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Original scientific paper

Modeling and Visualization of Noise Levels Near Mining Operations

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ABSTRACT: The study presents an in-depth analysis of the impact of noise from mining operations, focusing on the spatial distribution of noise levels and their compliance with regulatory limits. Utilizing advanced modeling and visualization techniques, it demonstrates effective noise management strategies that ensure compliance with national regulations. Findings highlight the importance of integrating environmental assessments and technological innovations in mitigating noise pollution, underscoring the mining industry's commitment to sustainable practices and community well-being. This research contributes valuable insights into environmental management, offering a model for balancing industrial activities with ecological and health considerations. Key findings emphasize the significance of integrating environmental assessments and technological innovations to mitigate noise pollution, showcasing the mining industry's commitment to sustainable practices and community well-being. The study underlines the importance of noise management strategies that align with national regulations to protect both the environment and public health. Using advanced modeling and visualization techniques, the research offers valuable insights into environmental management, presenting a model for balancing industrial activities with ecological and health considerations. It contributes significantly to the understanding of noise pollution in the mining sector, proposing effective solutions for its control. This work is grounded in a broad review of literature on environmental pollution and specific studies on noise pollution's effects on health, highlighting the broader context of industrial and urban noise sources. It presents a detailed analysis of noise levels around a specific mining operation, including modeling and visualization of noise propagation and its impact on surrounding residential areas. The conclusion drawn from this study is that through strategic planning, technological interventions, and adherence to regulations, mining operations can effectively mitigate noise pollution. This ensures that noise levels remain within acceptable limits, thereby minimizing their impact on nearby communities and contributing to a safer and more sustainable mining environment.

Keywords: noise, modeling, visualization, mining

INTRODUCTION

Every day, the environment is more polluted with different types of pollutants due to the constant development of industry, traffic and other anthropogenic activities (Barbosa et al., 2008; Gašić et al., 2010; Lammel et al., 2010a, 2010b, 2011; Ilić 2015; Ilić et al., 2018a, 2019a, 2020a, 2020b; Wang et al., 2020; Ilić and Maksimović, 2021; Zhanibekov et al., 2022; Radović et. al 2022; Ilić et al., 2021a, 2021b; Ćirišan et al., 2023; Popović and Ilić, 2023a, 2023b). In the 20th century, due to accelerated, unilateral, and uncontrolled technological development, significant depletion of natural resources, increase in the Earth's population, insufficient knowledge about the environment, and disregard for ecological ethics, large amounts of waste and other polluting substances were emitted into the natural environment, significantly degrading it. (Nešković Markić et al., 2019; Stojanović Bjelić et al., 2022a; Ilić et al., 2021a, 2021b, 2021c, 2021d; Ilić et al., 2022; Ilić and Maksimović, 2021; Stojanović Bjelić et al., 2022b; Ilić et al., 2023a). Unaltered and preserved natural environments are increasingly scarce, while human activity zones are continuously expanding, and within them, the conditions for living and working cease to meet the most basic requirements of ordinary life (Ilić and Maksimović, 2021; Ilić, Govedar, Trkulja, 2023). All unwanted changes in the physical, chemical and biological properties of the basic components of the environment that adversely affect life by disrupting ecological systems are labeled as pollution, and appear in the form of pollutants (substances, fields) or pollutants in different components of the environment (Ilić et al., 2012; Luković et al., 2018; Ilić et al., 2018a, 2018b; Fino 2019; Ilić et al., 2019a, 2019b; Ilić et al., 2022; Ćirišan et al., 2023; Popović and Ilić, 2023; Farooqi et al., 2023; Ilić et al., 2023a, 2023c; Nešković Markić et al., 2023; Stojanović Bjelić et al., 2023).

Environmental noise represents one of the key problems of modern society (Popović et al., 2024), with a wide range of sources and impacts on people's health as well as their overall well-being. Diversity of noise sources including traffic, industrial activities, construction works and urban operations Farooqi et al., (2022), has significant socioeconomic consequences that require more effective control strategies. These authors discuss the types of noise in detail, identifying key sources and suggesting its measures in order to mitigate its impact on the community. The work of Ilić et al., (2021e) focuses on the determination, mapping and prediction of noise pollution, providing a methodology for the analysis and management of noise in urban environments. Similarly, Božić et al., 2020 investigate noise levels in modern urban intersections, while Ilić et al., 2012, 2017, 2018c, 2018e, 2018e, 2018f and Božić et al., 2018) consider traffic noise levels in the city of Banja Luka , providing valuable data on urban noise pollution. Additional studies, such as the work by Stojanović Bjelić et al., 2022 b), deal with noise in the environment with a special focus on thermal power plants. Janjuš et al., (2015a, 2015b) analyze noise generators in the City of Banja Luka and the municipality of Kotor Varoš, contributing to a broader understanding of the noise problem and its economic aspects. Noise pollution, defined as unwanted or harmful outdoor sound, has emerged as a significant environmental and health issue in modern societies. Its sources are diverse, ranging from industrial activities, transportation systems, construction works, to various recreational activities. Among these sources, mining operations represent a particularly intensive contributor, due to the nature and scale of the activities involved. Faster and more extensive creation of goods, construction of new transport links and more diverse application of auxiliary means and devices in all branches of life (especially in industry and mining) and many other factors that keep pace with modern society enable the comfort of life, but at the same time affect the endangerment of people's health. The negative consequences of such a modernized life, such as noise and non-ionizing electromagnetic radiation, can cause complex damage of human health, occur in industrially developed cities but also in urban areas in general (Popović and Ilić, 2023a, 2023b).

