specifically in the scenario of "Extinguishing a fire in a room on the $7^{th}$ floor of a student dormitory near the Faculty of Electronics in Niš."

The Success Likelihood Index Method (SLIM) is based on expert evaluation of performance shaping factors (PSFs) and the quality of the task being analyzed. Through this assessment, the probability of human error occurrence is determined. PSFs are factors that can either positively or negatively affect human performance. They are considered the root causes of errors, and during the SLIM process for a given task, a group of experts identifies these factors [6, 7]. Typical PSFs used in the analysis of human errors include [8]: time pressure, quality of information, task complexity, teamwork, training, operator experience, type and quality of procedures, and more. During the implementation of this method, a group of experts evaluates potential human errors that may occur during a specific activity or task, while also assessing the extent to which performance-shaping factors influence the likelihood of those errors.

This paper examines 10 most common human errors when performing fire-rescue interventions: Failure to use or not wearing personal protective equipment that is correctly fitted, Errors in routine operations, Routine work/tasks, Underestimating the situation and focusing only at its segments, Omitting procedural steps in the field, Failure to perform or refusal to carry out the commander's orders, Poor mental and physical condition of workers, Failure to use means of communication (radio station), Use of untested equipment (e.g., the owner's ladder), and Inadequate use and maintenance of equipment. Also, 6 typical PSFs were selected, which influence the occurrence of these errors: Training, Procedures, Time, Teamwork, Communication, and Experience.

## 2. A DESCRIPTION OF THE CASE STUDY

For the purposes of research, and in cooperation with the employees of the Fire and Rescue Unit in Niš, the scenario "Extinguishing a fire in a room on the $7^{th}$ floor of a student dormitory near the Faculty of Electronics in Niš" was selected [9].

After receiving the fire incident report at 1:29 p.m., the report was verified, confirming it as a real event. A team comprising 12 personnel and 4 vehicles was dispatched to the scene: one naval vehicle with 5 personnel, one tanker with 4 personnel, one hydraulic telescopic platform with 1 person, and one command vehicle with 2 personnel. Meanwhile, a telephone operator and 8 personnel, along with the deputy brigade commander, remained at the unit. At 1:33 p.m., the Information Center and the police were notified, followed by a notification to the Electric Power Company service at 1:34 p.m.

The distance between the event site and the Fire and Rescue Unit is approximately 2,500 meters. During the arrival at the fire scene, traffic was regular. The "Tetra" system was used for radio communication between the action manager and the Communication Center.

Upon arrival, the fire-rescue team observed thick black smoke and flames billowing from one of the windows. They received additional information indicating that the burning student room was located on the $7^{th}$ floor and that several students and maintenance workers remained inside the building.

The team found the fire in an advanced stage, affecting the room on the $7^{th}$ floor in the southeast corner of the building, with a tendency to spread vertically. The police, emergency medical services, and a team from Electric Power Company service were also on-site because of the large number of students present and the pressing need to focus on rescue and firefighting.

At the time of arrival of the fire-rescue unit, the area affected by the fire was approximately 15 $m^2$ out of a total floor area of 600 $m^2$. The aggravating circumstances included: high temperatures inside the building, the number of floors, a large number of people inside, heavy smoke spreading from the $4^{th}$ to the $10^{th}$ floor, and the inoperability of the hydrant network due to a power outage.

Upon arrival of the fire-rescue unit, the formation of two work sectors began immediately:

1. Rescue and Evacuation Sector (internal rush and external rush using a hydraulic telescopic platform);
2. Firefighting Sector (internal rush).

In conjunction with reconnaissance efforts, the evacuation of vulnerable individuals from the upper floors was carried out, along with the opening of vents and windows to clear the space. An order was issued to clear a path through the staircase inside the building. Additionally, a logistics team was formed to deliver the necessary equipment to the scene and refill compressed air bottles.

Within both work sectors, two sub-sectors were formed. The first sub-sector, responsible for rescuing and evacuating individuals inside the building threatened by smoke, consisted of three members. The second sub-sector, focused on external rescue and evacuation, conducted reconnaissance using a hydraulic telescopic platform with three operators.

In the firefighting sector, the first sub-sector, with four members, was tasked with scouting and extinguishing the fire in the room on the seventh floor and protecting the rooms on the eighth floor. The second sub-sector was responsible for establishing a track from the vehicle to the room on the seventh floor, supported by the remaining available personnel. As operations progressed, regular rotations were made to replace tired personnel with more rested team members.

The fire was contained at 2:04 p.m. After localization, rested personnel replaced the initial team, and the extinguishing of smaller hotspots began. Both the deputy commander of the Fire and Rescue Brigade in Niš and the deputy head of the Emergency Situations Administration in Niš were present at the scene. They received verbal and radio reports from sector leaders, as well as from the crew leader.

Logistics continually delivered the necessary equipment to the scene. Coordination with members of the traffic police from the Niš Police Department ensured faster access for fire engines. The fire was fully extinguished at 3:40 p.m. through the coordinated efforts of all sectors, as well as other personnel involved in the intervention.

After the fire was extinguished, the personnel were replaced by a new team from the Fire and Rescue Brigade in Niš, who remained on duty until 7:30 p.m. Following that, the fourth crew conducted several inspections of the building throughout the night.

During the intervention, around twenty people were evacuated, and approximately 600 m² of living space on the seventh and eighth floors was saved. The fire chief remained in command throughout the intervention, with no need to involve additional firefighting units, local government, or citizens. There were no equipment failures during the operation.

