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AMBIENT AIR QUALITY NEAR THE COPPER MINE BOROV DOL

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ABSTRACT

This study investigates the ambient air quality in the immediate vicinity of the *Borov Dol* copper mine near Radoviš, where three monitoring sites were selected at different locations surrounding the mine's concession area. The measurements were conducted over a period of six months, covering both winter and spring seasons.

For measuring the concentration of suspended particulate matter, fraction (PM_{10}) in ambient air, ES-642 Met One (USA) instruments were used, which are certified for indicative monitoring in accordance with the MCERTS (UK) standards. The measurements were performed using an automatic method based on nephelometric light scattering, which allows continuous real-time monitoring and recording of particulate concentrations.

The data analysis revealed slightly elevated PM_{10} concentrations during winter months, attributed to frequent temperature inversions and low dispersion conditions, whereas lower concentrations were recorded during spring under more favorable meteorological conditions. The majority of measured values remained below the national and EU limit values, indicating that the mine's impact on ambient air quality is relatively minor. Overall, the results confirm that effective management and mitigation strategies can minimize air quality impacts associated with copper mining operations.

Key words: *PM_{10}, monitoring, sustainable development, emissions.*

INTRODUCTION

In recent decades, international initiatives for air protection and climate action — such as the European Union Air Quality Directive (2008/50/EC) [1], the World Health Organization (WHO) Air Quality Guidelines [2], and the United Nations Sustainable Development Goals (UN SDGs) [3] — have emphasized the need for continuous monitoring, transparency, and reduction of emissions from industrial sectors, including mining. In this context, systematic measurement and analysis of PM_{10} concentrations in areas surrounding mining operations represent a key element in the development of effective air quality management strategies and in planning preventive measures.

Ambient air quality is one of the most important factors affecting human health, ecosystems, and the sustainable development of local communities. The mining industry — particularly open-pit extraction and processing of metallic ores such as copper — constitutes a significant source of dust and heavy metal emissions. The main emission sources typically arise from activities such as ore excavation and crushing, material transport, drilling and blasting, tailings disposal, and flotation and smelting processes [4–6].

Numerous studies have shown that suspended particulate matter (PM_{10} and $PM_{2.5}$) and heavy metals such as arsenic, lead, cadmium, and copper can cause serious health disorders. Long-term exposure to these pollutants is associated with respiratory diseases, organ damage, and increased risk of chronic illnesses [7–9]. Beyond the direct effects on human health, emissions from industrial and mining activities contribute to soil degradation, contamination of water resources, and disruption of local flora and fauna [10]. These impacts underline the necessity of systematic monitoring and evaluation of ambient air quality, particularly in regions with intensive mining operations, in order to develop effective strategies for risk management and environmental protection and public health protection.

In order to ensure compliance with environmental standards and support the principles of sustainable development, the Borov Dol copper mine systematically measures and analyzes PM_{10} concentrations in the areas surrounding its mining operations. These activities are aimed at developing effective air quality management strategies and implementing preventive measures to minimize potential environmental impacts.

MATERIAL AND METHODS

Location of the study area

The study was conducted in the immediate vicinity of the active copper mine Borov Dol, with monitoring instruments installed in residential areas.

The first monitoring station was located in the village of Damjan, situated northeast of the mine, at a distance of approximately 1500 m from the concession area. Damjan is a hilly village at an altitude of about 550 meters. According to the 2021 census, the village has a population of 311 inhabitants; however, according to local sources, only about 40 residents currently live there permanently, while the rest have relocated to Radoviš. The local population is primarily engaged in agriculture and livestock farming. [11]

The second monitoring site was established in the village of Brest, located northwest of the mine, approximately 600 m from the concession area. Brest is also a hilly village, situated at an altitude of 600 m. According to the 2021 census, the village has 8 inhabitants, according to local sources only 3 are permanent residents. The remaining population consists mainly of elderly individuals involved in livestock farming. [11]

The third monitoring site was the settlement of Mantovo, at an altitude of approximately 400 m and located around 1000 m from the mine concession area. Mantovo consists of about 30–40 weekend houses, which are primarily occupied on weekends. Only a few houses are inhabited by permanent elderly residents, who are engaged in livestock farming. [11]

Figure 1. Map of measurement sites

This monitoring focuses on the period from 1 December 2024 to 31 May 2025, covering both winter and spring seasons, in order to compare seasonal variations in air quality influenced by mining activities.

Measurement of Suspended Particulate Matter (PM_{10})

To determine the mass concentration of suspended particulate matter, continuous monitoring instruments ES-642 (Met One Instruments, USA) were used. These instruments operate on the nephelometric principle with time correction, allowing automatic sample collection and real-time display of PM_{10} concentrations [12].