Environmental noise pollution is a pervasive component of the urban landscape, contributing to a range of adverse health states. The World Health Organization (WHO) has identified environmental noise as a significant threat to public health, second only to air pollution among environmental hazards (WHO, 2018). It is associated with various health risks including hearing loss, cardiovascular diseases, cognitive impairment in children, sleep disturbances, and a general reduction in quality of life (Basner et al., 2014).

Research by Farooqi et al., (2021), provides insight into urban noise and its non-auditory health effects on residents, highlighting significant effects of noise to the quality of life in urban areas. Obtained findings are consistent with the study of Farooqi et al., (2020), which deals with the assessment of noise pollution and its effects to the human health, showing that noise is not only an urban problem, but also a challenge in industrial zones. The effects of the harmful impact of noise on human health are varied, from psychological manifestations to irreversible damage to the sense of hearing (Popović and Ilić, 2023).

Mining operations, essential for extracting valuable minerals and resources, significantly contribute to local and regional noise pollution levels. The processes involved in mining, such as drilling, blasting, crushing, and material transportation, are inherently loud and can generate noise levels exceeding 85 decibels (dB) near the noise sources. For instance, studies have shown that noise levels near drilling sites and during blasting operations could reach levels harmful to human health, necessitating comprehensive noise management strategies (Dzhambov, 2015). The health impacts of noise pollution from mining operations are profound, particularly on workers and nearby residents. Workers are at an increased risk of noise-induced hearing loss (NIHL), one of the most common occupational illnesses in the mining industry. Furthermore, communities living in proximity to mining sites may experience disturbances in daily activities, reduced quality of life, and increased risks of cardiovascular diseases due to elevated noise levels (Niemann et al., 2006). Addressing noise pollution from mining operations requires a multifaceted approach, including technological, regulatory, and community engagement strategies. Technological solutions involve the use of quieter machinery, sound barriers, and the strategic planning of mine site operations to minimize noise emissions. Regulatory approaches include the establishment of noise level standards, monitoring compliance, and implementing zoning regulations to protect residential areas from excessive noise. Community engagement is also crucial in developing and implementing noise mitigation strategies, ensuring that the concerns of affected populations are addressed (Hammer et al., 2014). Noise pollution remains a critical environmental and public health challenge, with mining operations contributing significantly to the issue. Through a combination of technological innovations, regulatory frameworks, and community engagement, it is possible to mitigate the adverse effects of noise pollution and protect the health and well-being of workers and communities.

This work aims to explore the multifaceted aspects of noise pollution, with a special focus on the implications of mining operations. Here is given assessing of the noise level at the surface of the mine and its impact over the surrounding population. Modeling and visualization of noise levels around surrounding objects will be done in the work.

MATERIALS AND METHOD

Location

The subject of the research noise influence originated from surface mine Ostružnja, Stanari. South part of mine basin was examined known as Ostružnja deposit, while the south part of basin is known as deposit Raškovac. Ostružnja belongs to the Stanari municipality, in vicinity of railway and main road which connected Doboj and Prnjavor. Municipality Stanari is placed at favorable geographical position, while in accordance to the terrain configuration this area a fairly homogeneous space in size of 161 km^2. The territory of the Stanari is neighboring by the municipalities of Teslić, Tešanj, Doboj, Prnjavor and Derventa. The relief of the residential area is mostly slightly hilly and hilly with the highest altitude of 343 m and the lowest 138 m.

The model used for assessment of noise level

In order as possible faithfully presentation of the noise level, a noise map was constructed, and the results obtained via calculations were projected onto the Google map. These projections on the Google map were preceded by the drawing of clear boundaries of the front of the pit of the surface mine Ostružnja with accordance to the project documentations. According to the plan, the solid black line on map labeled the boundary of the mine, which represents the exploitation front, behind are populated areas where noise propagation is examined. The space between the white and black solid lines represents the intended protective belt of greenery, chosen in order to protect populated areas against the noise, dust, or unexpected collapse of the rim during mining operations. (Figures 1, 2, 4, 6, 8, and 10).