The primary dangers included high temperatures, thick smoke, working at heights, and the risk of injuries, cuts, and burns. To ensure safety during rescue, evacuation, and firefighting operations, all personnel involved in the internal rush wore appropriate personal protective equipment (protective suits, helmets, belts, gloves, and boots), as well as shared equipment (respiratory protection devices and Tetra radio stations). This minimized the risk of injury.

Throughout the intervention, the weather conditions were as follows: the outside air temperature was 26°C, with a wind speed of approximately 2 m/s. The weather remained mostly unchanged during the operation, with no precipitation.

### 2.1. Description of the SLIM Procedure

The human reliability assessment in fire-rescue interventions was conducted using SLIM. Based on the described scenario, potential errors were identified and quantified to establish preventive and corrective measures, ensuring the safe and reliable operation of fire-rescue units during interventions.

### 2.2. Selection of Experts

This research involved four experts and a coordinator, all of whom have professional experience in firefighting and rescue interventions.

### 2.3. Human Error Identification

The experts identified several characteristic mistakes made by firefighters and rescuers that occur or may occur during interventions [9]:

1. Failure to use or not wearing personal protective equipment that is correctly fitted;
2. Errors in routine operations;
3. Routine work/tasks;

4. Underestimating the situation and focusing only at its segments;
5. Omitting procedural steps in the field;
6. Failure to perform or refusal to carry out the commander's orders;
7. Poor mental and physical condition of workers;
8. Failure to use means of communication (radio stations);
9. Use of untested equipment (e.g., the owner's ladder);
10. Inadequate use and maintenance of equipment.

### 2.4. Elicitation of Typical PSFs

For this research, six typical PSFs were selected that influence the occurrence of errors during the interventions of fire and rescue teams:

1. Training (exercises);
2. Procedures (type and quality of procedures);
3. Time (time pressure);
4. Teamwork (team structure and cooperation);
5. Communication (written or verbal);
6. Experience (current level of experience and skill).

The experts assessed the impact of each PSF on the 10 selected errors using a scale from 1 to 9, where 1 represents the least impact and 9 represents the greatest impact.

## 3. RESULTS AND DISCUSSION

After identifying potential human errors and defining the PSFs, the experts assessed the impact of each PSF on the ten previously identified errors. Further data processing, including value normalization, determined the contribution of each PSF to the occurrence of errors. The experts' ratings and the normalized values of the PSFs are presented in Table 1.

**Table 1** The estimated and normalized PSF values

| Error N° | *$R_{ij}$ | | | | | | ∑ |
|---|---|---|---|---|---|---|---|
| | Training | Procedures | Time | Teamwork | Communication | Experience | |
| 1. | 6 | 9 | 7 | 9 | 6 | 7 | 44 |
| 2. | 5 | 8 | 8 | 9 | 7 | 6 | 43 |
| 3. | 8 | 8 | 9 | 9 | 7 | 8 | 49 |
| 4. | 6 | 9 | 6 | 9 | 5 | 8 | 43 |
| 5. | 7 | 8 | 7 | 9 | 6 | 7 | 44 |
| 6. | 6 | 9 | 8 | 9 | 7 | 8 | 47 |
| 7. | 8 | 8 | 9 | 9 | 7 | 7 | 48 |
| 8. | 8 | 9 | 8 | 9 | 7 | 6 | 47 |
| 9. | 7 | 9 | 7 | 8 | 8 | 6 | 45 |
| 10. | 7 | 9 | 8 | 9 | 6 | 7 | 46 |
| ∑ *PSF* | 68 | 86 | 77 | 89 | 66 | 70 | 456 |
| $W_i$** | 0.149 | 0.188 | 0.169 | 0.195 | 0.145 | 0.154 | 1 |

*$R_{ij}$ rating of task on the given PSF
(1 represents the smallest, while 9 represents the highest influence of PSF on a specific task);
$W_i$** normalized importance weighting for the given PSF

The total Success Likelihood Index (*SLI*) for a specific task j (denoted as $SLI_j$) is calculated using the following expression [10]:

$$SLI_j = SUM(R_{ij} \cdot W_i) \text{ , for i=1, … i=x} \quad (1)$$

where x is the number of PSFs considered.

The obtained values of the SLI are presented in Table 2.

**Table 2** Success Likelihood Index (SLI)

| Error N° | $R_{ij}$* | | | | | | ∑SLI |
|---|---|---|---|---|---|---|---|
| | Teamwork | Procedures | Time | Experience | Training | Communication | |
| 1. | 1.755 | 1.692 | 1.183 | 1.078 | 0.894 | 0.870 | 7.472 |
| 2. | 1.755 | 1.504 | 1.352 | 0.924 | 0.745 | 1.015 | 7.295 |
| 3. | 1.755 | 1.504 | 1.521 | 1.232 | 1.192 | 1.015 | 8.219 |
| 4. | 1.755 | 1.692 | 1.014 | 1.232 | 0.894 | 0.725 | 7.312 |
| 5. | 1.755 | 1.504 | 1.183 | 1.078 | 1.043 | 0.870 | 7.433 |
| 6. | 1.755 | 1.692 | 1.352 | 1.232 | 0.894 | 1.015 | 7.940 |
| 7. | 1.755 | 1.504 | 1.521 | 1.078 | 1.192 | 1.015 | 8.065 |
| 8. | 1.755 | 1.692 | 1.352 | 0.924 | 1.192 | 1.015 | 7.930 |
| 9. | 1.560 | 1.692 | 1.183 | 0.924 | 1.043 | 1.160 | 7.562 |
| 10. | 1.755 | 1.692 | 1.352 | 1.078 | 1.043 | 0.870 | 7.790 |