The Met One Instruments MCERTS Particulate Monitor (Model ES-642) is a type of nephelometer which automatically measures real-time airborne PM_{10}, $PM_{2.5}$, or TSP particulate concentration levels using the principle of forward laser light scatter. Sample air is drawn into the ES-642 and through the laser optical module, where the particulate in the sample air stream scatters the laser light through reflective and refractive properties. This scattered light is collected onto a photodiode detector at a near-forward angle, and the resulting electronic signal is processed to determine a continuous, real-time measurement of airborne particulate mass concentrations [13].

The instruments are certified according to the MCERTS (UK) as devices for indicative ambient air quality monitoring, ensuring reliable and comparable data in line with standard methods, particularly under field conditions in mining areas [14].

The instruments were installed at appropriate heights and positions in accordance with ambient air measurement requirements. Measurements were conducted in 24-hour intervals with data recorded at hourly resolution. The collected data was automatically stored and subsequently processed for statistical analysis and comparison with regulatory standards, including:

- The Regulation on Limit Values for Pollutant Levels and Types in Ambient Air, Alarm Thresholds, Deadlines for Achieving Limit Values, Tolerance Margins, Target Values, and Long-term Goals [15].
- The Rulebook on Criteria, Methodology, and Procedures for Assessing Ambient Air Quality [16].

Figure 2. Measuring instrument

RESULTS AND DISCUSSION

According to national legislation, the established 24-hour limit value for PM_{10} is 50 µg/m³. The 24-hour PM_{10} values must not be exceeded more than 35 times within a calendar year, and the annual average should not exceed 40 µg/m³. [17].

Table 1 presents the measured monthly average concentrations of PM_{10} at the three monitoring sites — Damjan, Brest, and Mantovo — over the six-month period from December to May. The data shows clear temporal and spatial variations. Higher concentrations were observed during the winter months (December–February), particularly at the Brest site, while significantly lower values were recorded in the spring months (March–May) across all three locations.

Table 1. Monthly values of PM_{10} [µg/m³]

Site	December	January	February	March	April	May
Damjan	13	24	20	9	4	3
Brest	4	40	28	16	9	14
Mantovo	4	37	15	9	6	6

The elevated winter concentrations are likely influenced by meteorological factors, such as temperature inversions and limited vertical mixing, which can trap pollutants near the ground, especially in hilly or elevated areas [18]. In contrast, increasing temperatures and improved atmospheric mixing during spring promote dispersion of particulate matter, resulting in lower PM_{10} concentrations at all sites [2].

Spatial differences between the monitoring sites are also evident. Brest, situated at 600 m altitude with minimal permanent population, recorded the highest winter PM_{10} values, whereas Mantovo, at 400 m and primarily used for weekend residences, showed lower concentrations throughout the period. Damjan, at 550 m and with a small permanent agricultural population, exhibited intermediate values. These variations suggest that local topography and population activities have a secondary influence, while meteorological conditions have a major role in seasonal fluctuations.

The graphs below show the daily measured concentrations of PM_{10} in the period from December to May for all measurement sites separately.