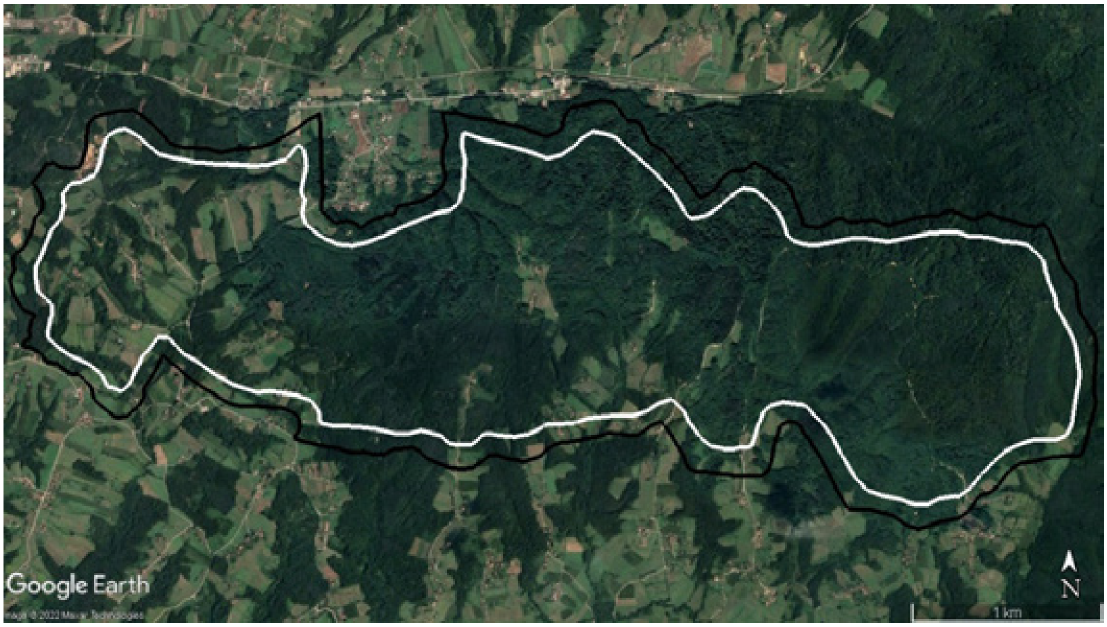

Figure 1. The black solid line represents the exploitation front. The area between the black and white lines is the noise protection zone created of the Ostružnja surface mine

The main source of noise is transportation and discontinuous heavy machinery, used for exploitation in the mine, for which it is envisaged to move or set up along the entire length of the mine boundary (along the white line). The most unfavorable case is considered when there is the spread of noise from dynamic sources, generated by excavators that produce the highest noise level in the amount of 90 dB, but also by other moving machinery which is also taken into account. Assessed length of the mine front border, where is expected exceed noise level at the mine is 17191 m.

We done an effort to assess the noise level over the target populated area objectively as is possible, where heavy machines are taken into account and considered their full contribution. This is taken as a part of discontinuous mechanization, that are placed in the more prominent parts of the mine surface on the very perimeter, on the shortest distance from the populated areas, which achieves the maximum contribution to the noise level of these machines in settlements and assumes the most unfavorable scenario. Spreading of the sound is followed by damping caused by various physical effects including friction, temperature but humidity which causes more absorption of sound energy. Amount of attenuation index of the noise accounted for its spreading through air in the calculation is $\Delta L_{air} = 2\ dB$ (Wunderli et al., 2016).

Used calculation model is simple free space analysis, where is considered the propagation of sound that does not encounter a physical obstacle. Follow this, the assessment was made for extreme case, which is the beginning of the implementation of the works, when heavy mobile machines are on the surface intended for the formation of the mine in the level of inhabited buildings. In the theoretical assessment of the noise level it is assumed that the transportations speed of moving is constant, and that their activity is twice as lower in the periods defined as evening and night according to national regulation (Regulation 2/23).

In accordance with the current national regulation (Regulation 2/23), given investigation zone belongs to the IV category that could contain: commercial, business, residential buildings with traffic corridors. For this zone, the daily, evening and night limit noise levels are 65 dB, 65 dB and 50 dB, respectively. The maximum equivalent value of the noise level in the vicinity of the mine was obtained taking into account that 10 heavy transport machines (excavator and dumper type) and all discontinuous machinery, listed in the table below, are active there daily, while the activity of all machines is reduced twice during the evening period and at night. Noise levels measured at a standard distance from heavy machinery deployed over the mine surface, whose harmfull contribution is expected in a populated area. List of masihnes deployed on minte is given in (Table 1) along with noise level they produce at referent values of 7.5 m distant, from where they could be considered in the calculation model as a point sources.

Table 1. Overview of heavy machinery and their distribution across the mine along with noise levels they produce, measured at a standard distance from each one d_0

Machine	Noise level in dB
Crusher	89
Tanker	70
Skip	80
Grader	80
Dumper	80
Bulldozer	80
Loader	85
Excavator	90
Self-propelled transporter	83
Rotary excavator	80
Procrastinator	72

The method of noise level calculation

Overview of the basic quantities, concepts and methods according to which the given assessment was performed are in accordance with the appropriate technical standard according to national regulation (Regulation 2/23). Noise level in the point (*x, y*) genarated by the source labeled with index *i* in the moment t_j postioned at (x_i,y_i), is given by next exression:

$$L_i(x,y,t_j) = L_0 + 10\log_{10}\frac{{d_0}^2}{(x_i-x)^2+(y_i-y)^2}$$

where L_0 is sound level of vehicle, according to the standard calculations (Du et al., 2021) measured at referent distance d_0 = 7,5 *m*. Average contribution to the noise level at each point of the observed location, caused by the uniform movement of mobile heavy machinery along the mine roads, was taken into account. If there are several heavy machines (*m* total number) at the location, their total contribution to the noise level at each point of the space at a given moment is summarized as follows:

$$L(x,y,t_j) = 10\log_{10}\sum_{i=1}^{m}10^{0,1L_i(x,y,t_j)}$$

Equivalent noise levels (L_{eq}) are obtained by averaging the loudness over time, at each point of the surface, as well as taking into account all possible contributions comming from heavy machines, whose work is foreseen on pile 3. These time averaging calculations were performed in according to the relation

$$L_{eq}(x,y) = 10\log_{10}\frac{1}{T}\int_0^T 10^{0,1L(x,y,t)}dt$$

where TT is the full time of movement of the transport vehicle along the path with the greatest predicted contribution to the noise level in populated areas.