The *SLI* serves as an indicator of the relative probabilities of different errors, ranking them in order of likelihood but does not define absolute probabilities. The transformation of *SLI* into *HEP* is achieved by establishing their logarithmic relationship using the following expression [10]:

$$\log(HEP) = a(SLI) + b \quad (2)$$

where a and b are coefficients that can be derived by the process of simultaneous equalization until at least two measurement probabilities are evaluated. In this way, the probability of the occurrence of specific human errors is reached.

For this research, the values assigned to coefficients a and b are – 0.75 and 2.35, respectively. The resulting Human Error Probability (HEP) values are also presented in Table 3.

**Table 3** Human Error Probability (HEP)

| Error N° | HEP |
|---|---|
| 1. Failure to use or not wearing personal protective equipment that is correctly fitted | 0.00056 |
| 2. Errors in routine operations | 0.00076 |
| 3. Routine work/tasks | 0.00015 |
| 4. Underestimating the situation and focusing only at its segments | 0.00073 |
| 5. Omitting procedural steps in the field | 0.00059 |
| 6. Failure to perform or refusal to carry out the commander's orders | 0.000248 |
| 7. Poor mental and physical condition of workers | 0.0002 |
| 8. Failure to use means of communication (radio stations) | 0.00025 |
| 9. Use of untested equipment (e.g., the owner's ladder) | 0.00048 |
| 10. Inadequate use and maintenance of equipment | 0.00032 |

The HEP values for each of the considered errors are shown in Figure 1.

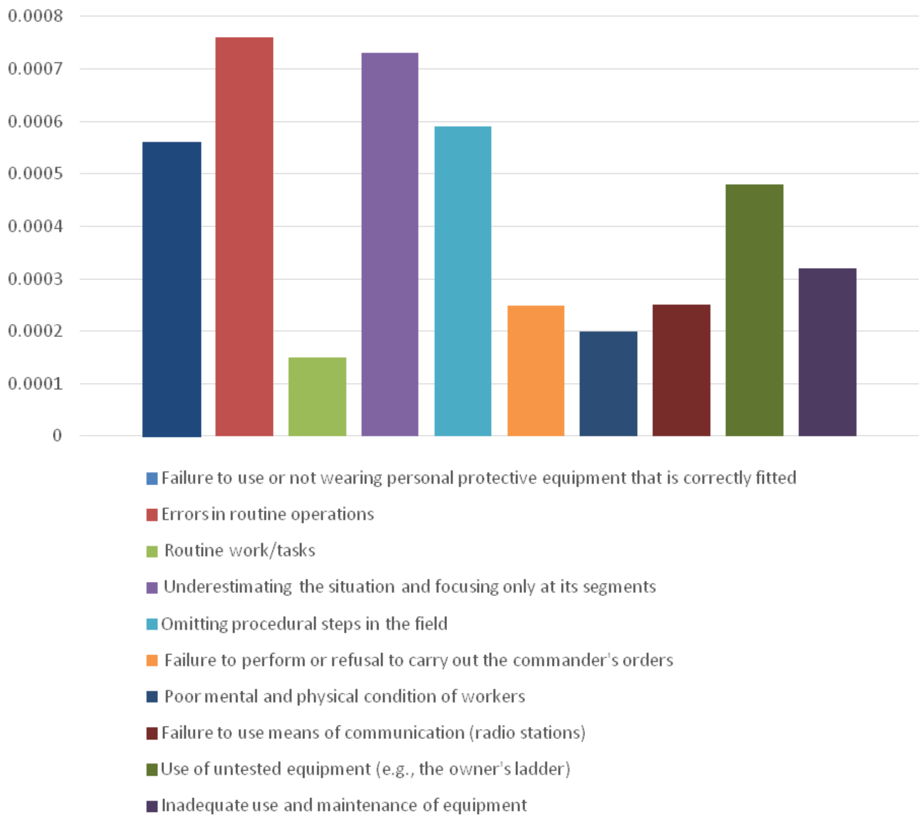


**Fig. 1** HEP values for specific tasks during firefighting interventions

Based on the results and normalized PSF values (Figure 2), it can be concluded that "Teamwork" and "Procedure" are the two most significant factors influencing performance, with the greatest impact on error occurrence. These are followed by "Time" and "Experience," while "Training" and "Communication" were evaluated as the PSFs contributing the least to human error in this case.

Given that "Teamwork" is the PSF with the greatest impact on error occurrence, it can be concluded that aspects such as team structure, socializing with colleagues, positive interpersonal relationships, cooperation, and mutual support in completing tasks contribute to reducing human errors. Effective teamwork requires strong communication, mutual respect, and trust, as well as collaboration in distributing tasks and responsibilities.

The second most PSF is "Procedures," highlighting the critical need for the manager to be aware of the order of priorities at all times during the intervention. These priorities include the safety of firefighters and rescuers, the safety of vulnerable individuals, event stabilization, and property protection. Deviating from this order can lead to unforeseeable consequences.