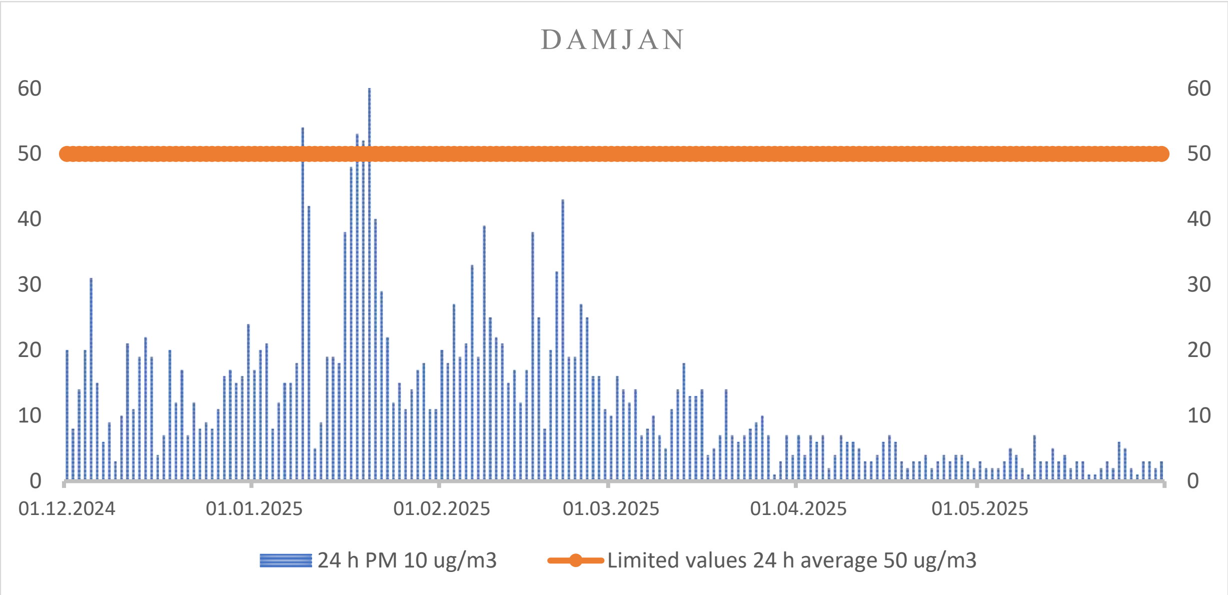

Figure 3. 24h average concentrations of suspended particles (fraction PM 10) during the months of December-May, measuring site Damjan

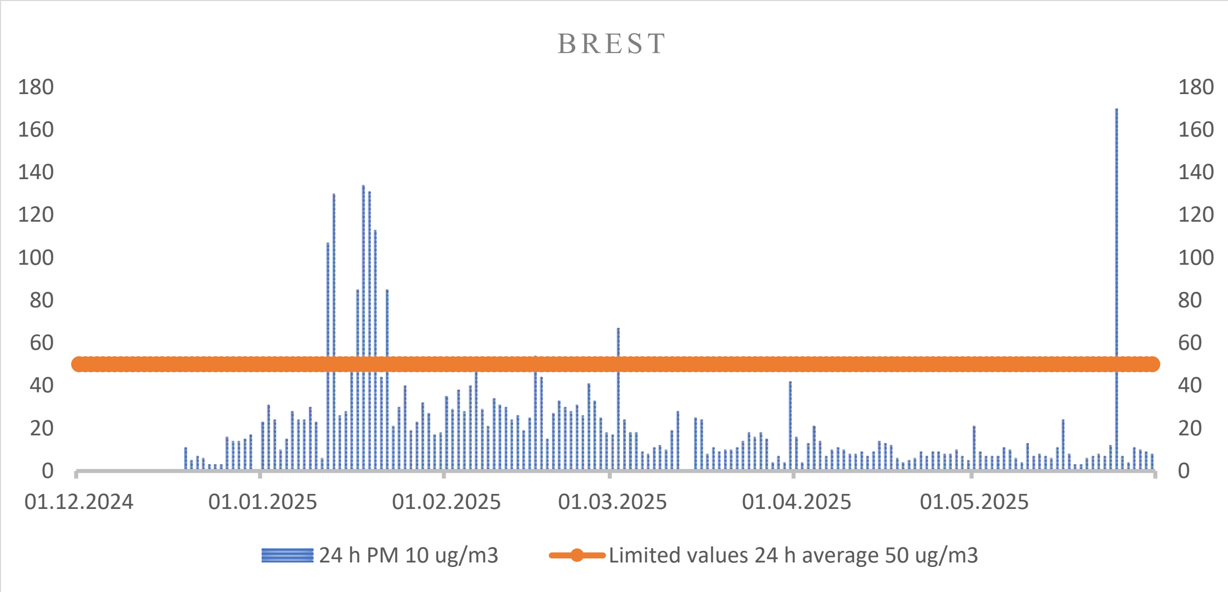

Figure 4 24h average concentrations of suspended particles (fraction PM 10) during the months of December-May, measuring site Brest