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RESULTS AND DISCUSSION

Noise map

Based on the data obtained regarding the schedule of mining machinery, the number of heavy machines their distribution and the planned position of the mine, noise levels at the mine surface, its nearest residential areas, and beyond have been estimated. The studied mine covers a large area, with a perimeter of 17.2 km; therefore, to objectively present the noise levels in the field in directly exposed residential parts, the map needs to be devided on segments and results should be displayed partially to ensure clear and quality visibility of the exposure of residential area, and with it, an assessment of noise levels within them. For this purpose a total of 5 projections for different segments of the mine, which include residential areas, were made. The computationally obtained values were projected onto Google maps, resulting in noise maps, to provide as accurate a depiction as possible of the noise load in residential areas during the day and night. Assuming that the highest noise level will be during the beginning of excavation, while heavy machinery is at the level of residential areas, the dominant source of noise, the "hotspot," becomes the boundary belt, located 50 m from the mine's edge on the maps marked with a white line along which heavy machinery will be placed during the indicated phase. The green belt, on maps recognized as area between the black and white curve, serves for sound attenuation and stopping the spread of dust. To substantiate these observations, recent studies such as Pantelić et al., (2023) have underscored the significance of environmental noise impact assessments in large-scale mining operations, emphasizing the necessity of integrating noise control measures into mine planning to mitigate adverse effects on nearby communities. Similarly, Li et al., (2021) have demonstrated through simulation experiments the tangible impacts of noise on miners' safety behavior, further illustrating the critical need for effective noise management in mining environments. Moreover, research by Lokhande et al., (2018) on the upsurge of noise pollution due to open-cast mining activities has highlighted the value of utilizing modeling and mapping tools for a more faithful representation of noise exposure levels in residential areas adjacent to mining sites.

The noise field, represented by contour plots, illustrates the computationally predicted spatial distribution of noise levels, derived from a model previously described, highlighting areas exposed above and below the threshold values prescribed for day and night (Morillas et al., 2018). Reducing the intensity of heavy machinery operation at night narrows the zone where intensity exceeds the threshold and expands the area with lower sound levels (Verbeek, 2018). The contour plots are transparent, allowing all features of the Google map, including residential and other buildings, fields, forests, and roads, along with a black line denoting the boundary beyond which noise levels in residential areas are assessed, to be clearly visible. The color of each point on the image corresponds to the noise intensity at that specific real-world location as captured from satellite imagery (maps), which can be interpreted using the dB scale provided with each contour plot or along the contours on the image (Zipf et al., 2020). The analysis covers a wide belt that includes residential and other ancillary buildings of rural households, while uninhabited areas (forests, pastures) are not included.

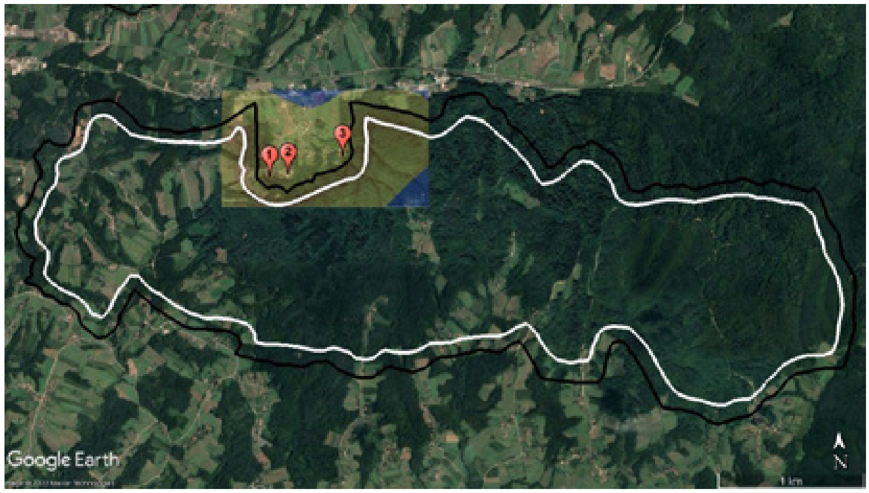

Figure 2. The first examined segment of the mine front, 2317 m long, with proposed measuring points, next to residential areas near the potentially most affected by emitted noise from heavy machinery

Areas of different colors on the provided images represent surfaces exposed to various noise levels, expressed in dB, as described in the legend of the plots. Residential buildings, located behind the front of the mine (black line) whose exposure is assessed, fall within a zone where, during the mine's daytime operational regime, image under a), the maximum predicted noise is below 60 dB, while during the evening and night, image under b), the maximum intensities do not exceed 50 dB. This means that during the two operational regimes, the noise values during all three analyzed periods (day, evening, and night) are within the limits defined by national regulation (Regulation 2/23) for Zone IV, to which this area belongs.