**Fig. 2** Normalized PSF values

Firefighter-rescuer interventions are characterized by constant, dynamic changes in conditions. As a result, "Time" was rated as the third most important PSF, with "Experience" ranked fourth. Due to the lack of time to assess the situation, constant changes in the intervention conditions and correction of the primary decision are inevitable. Decision-making and action are often based on past experiences, making "Experience" a crucial factor in shaping performance, one that should not be overlooked.

One of the key causes of human error is insufficient knowledge of how tasks should be performed, particularly in critical and dangerous situations. In the analyzed case, "Training" ranked as the fifth most important PSF, while "Communication" was placed sixth. During interventions, communication can occur directly or via radio, and an effective exchange of information can significantly accelerate the decision-making and management process.

## 4. Conclusion

To analyze human errors and quantify performance-shaping factors (PSFs) that can both contribute to and reduce errors in fire-rescue interventions, the Success Likelihood Index Method (SLIM) was applied to the scenario "Extinguishing a fire in a room on the 7$^{th}$ floor of a student dormitory near the Faculty of Electronics in Niš."

In this scenario, human errors with the highest probability of occurrence are „Errors in routine operations" (HEP = $7.6\cdot10^{-4}$), "Underestimating the situation and focusing only at its segments" (HEP = $7.3\cdot10^{-4}$) and „Omitting procedural steps in the field" (HEP = $5.9\cdot10^{-4}$). After that, the following errors are "Failure to use or not wearing personal protective equipment that is correctly fitted" (HEP = $5.57\cdot10^{-4}$), „Use of untested equipment (e.g., owner's ladder)" (HEP = $4.8\cdot10^{-4}$), and "Inadequate use and maintenance of equipment" (HEP = $3.2\cdot10^{-4}$). Similar probabilities of occurrence have „Failure to use means of communication (radio stations)" (HEP = $2.5\cdot10^{-4}$) and „Failure to perform or refusal to carry out the commander's orders" (HEP = $2.48\cdot10^{-4}$). Errors with the lowest probability of occurrence value are, „Poor mental and physical condition of workers" (HEP = $2\cdot10^{-4}$), and „Routine work/tasks " (HEP = $1.5\cdot10^{-4}$).

In the given example, the selected PSFs were: "Training (exercise)," "Procedures (type and quality of procedure)," "Time (time pressure)," "Teamwork (team structure and cooperation)," "Communication (written or verbal)," and "Experience (current level of experience or skill)." The analysis revealed that "Teamwork" has the greatest impact on the occurrence of errors, while "Errors in routine operations" have the highest probability. The research results demonstrate that SLIM provides an effective framework for identifying and assessing human errors, as well as for defining corrective measures to reduce the likelihood of errors during fire-rescue interventions.

The complexity and seriousness of various fire-rescue interventions highlight that the readiness and proper equipment of these units for rapid and effective response is a fundamental prerequisite for successfully protecting and rescuing people and property. This is especially crucial in cases of extinguishing large-scale fires and mitigating their aftermath. Observing real situations during interventions reveals that implementing protective measures, using specialized protective equipment, and adhering to operational protocols significantly reduce the number of risky events. Moreover, if any such events do occur, their negative consequences – such as property damage or injuries to intervention participants – are minimized.

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# ANALIZA LJUDSKIH GREŠAKA – STUDIJA SLUČAJA

*Zbog visokog rizika i nepredvidivosti situacija u kojima se vatrogasci nalaze u vatrogasno-spasilačkim intervencijama, procena ljudske pouzdanosti je od suštinske važnosti, jer bilo kakva greška može imati ozbiljne posledice po bezbednost vatrogasaca, ugroženih osoba, prirodna i materijalna dobra. U ovom radu primenjena je metoda indeksa verovatnoće uspeha (SLIM) za analizu ljudskih grešaka u vatrogasno-spasilačkim intervencijama. Za analizu ljudskih grešaka korišćen je scenario gašenja požara na 7. spratu studentskog doma kod Elektronskog fakulteta u Nišu.*

*U radu su analizirani tipični faktori oblikovanja učinka (PSFs), a identifikovano je i 10 karakterističnih grešaka vatrogasaca-spasilaca, za koje je određena verovatnoća nastanka grešaka (HEP). Procenjeno je da "greške u rutinskim operacijama" imaju najveću verovatnoću, a faktori oblikovanja učinka koji najviše doprinose njihovoj pojavi su timski rad i procedure. Rezultati pokazuju da SLIM omogućava identifikaciju kritičnih tačaka gde greške najčešće nastaju, i daje dobre smernice za definisanje korektivnih mera i smanjenje verovatnoće nastanka grešaka kod vatrogasaca-spasilaca.*

Ključne reči: *ljudska greška, metoda indeksa verovatnoće uspeha (SLIM), verovatnoća ljudske greške (HEP), faktori oblikovanja učinka (PSFs), vatrogasno – spasilačke intervencije.*

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# WORK STRESS AMONG PRESCHOOL AND KINDERGARTEN TEACHERS

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**Abstract.** *The aim of this research is to determine the etiological factors (causes) that influence the occurrence of work stress among employees in preschool institutions. Using a questionnaire, data on the employees of the preschool institution were obtained and processed using the method of descriptive statistics. The results show that symptoms related to work stress are manifested to a greater extent among younger employees (up to 30 years old) as well as among older people who are over 55 years old. Employees work with a large number of children and the very responsibility for one's life increases the possibility of of experiencing stress. Daily interactions and encounters with different personality types, including colleagues, parents and co-workers, increase the potentia; for stress and burnout syndrome at work. Additionially, teaching involves a significant amount of work-related stress.*