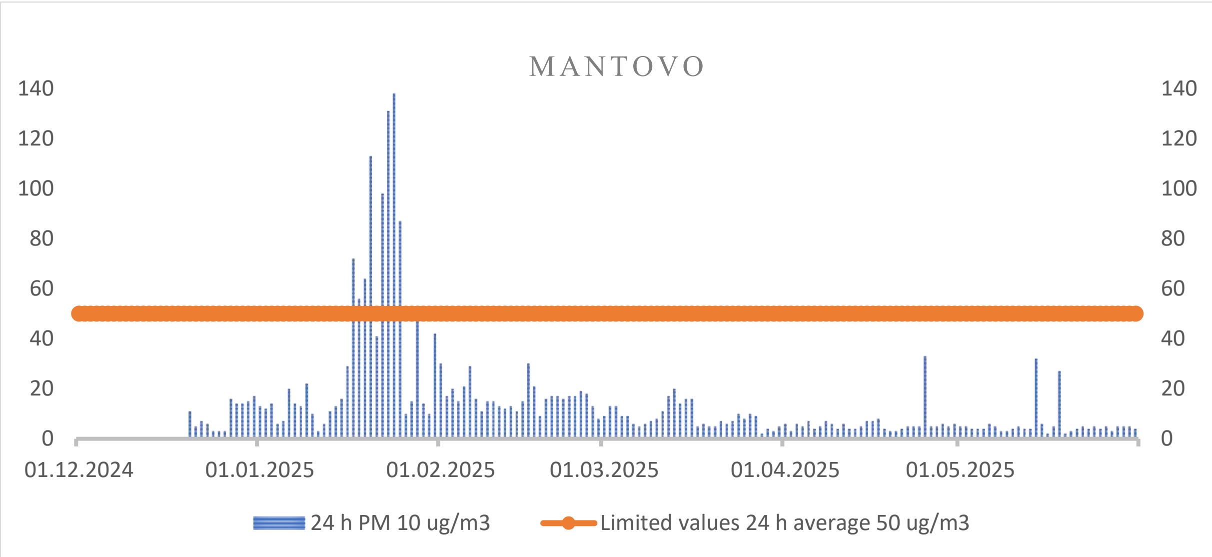

Figure 5. 24h average concentrations of suspended particles (fraction PM 10) during the months of December-May, measuring site Mantovo

During the winter months (December 2024–February 2025), PM_{10} concentrations exhibited considerable variability, with frequent peaks exceeding the regulatory limit values. This pattern is typical of the winter season, when increased household heating, adverse meteorological conditions, and limited atmospheric dispersion contribute to elevated particulate levels [19-21]

Key meteorological factors influencing these winter peaks include:

1. Temperature inversions – Layers of warmer air trap cooler air near the surface, preventing vertical mixing and concentrating pollutants close to the ground [19,20].
2. Low wind speeds – Limited horizontal transport of air masses reduces dispersion, causing local accumulation of PM_{10} [21].
3. Stable atmospheric conditions – Calm, clear winter nights lead to minimal turbulence, enhancing the persistence of particulate matter near the surface [18].
4. Topography – Hilly and valley regions, such as the locations of Damjan, Brest, and Mantovo, can form localized "pollution pockets" under inversion conditions [20].

Spatial differences were evident: Brest, at 600 m with a small permanent population, recorded the highest winter PM_{10} values, whereas Mantovo, at 400 m and primarily consisting of weekend residences, showed lower concentrations. Damjan (550 m, small permanent agricultural population) exhibited intermediate values. These differences suggest that local topography and human activities have a secondary influence, while meteorological factors are the primary drivers of seasonal variation [21,22].

In contrast, during the spring months (March–May 2025), PM_{10} concentrations generally declined and stabilized below the regulatory limit values. This reduction is attributed to improved meteorological conditions, including higher temperatures, increased wind activity, and precipitation events, which promote both horizontal and vertical dispersion and removal of airborne particles. Additionally, reduced emissions from local heating during this period contribute to lower particulate levels [20,22,23].

The results indicate that the copper mine has an insignificant impact on ambient air quality. No notable increases in PM_{10} concentrations were observed, particularly during the winter months, when meteorological conditions limit dust dispersion. Higher particulate levels may occur in spring and summer under dry conditions, emphasizing the need to differentiate between natural and industrial sources of dust.

CONCLUSION

The measurements of PM_{10} concentrations at the Damjan, Brest, and Mantovo sites exhibited clear seasonal variability. The highest values were recorded during the winter months, particularly at Brest and Mantovo, while concentrations decreased significantly at all three locations during the spring months. Analysis of the data, in combination with meteorological conditions, indicates that these variations are primarily driven by natural factors, such as temperature inversions and limited vertical mixing of the atmosphere during colder periods. Temperature inversions, especially in valley and highland areas, can trap air pollutants near the surface, leading to temporary increases in PM_{10} concentrations even in rural areas without significant local emission sources.

In the context of the copper mine, the data indicates that its impact on ambient air at the monitored sites is negligible. There is no clear evidence that mining activities lead to a significant increase in PM_{10} concentrations, particularly during the winter months, when meteorological conditions limit dust emissions from the mine. Increased dust emissions from the mine are expected during the spring and summer periods, especially during dry conditions. This highlights the need for careful distinction between natural meteorological factors and industrial sources when assessing air quality.

These findings emphasize the importance of air quality monitoring within the context of local meteorological conditions, as well as the need for locally adapted measures to control air pollution, particularly during winter. While industrial sources can be significant in certain regions, in the case of the copper mine in the studied area, natural conditions are the primary drivers of temporary increases in PM_{10} concentrations.

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