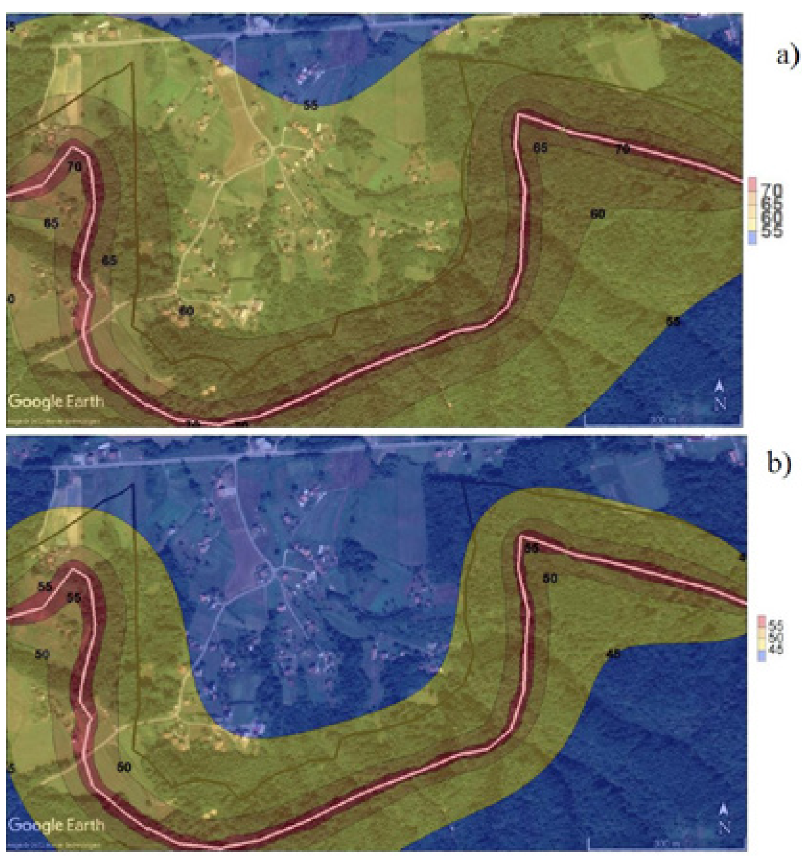

Figure 3. The first examined segment of the mine front of 2317 m length, with different colored areas with various noise levels, defined on the scale right

For the first partial segment, noise intensity exceeding according to the valid threshold values for category IV periods is not anticipated. Nowhere in the first segment, on the surface behind the black line, i.e., behind the front of the mine, during the day, the value of 60 dB is exceeded, also during the evening and night, the noise level does not exceed 50 dB. This means that during the two work regimes, the noise values during all three analyzed periods (day, evening, and night) are within the limits defined by national regulation (Regulation 2/23) for Zone IV, to which this area belongs. The studies by Peterson (2018) and Madahana et al., (2019) provide evidence supporting the effectiveness of noise management strategies in mining operations, ensuring that noise levels remain within legal limits to protect the health and safety of mine workers and nearby residential areas.

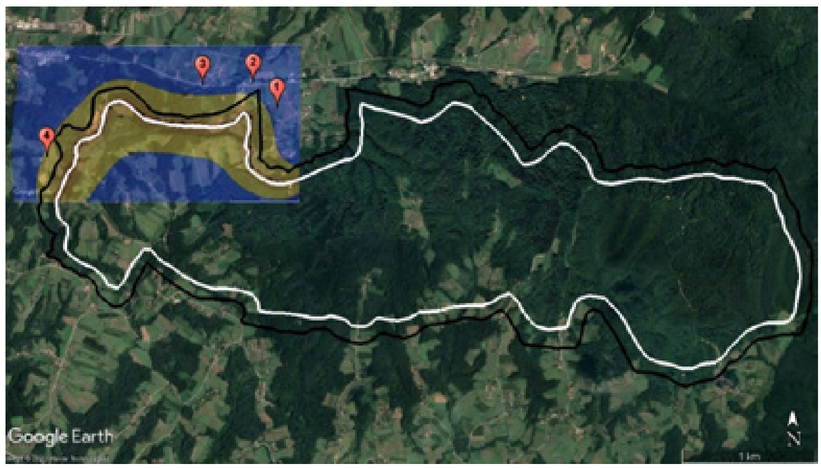

Figure 4. The second examined segment of the mine front of 2938 m length, with proposed measuring points next to residential buildings near the mine, potentially most affected by noise

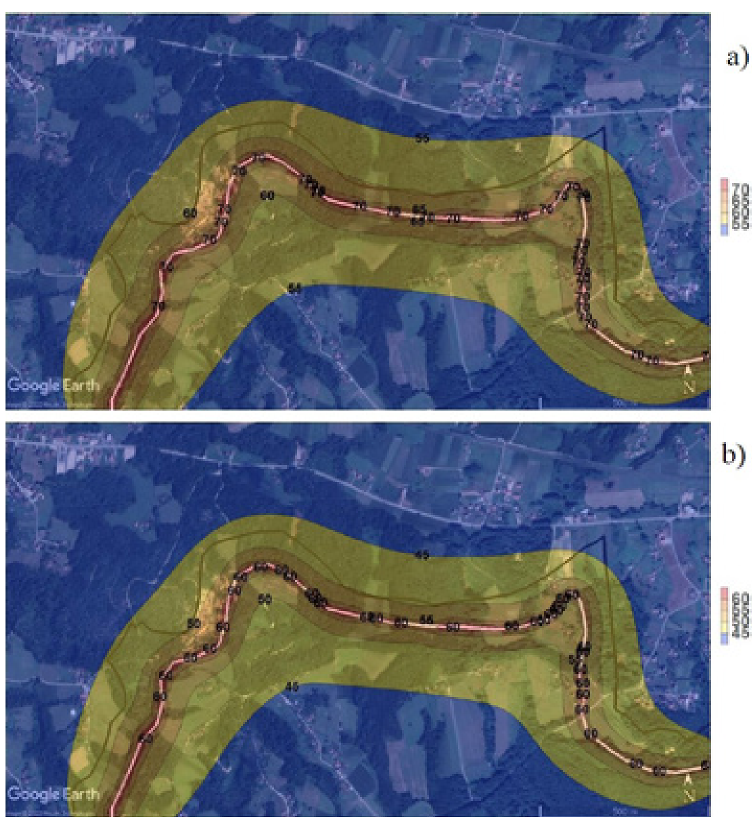

Figure 5. The second examined segment of the mine front of 2938 m length, with the different colored area exposed to various noise levels, defined on the scale on right