**Key words**: *work stress, preschool institution, preschool and kindergarten teachers*

## 1. INTRODUCTION

Work stress is a series of harmful, physiological, psychological and behavioral reactions to situations in which the demands of the job are not in accordance with the capabilities, abilities and needs of an employee. In modern business conditions, work stress, especially the "burn-out" syndrome, is a sign of social and professional issues that eventually impact an employee's motivation, work output, and overall quality of life [9]. Stress is essentially psychological pressure, characterized by a relationship between individuals and their environment that is perceived as harmful or threatening [12]. According to Ivančević and

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Maytson, sources of stress at work can be divided into three groups: personal, interpersonal and organizational. As far as personal factors are concerned, personality types, life changes and demographic characteristics have been studied the most so far [8]. Personality factors that are important for the reaction to stress are ego strength, motivational structure and defense forces [7]. Numerous studies have proven that work stress is prevalent in Serbia. It is relatively easy to fire an employee in Serbia, as labor legislation is not yet fully aligned with European workers' rights [4]. In addition to this, abuse of subordinates by superiors is present to a large extent. The present desire for a faster and more successful career, jealousy and envy towards colleagues' achievements, results in psychological abuse among workers in similar positions. [4]. Working in preschool institutions is very complex and it requires maximum engagement, with intense physical and mental strain. Work stress is common among employees in preschool institutions due to daily frustrations, concerns about the safety of the children in their care, as well as frequent misunderstandings with parents, colleagues, and others in the work environment. Risk factors among employees in preschool institutions include unfavorable working conditions, a type of preschool institution, numerous groups, low salaries, age of children, marital status, etc.

## 2. Research Objective

The aim of the research includes the following:

- To determine the etiological factors (causes) that influence the occurrence of work stress among employees in preschool institutions.
- To present data on the impact of work stress on the health of employees in preschool institutions, as one of the health risk factors.
- to identify measures to prevent work stress among employees in preschool institutions.

## 3. Materials and Methods

The method of this research is descriptive analytics. Using a questionnaire, data on the employees of the preschool institution were obtained and processed using the method of descriptive statistics and presented in graphs and tables. The statistical significance of the difference in the connection between gender and age on the one hand and the influence of risk factors on the other hand was determined by the $\chi 2$ (chi-square) test.

The questions for the survey questionnaire were modeled on various questionnaires of the World Health Organization (WHO) on general health, demographic indicators and self-assessment of stress [13].

The subjects of the research were the employees of the preschool institution "Rakovica", the kindergarten "Labudić" - Gočka 59, Rakovica, in Belgrade. The research was conducted in 2023.

## 4. Results and Discussion

Based on the survey, the following structure of respondents was obtained (table 1):

**Table 1** Structure of respondents

| Characteristics of respondents | | N | % |
|---|---|---|---|
| Gender | Female | 70 | 93.3 |
| | Male | 5 | 6.7 |
| Age (years) | Up to 30 | 13 | 17.3 |
| | 31-40 | 39 | 52.0 |
| | 41-55 | 12 | 16.0 |
| | Over 55 | 11 | 14.7 |
| Marital status | Married | 41 | 54.7 |
| | Unmarried | 25 | 33.3 |
| | Divorced | 9 | 12.0 |
| Number of children | Without | 24 | 32.0 |
| | One | 13 | 17.3 |
| | Two | 35 | 46.7 |
| | Three | 3 | 4.0 |
| Residential question | Have their own apartment | 39 | 52.0 |
| | Do not have their own apartment | 36 | 48.0 |
| Education | Primary school | 2 | 2.7 |
| | High school | 43 | 57.3 |
| | College | 23 | 30.7 |
| | Faculty | 7 | 9.3 |
| Work experience (years) | Up to 20 | 16 | 21.3 |
| | 21-30 | 53 | 70.7 |
| | Over 30 | 6 | 8.0 |
| Working hours | Just before noon | 68 | 90.7 |
| | Before and afternoon | 7 | 9.3 |
| Health state | Bad | 3 | 4.0 |
| | Good | 61 | 81.3 |
| | Very good | 6 | 8.0 |
| | Perfect | 5 | 6.7 |
| Chronic diseases | No chronic diseases | 54 | 72.0 |
| | One | 15 | 20.0 |
| | Two or more | 6 | 8.0 |
| Alcohol consumption | Never | 61 | 81.3 |
| | Sometimes | 13 | 17.4 |
| | Often | 1 | 1.3 |
| Cigarette consumption | Smokers | 40 | 53.3 |
| | Non-smokers | 35 | 46.7 |
| Sedative usage | Yes | 4 | 5.3 |
| | No | 71 | 94.7 |

Out of the total number of respondents (75), five of them are male. Such a small number of male respondents is probably a consequence of professional orientation because a significantly larger number of female candidates apply for the position of preschool teacher and nursery teacher. 52% of employees were between 31 and 40 years old, and most respondents were married (54.7%). The largest number of respondents have two children (46.7%) and 52% of respondents have resolved their housing issue. Most of the employees in the preschool institution have secondary education and more than half of the employees (57.35%) have 20-30 years of experience in that institution.

The largest number of respondents work before and after noon, 90.7% (68 employees) work for eight hours. 61 respondents (81.3%) rate their state of health as good, while when asked about chronic diseases, 28% of respondents answered that they have one, two or more diseases, 81.2% do not consume alcohol, 53.3% of respondents are smokers, and only 5.3% of them take sedatives.

Table 2 shows the workplace factors that, according to the survey, bother employees the most. The $\chi^2$ square test determined whether there are significant differences in the presence of risk factors between men and women, as well as between subjects belonging to different age categories. The significance of these tests is shown in the columns marked with "sig".

Table 2 Workplace factors that bother employees the most

| What bothers you most at work? | All respondents | | Male | | Female | | sig | Up to 30 | | 31-40 | | 41-55 | | Over 55 | | sig |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | | N | % | N | % | N | % | N | % | |
| Low salary | 75 | 100.0 | 5 | 100.0 | 70 | 100.0 | 1.000 | 13 | 100.0 | 39 | 100.0 | 12 | 100.0 | 11 | 100.0 | **0.000** |
| Too much administration | 70 | 93.3 | 0 | 0.0 | 70 | 100.0 | **0.000** | 13 | 100.0 | 34 | 87.2 | 10 | 83.3 | 3 | 27.3 | **0.000** |
| Lack of protocol at work | 42 | 56.0 | 5 | 100.0 | 37 | 52.9 | **0.040** | 2 | 15.4 | 29 | 74.4 | 8 | 66.7 | 3 | 27.3 | **0.000** |
| Bad working conditions | 56 | 74.7 | 5 | 100.0 | 51 | 72.9 | 0.178 | 6 | 46.2 | 35 | 89.7 | 12 | 100.0 | 3 | 27.3 | 0.127 |
| Too many children in a group | 72 | 96.0 | 3 | 60.0 | 69 | 98.6 | **0.000** | 10 | 76.9 | 33 | 84.6 | 12 | 100.0 | 7 | 63.6 | **0.000** |
| Lack of professional satisfaction | 25 | 33.3 | 5 | 100.0 | 20 | 28.6 | **0.001** | 0 | 0.0 | 5 | 12.8 | 11 | 91.7 | 9 | 81.8 | **0.001** |
| Difficulty in parent-teacher communication | 28 | 37.3 | 0 | 0.0 | 28 | 40.0 | 0.074 | 9 | 69.2 | 6 | 15.4 | 7 | 58.3 | 6 | 54.6 | **0.000** |
| Excessive attention from the public | 35 | 46.7 | 2 | 40.0 | 33 | 47.1 | 0.757 | 12 | 92.3 | 10 | 25.6 | 5 | 41.7 | 8 | 72.7 | **0.000** |
| Regular children's injuries | 58 | 77.3 | 1 | 20.0 | 57 | 81.4 | **0.002** | 13 | 100.0 | 22 | 56.4 | 12 | 100.0 | 11 | 100.0 | **0.000** |
| Overload due to long working hours | 25 | 33.3 | 5 | 100.0 | 20 | 28.6 | **0.001** | 0 | 0.0 | 2 | 5.1 | 12 | 100.0 | 11 | 100.0 | **0.000** |
| Excessive reliance on computers | 54 | 72.0 | 2 | 40.0 | 52 | 74.3 | 0.099 | 3 | 23.1 | 28 | 71.8 | 12 | 100.0 | 11 | 100.0 | 0.199 |
| Mobbing | 2 | 2.7 | 0 | 0.0 | 2 | 2.9 | 0.702 | 0 | 0.0 | 0 | 0.0 | 1 | 8.3 | 1 | 9.1 | 0.332 |
| Conflict with colleagues | 3 | 4.0 | 1 | 20.0 | 2 | 2.9 | 0.059 | 1 | 7.7 | 0 | 0.0 | 1 | 8.3 | 1 | 9.1 | **0.000** |

Based on the obtained results, it can be seen that a statistically significant difference between men and women exists in the following factors: too much administration, numerous groups of children, regular children's injuries (these factors are more prevalent among women), lack of work protocols, poor working conditions, lack of professional satisfaction, overload due to long working hours (these factors are more prevalent among men).

Furthermore, differences between respondents from different age categories exist in the following risk factors: too much administration (most often among the youngest respondents, and least among the oldest respondents), lack of work protocols (most common among respondents from the 31-40 category), poor working conditions (most often among respondents from the two middle age categories), lack of professional satisfaction (most often among the respondents of the two oldest categories), difficulty in parent-teacher communication (most often among the youngest respondents), excessive attention from the public most often among the youngest respondents), regular children's injuries (most rarely among respondents from the 31-40 category, fully present in the other categories), overload due to long working hours (most often among the respondents of the two oldest categories), excessive reliance on computers (most often among the respondents of the two oldest categories).

The largest number of respondents stated that low salaries, a large number of children in groups, and injuries among children most often cause a negative attitude towards work.

In the "Labudić" kindergarten, all groups exceed the standard enrollment numbers, with the youngest daycare groups having 29 children, and the preschool age groups containing up to 45 children.

The $\chi^2$ square test was used to determine whether there are statistically significant differences in the presence of complaints between subjects belonging to different age categories. The significance of these tests is shown in the column marked with sig (Table3).