Calculations performed for noise spreading simulations in second segment, shown that there is no anticipated exceedance of noise levels according to the valid threshold values of Regulation 2/23 for periods defined for category IV. Nowhere outside the contour of the second segment, outlined by a black line, during the daytime period is the value of 60 dB exceeded, and during the evening and night, the level does not surpass 50 dB. This compliance ensures that during both operational regimes, the noise levels during all three analyzed periods (day, evening, and night) remain within the limits defined by national regulation (Regulation 2/23) for Zone IV, to which this area belongs.

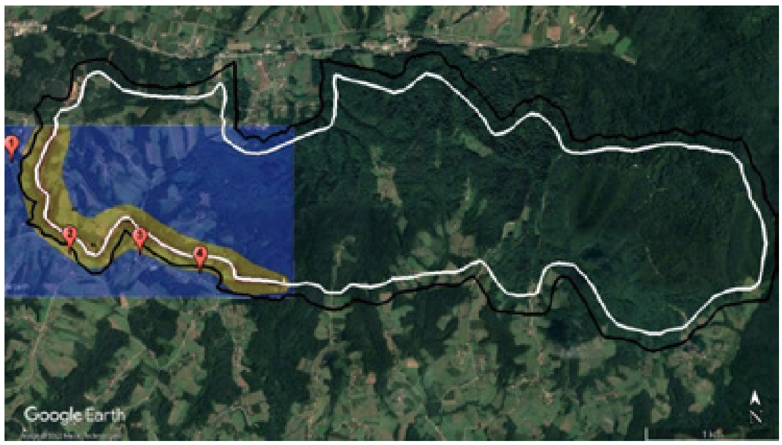

Figure 6. The third examined segment of the mine front, 3195 m long, with proposed measuring points, next to residential area, close to the mine potentially most affected by noise

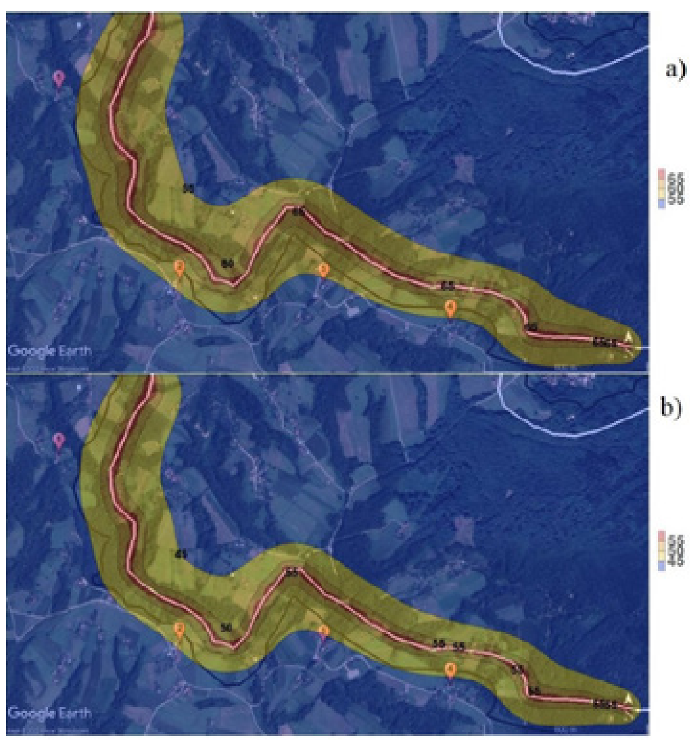

Figure 7. The third examined segment of the mine front of 3195 m long. The different colored areas are exposed to the noise of the level values given on the scale to the right side

The analysis for the third partial segment predicts that the noise levels will comply with the thresholds established by Regulation 2/23 for category IV. Within the third segment, beyond the black line or the front of the mine, the noise does not exceed 60 dB during the day, and remains below 50 dB during the evening and night, ensuring adherence to environmental standards and minimizing disturbance to surrounding areas.

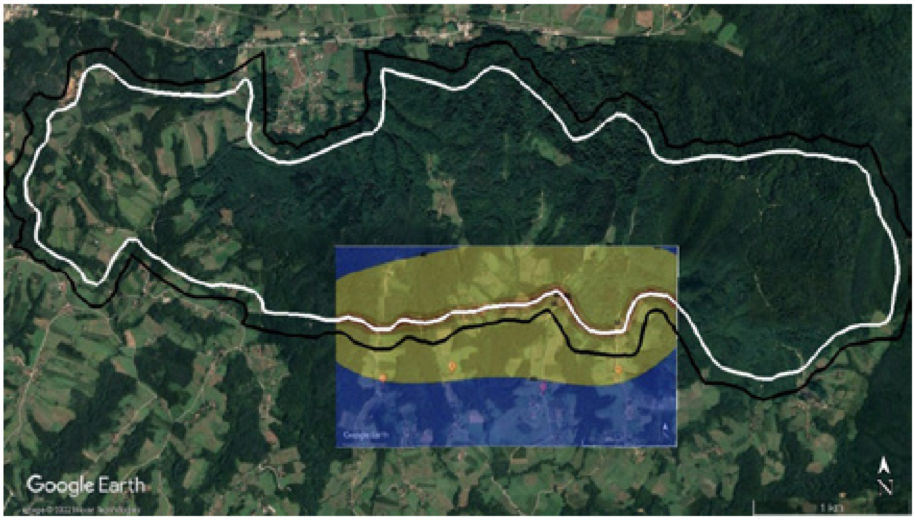

Figure 8. The fourth examined segment of the mine front of a 2773 m length and proposed measuring points, next to residential area near the mine, potentially most affected by noise