**Table 3** Presentation of complaints that the respondents stated that they have noticed in themselves

| Do you have any of the listed symptoms? | All respondents | | Up to 30 | | 31-40 | | 41-55 | | Over 55 | | sig |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % | N | % | |
| You frequently feel tired, irritable, and overly sensitive | 17 | 22.7 | 3 | 23.1 | 5 | 12.8 | 2 | 16.7 | 7 | 63.6 | 0.005 |
| You have frequent headaches, stomachaches or back pain | 32 | 42.7 | 6 | 46.2 | 8 | 20.5 | 10 | 83.3 | 8 | 72.7 | 0.000 |
| You feel tense and find yourself shouting at colleagues for something that has never happened | 5 | 6.7 | 0 | 0.0 | 2 | 5.1 | 1 | 8.3 | 2 | 18.2 | 0.324 |
| You suffer from insomnia | 15 | 20.0 | 1 | 7.7 | 5 | 12.8 | 4 | 33.3 | 5 | 45.5 | 0.041 |
| You started to hate the morning because of the sound of the clock reminds you that it's time to go to work | 65 | 86.7 | 13 | 100.0 | 32 | 82.1 | 12 | 100.0 | 8 | 72.7 | 0.093 |
| You imagine yourself on a desert island rather than doing the job you once adored | 58 | 77.3 | 5 | 38.5 | 34 | 87.2 | 12 | 100.0 | 7 | 63.6 | **0.000** |
| You have a lot of responsibilities and frequently fall behind schedule | 10 | 13.3 | 1 | 7.7 | 3 | 7.7 | 2 | 16.7 | 4 | 36.4 | 0.086 |
| I don't have any mentioned symptoms | 9 | 12.0 | 6 | 46.2 | 2 | 5.1 | 1 | 8.3 | 0 | 0.0 | **0.000** |

Based on the significance obtained, it can be seen that statistically important differences in the occurrence of complaints between respondents of different age categories exist in the following complaints: you frequently feel tired, irritable, and overly sensitive (most often among the oldest respondents), you have frequent headaches, stomachaches or back pain (most often among the respondents from the two oldest categories), you suffer from insomnia (most often among the respondents from the two oldest categories), you imagine yourself on a desert island rather than doing the job you loved before (most often among the respondents from the two middle age categories), I don't have any mentioned symptoms (the most common response of the youngest respondents).

A smaller percentage of employees have stress-related symptoms. The most common complaints that indicate work stress are reported by people over 55 years old (tired, irritable), while headaches, back pain and stomach aches are most common among employees aged 41-55.

Problems in communication and satisfaction with the quality of life of employees are given in Table 4.

**Table 4** Interpersonal relationships and quality of life

| Questions | Answers | N | % |
|---|---|---|---|
| Do you bring work issues home? | no | 19 | 25.4 |
| | to a lesser extent | 34 | 45.3 |
| | yes | 22 | 29.3 |
| Is there nervousness and intolerance towards superiors and colleagues? | never | 27 | 36.0 |
| | sometimes | 42 | 56.0 |
| | often | 4 | 5.3 |
| | every day | 2 | 2.7 |
| Do you get into conflict with children's parents? | never | 41 | 54.7 |
| | sometimes | 32 | 42.6 |
| | often | 2 | 2.7 |
| Do you get into conflicts with co-workers? | never | 58 | 77.4 |
| | sometimes | 16 | 21.3 |
| | often | 1 | 1.3 |
| Are you familiar with how to channel stress? | yes | 63 | 84.0 |
| | I'm not interested | 1 | 1.3 |
| | No, I'd like to know how | 11 | 14.7 |
| Are you satisfied with the quality of life? | yes | 15 | 20.0 |
| | mostly | 45 | 60.0 |
| | no | 15 | 20.0 |

74.6% of employees take their work problems home after their shift, while 25.4% forget them after leaving work.

The results show that nervousness and intolerance towards superiors and colleagues are sometimes present among 56% of respondents, never among 36%, often among 5% and every day among 3% of respondents.

When asked about conflicts with children's parents, 54.7% of respondents answered that they never get into conflicts, 42.6% sometimes, and 2.7% often have conflicts with children's parents. When it comes to conflicts with their co-workers, 77.4% of respondents answered that they never get into conflicts, 21.3% sometimes, and 1.3% have frequent conflicts with co-workers.

When asked about satisfaction with the quality of life, 45 (60%) respondents were generally satisfied, while there is an equal number (20%) of those who answered that they were satisfied and those who answered that they were not.

The employees of the preschool institution are mostly (as much as 84%) familiar with the method of channeling stress, and only one respondent stated that he is not interested in channeling stress.

In order to cope with stress, respondents resort to different techniques and behavioral modalities. The largest percentage, 37.33% (28 respondents), employees in preschool institutions, cope with stress by being active. Talking with colleagues is important for 24 of them, while 11 respondents can rely only on themselves, and the same number have no problems with stress, while only one respondent copes with stress by taking sedatives.

The obtained results indicate that symptoms related to work stress are manifested to a greater extent among younger employees (up to 30 years old), and especially in those over 55 years old. Stress is most often managed through leisure activities and discussions with colleagues.

Work stress and burnout syndrome at work have been investigated by preschool and kindergarten teachers and primary and high school teachers in numerous countries, which indicates that it is a recognized and widespread public health problem [6]. These studies have shown a high frequency of work stress and burnout syndrome with a prevalence of up to 70%, depending on whether the measured frequency was assessed by high emotional exhaustion, high depersonalization or low inefficiency and feeling of unfulfillment at work. An analysis of the frequency of burnout syndrome among preschool and kindergarten teachers and primary and high school teachers in 36 countries showed a prevalence of burnout syndrome of 38.29% for emotional exhaustion, 29.45% for cynicism, 68.75% for feeling ineffective and unfulfilled at work, with significant differences among countries. The countries with the highest frequency of emotional exhaustion are: South Africa, China, Cyprus and South Korea. In contrast, Mexico and Belgium have the lowest levels of burnout [6].