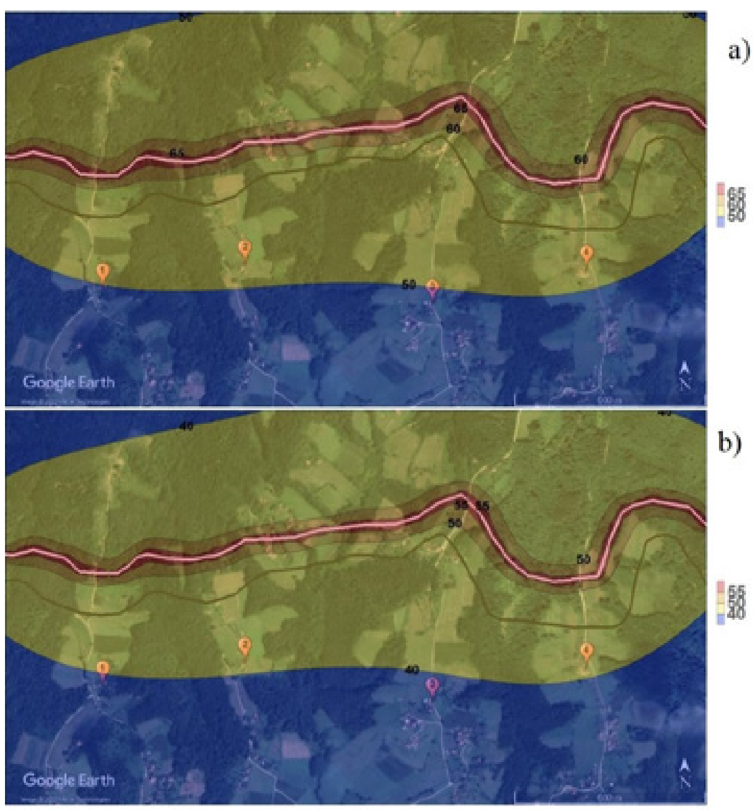

Figure 9. The fourth examined segment of the mine front is 2773 m long. The different colored areas are exposed to the noise levels given on the scale to the right side

The analysis for the fourth segment indicates that noise levels will remain within the limits established by Regulation 2/23 for category IV. Specifically, outside the boundaries of the fourth segment, marked by a black line, where noise level does not exceed 60 dB during daytime but also remains below 50 dB during evening and nighttime hours. This compliance demonstrates the effectiveness of noise control measures in maintaining environmental standards and safeguarding the well-being of nearby communities.

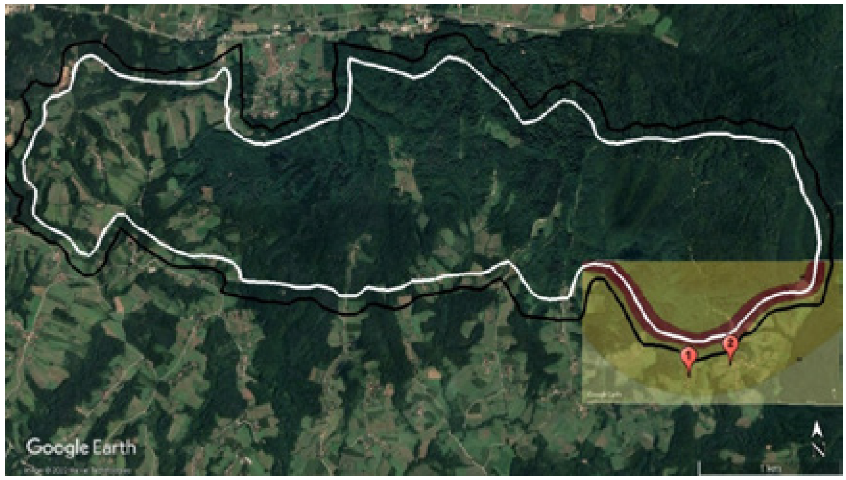

Figure 10. The fifth examined segment of the mine front of 2645 m length, with proposed measuring points, next to residential buildings near the mine, potentially most affected by noise