Kiparski et al. indicate that numerous studies have confirmed that the teaching profession has turned into a very stressful occupation [5]. It has been shown that about 10% to 40% of teachers in Eastern European countries suffer from intense stress or burnout, while the percentage is 50% to 70% in countries like Japan and Taiwan. Some studies in European countries have indicated that 60% to 70% of teachers are under stress, and about 30% of teachers show signs of burnout [2]. There is evidence that teachers who experience stress show a wide range of non-specific symptoms of ill health and are more likely to smoke cigarettes [3]. A Hungarian study found that: laryngitis, diseases of the loco motor system as well as the cardiovascular system are more common among teachers than among people who aren't teachers. It was found that teachers in kindergarten, primary and secondary schools are subject to a higher risk compared to teachers in higher education. Teachers and nurses in kindergarten and preschool settings are recognized as a key professional group in the research on workplace burnout syndrome [8].

A special challenge for the profession of a teacher is the introduction of inclusive education into the educational system starting from preschool institutions and the earliest ages [10].

Preschool and kindergarten teachers do not have the initial knowledge and skills to work with children with developmental disabilities. Their professional and personal experiences with children with developmental disabilities are only sporadic and the experience of isolation and neglect is common [11]. At the same time, their work is not sufficiently recognized as significant. Preschool and kindergarten teachers who work with children with developmental disabilities are exposed to additional stressful situations, so there is a greater risk of experiencing stress and burnout.

As professional stress and burnout syndrome at work is increasingly recognized as a factor that affects health and is examined among different professional groups, there is a need for a reliable and valid instrument for its examination, as well as interventions for its reduction [1]. There is ample evidence from the general literature that the nature and effectiveness of individual coping behavior moderates the relationship between stress and health and that personality characteristics may be important determinants of coping [8].

## 5. Conclusions

Based on the results of this research, the following can be concluded:

- Seventy-five people are employed in the Rakovica Preschool, DV "Labudić", most of them female due to the peculiarity of the profession.
- Symptoms related to work stress (irritability, hypersensitivity, headache, stomachache, back pain, insomnia, chronic fatigue, etc.), are manifested to a greater extent among young employees (up to 30 years old) as well as among older employees who are over 56 years old.
- Employees work with a large number of children and the very responsibility for one's life leads to an increase in the possibility of being stressed out.
- Daily events and encounters with different personality types, both among colleagues, parents and co-workers, increase the level of possibilities for stress and burnout syndrome at work.
- Employees are dissatisfied with their personal income.
- Preschool employees are generally familiar with the method of channeling stress.
- Management organizes trainings and various types of support for employees in order to empower them to prevent stress.
- Being a teacher entails a high level of work stress.

The effectiveness of overcoming stress largely depends on the intensity and duration of stress disorders caused by stress factors, but also on the situation and general circumstances in which measures to overcome stress are used, as well as on the capacity and ability of the person who experienced stress.

Given the fact that the profession of preschool and kindergarten teachers is considered one of the occupations with a risk of work stress, it is important to prevent the possible consequences of stress in the workplace. The proposal for measures arising from the analyzed results and conclusions, with the aim of reducing work stress in the work of preschool and kindergarten teachers employed at DV "Labudić", is the following:

- professional selection
- full and timely information of all who may be exposed to stress
- improving working conditions (fewer children in a group, a sufficient number of employees, reducing administration, etc.)
- organizing work in a better way and improving teamwork
- implementing good technological, organizational and psychological measures
- controlling the health status of employees more often (periodic systematic examinations)

- improving the motivation of employees through constant rewards and praise for a job that is well done
- improving communication with superiors and colleagues
- training (on computers) and preparation program for dealing with stressful situations.

In this way, in addition to adequate personal income and protection at work, the quality of work increases, stress is reduced and the quality of life is improved.

Future research could show which of these preventive measures is the most effective over a longer period of time. However, the question still remains whether the ability to manage stress is primarily determined by the personality characteristics of the employees or by the adequate implementation of prevention measures.

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# PROFESIONALNI STRES KOD VASPITAČA

*Cilj ovog istraživanja je utvrđivanje etioloških faktora (uzroka) koji utiču na pojavu profesionalnog stresa kod zaposlenih u predškolskim ustanovama. Pomoću upitnika su dobijeni podaci o zaposlenima u predškolskoj ustanovi koji su obrađeni metodom deskriptivne statistike. Rezultati pokazuju da se simptomi vezani za profesionalni stres u većoj meri manifestuju kod mlađih zaposlenih (do 30 godina), kao i kod starijih osoba preko 55 godina. Zaposleni rade sa velikim brojem dece, sama odgovornost za nečiji život dovodi do povećanja mogućnosti stresa. Svakodnevni događaji i susreti sa različitim tipovima ličnosti, kako među kolegama, roditeljima, tako i među saradnicima, povećavaju nivo mogućnosti za stres i sindrom sagorevanja na poslu. Profesija vaspitača spada među profesije sa velikim stepenom rizika od nastanka profesionalnog stresa.*

Ključne reči: *profesionalni stres, predškolske ustanove, vespitači*

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