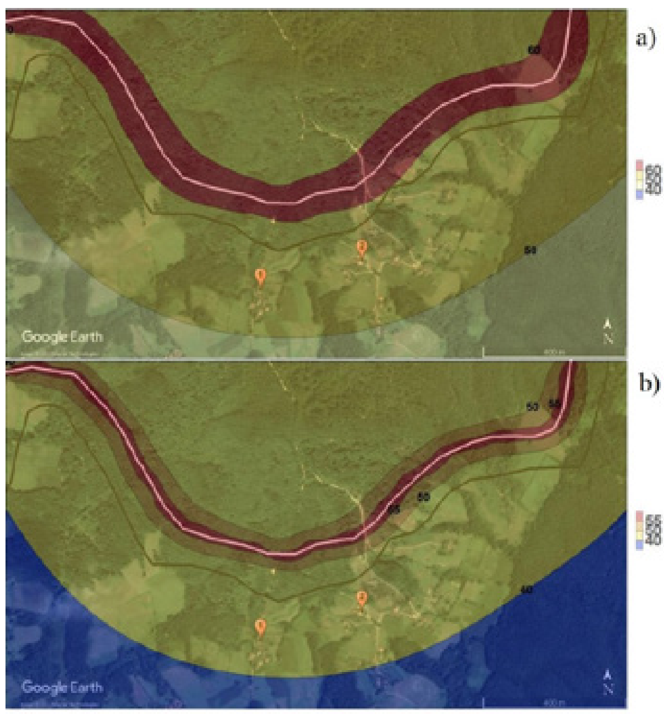

Figure 11. The fifth examined segment of the mine front is 2645 m long with the levels of noise and associate scale on right side

The analysis for the fifth segment predicts that noise levels will not exceed the limits set by Regulation 2/23 for category IV during any period. Specifically, outside the contour of the fifth segment, in front of black line, the noise level does not surpass 60 dB during the day but also stays below 50 dB during the evening and night. This indicates effective noise management strategies are in place, ensuring compliance with established environmental standards and minimizing the impact on surrounding areas.

In the analysis and discussions surrounding the management of noise pollution in mining operations, it becomes evident that addressing this challenge requires a multidisciplinary approach, combining regulatory compliance, technological innovation, and continuous monitoring. The calculated predictions for various segments of mining operations underscore the efficacy of current noise management strategies in adhering to established environmental standards, notably national regulation (Regulation 2/23) for category IV, ensuring that noise levels remain within acceptable limits both during the day and at night. These findings align with recent research that highlights the critical role of environmental impact assessments and the application of advanced modeling and mapping tools in mitigating noise pollution (Pantelic et al., 2023; Li et al., 2021; Lokhande et al., 2018).

Moreover, the inclusion of advanced noise prediction software tools and the adoption of comprehensive noise control measures further demonstrate the mining industry's commitment to reducing the adverse impacts of noise on workers and nearby communities (Lokhande et al., 2018). The continuous effort to maintain noise levels below the threshold of 60 dB during the day and 50 dB at night reflects an adherence to best practices and regulatory requirements, contributing to a safer and more sustainable mining environment.

Based on the presented results, the limit exposure during the daytime period for the area that belongs category IV, on the noise maps 3, 5, 7, 9, and 11 under a) was not exceeded anywhere (Figures 3, 5, 7, 9 and 11). All populated areas during this period are exposed to a noise level below 60 dB. During daytime operation within the planned protection zone of the mine, the sound level does not exceed the limit value of 65 dB. Therefore, based on the obtained data, according to the described model, it can be concluded that the noise level in populated areas during the daily working regime of the surface mine Ostružnja is below the level limits prescribed for the zone IV. During the evening and night periods, which coincide with the night mode of mine operation, on the noise maps 3, 5, 7, 9, and 11 shown above under b) (Figures 3, 5, 7, 9 and 11), it can be seen that the intensities in populated areas do not exceed the limit values defined by the national regulation (Regulation 2/23), i.e. are less than 50 dB.

CONCLUSION

The research results of modeling and visualization of noise levels in the vicinity of mining operations provide a significant contribution to the understanding of the impact of industrial activities on the quality of the environment and the health of local communities. The application of advanced modeling and visualization techniques enabled the identification of key zones with significant noise exposure. The research confirms that noise from mining operations is a relevant source of pollution, with far-reaching consequences for human health and well-being, highlighting the need for integration of environmental impact assessments and technological innovation in order to reduce noise pollution. The research also points to the importance of adopting comprehensive noise management strategies, including technological solutions, regulatory approaches and community engagement. Implementation of quieter machinery, use of noise barriers, strategic planning of mine site operations, and regulatory frameworks that set standards for noise levels, are key elements for effective noise management. Community engagement and transparency in communication are essential for development and implementation of noise mitigation strategies that adequately address the concerns of affected populations. This research demonstrates that through a combination of technological innovation, regulatory frameworks and community engagement, it is possible to mitigate the negative effects of noise from mining operations and protect the health and well-being of workers as well as local communities. Considering the complexity of the noise issue and its impact on various aspects of the environment and human health, future research should focus on the development and evaluation of new technologies and methodologies for noise assessment and management, as well as on further understanding of the long-term effects of noise on human health. Effective noise management in the context of mining operations is a key aspect of sustainable development, requiring a multidisciplinary approach and synergy between researchers, industry and decision makers. This research provides an important framework for considering future strategies and policies aimed at minimizing the impact of noise from mining like other industrial operations too on the environment and society.

Based on the previous analysis, it's evident that strategic planning and technological interventions have effectively mitigated noise pollution within regulated limits across various operational phases and segments of mining activities. The study conclusively demonstrates that the application of noise mapping, predictive modeling, and the implementation of noise attenuation measures, mining operations can coexist with residential areas without exceeding the noise thresholds established by environmental regulations. This represents a significant advancement in balancing of industrial activities with environmental stewardship and community well-being.

Conflict of Interest

The authors declare no conflict of interest.

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