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Analysis of the impact of mining plant operation on the environment based on noise, PM2.5, and CO_2 emissions

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Abstract
The article addresses selected aspects of the environmental impact of mining activities. The study was conducted using a dual approach: expert-based methods and empirical measurements of emissions performed in the proximity of the mining area. The expert methods included the AHP analysis and the Leopold matrix procedure. Key factors with a potentially negative impact on the environment were identified, as well as the atmospheric components most susceptible to adverse effects from industrial activity. The scope of the field research was to carry out the measurements of PM2.5 particulate matter, CO_2 emissions, and noise levels. Relationships between the aforementioned types of emissions and the intensity of traffic within the mining site were established. The research was performed at six designated measurement points
located in the vicinity of the mine.

Keywords
Mining, PM2.5, particulare matter, noise emission, CO_2, environment pollution, AHP analysis

Introduction

The environmental and societal impacts of the mining industry are a key issue that has been the subject of numerous studies. Despite the development of ever more advanced technologies for extracting and processing raw materials, as well as the implementation of pro-environmental programmes, mining activities continue to have a negative impact on the environment. (Pacana, 2024). The idea of sustainable consumption and production promotes the concept that something should be performed in the best possible way for a significant amount with fewer resources. Chemical processes are used for low-grade or complex ores that are difficult to treat, as well as for ores containing trace elements and secondary materials (waste). Traditional treatment methods may not always be sufficient to extract metal concentrates, making the use of chemical treatments crucial (Sudová, 2024). The newly formed waste deposits, spoil heaps, and dumps, which are anthropogenic forms of land surface shaping, lead to the pollution of the atmosphere, hydrosphere, lithosphere, biosphere, and anthroposphere through the emission of various harmful substances (Mocek, 2022; Kowalska and Sobczyk, 2015; Sengupta, 2021). This negative environmental impact of mining is caused not only by the underground exploitation but also by surface activities connected to open-pit exploitation and operations of mechanical processing of raw materials. The operation of mining plants significantly impacts the environment through land degradation, water pollution, and greenhouse gas emissions, disrupting local ecosystems and communities. However, integrating circular economy principles—such as resource recovery, waste minimization, and material reuse—can mitigate these effects and promote more sustainable mining practices (Šimková, 2023). This applies mostly to crushing and screening devices, especially in terms of dust and noise pollution (Paldyna et al., 2013; Saramak et al., 2016; Saramak and Naziemiec, 2019), but also a range of supporting and preparatory operations have a negative environmental impact through various emissions. Transportation can be among such operations, especially when it typically involves the use of heavy machinery and trucks. The adverse environmental impact of transportation includes, among others, the generation of mechanical vibrations, noise pollution, emissions of suspended particulates and gases containing harmful substances (Krause, 2018). Moreover, pollutant emissions also result from the degradation of vehicle components during operation, including tires, brake pads, and brake discs (Bebkiewicz et al., 2018). According to the European Environment Agency, in the year 2019, approximately 25% of CO_2 emissions in the European Union came from the transport sector, with 71.7% attributed to road transport (Wanag et al., 2021; Suproń and Łącka, 2023). Gaseous and dust pollutants, due to their small size, can be easily inhaled into the lungs and, upon entering the bloodstream, may cause various respiratory and cardiovascular diseases when the body is exposed to these substances (Report of Insp. Env. Prot., 2009; Library of Env., 2011). This may also be related to a higher level of stress, general feeling of discomfort, malaise, or even sleep disorders, especially for inhabitants in the proximity of the mining and processing plants.

Activities related to site preparation for resource exploitation constitute an additional factor negatively affecting the environment, especially in the case of open-pit mining. This process is accompanied by deforestation, which leads to the displacement of animals, a reduction in forested areas, and the exposure of soil, making it more susceptible to erosion. Another important aspect is waste generation, which may pose biological hazards or chemical threats to living organisms. Potential risks also include the presence of radium isotopes in mine waters, which are the products of the decay of the element radon and contribute to ionizing radiation in the atmosphere.

The aim of this article is to conduct a multi-faceted and multi-stage analysis of the environmental impact of selected aspects of mining activities. Expert-based methods were employed, including the Analytical Hierarchy Process (AHP) and Leopold matrix. Practical verification was carried out through on-site measurements of particulate pollution, gas emissions, and noise levels, which were conducted in the area of the mining plant operation. The study has also examined the impact of mining-related transportation on the dispersion of these pollutants in the atmosphere.

Materials and Methods

Investigations were conducted in the Mining Plant Brzeszcze, associated with TAURON Wydobycie S.A. The mine operates on an extraction area of 26.9 km², located in the Oświęcim Basin. The study was carried out in two stages:

- In the first stage, the impact of mining activity and the intensity of selected hazards on environmental components were examined,
- In the second stage, on-site investigations were conducted regarding the noise, dust, and gas emissions. Average levels of emissions were determined along with variability analyses.

AHP and Leopold Matrix methods

The Analytic Hierarchy Process (AHP) method is used as a decision-supporting tool for selecting an option in decision-making problems. This method, based on a multi-criteria approach, allows for an analysis of various factors, their interdependencies, as well as the strength of their impact on the analyzed problem (Saaty, 1980; Król and Tułecki, 2007). AHP can also be employed in the assessment of environmental impact caused by industrial plants (Ong et al., 2001; Tumidajski et al., 2008; Ramanathan, 2001). The idea of the method lies in pairwise comparison of decision alternatives and assigning appropriate weights to these pairs, determining the degree of dominance of one factor over the other. This enables a determination of the relational hierarchy of analyzed decision options and selection of an option that most effectively contributes to achieving the primary objective (problem). The primary research objective was to assess the impact of a coal mine on the natural environment, specifically on the following components: lithosphere, atmosphere, hydrosphere, biosphere, anthroposphere, and landscape aesthetics. Weights of individual elements were determined, and the consistency of comparisons was verified through the consistency index (formula 1) (Saaty, 1980).

$$Cl = \frac{\lambda max - n}{n-1} \tag{1}$$

where: n – number of alternatives, λ_{max} - maximum eigenvalue of the corresponding pairwise comparison matrix. If $CI \leq 0{,}1$, the comparisons are deemed to be consistent. In the final stage, the consistency ratio (*CR*) is determined as the quotient of the consistency index (*CI*) and Saaty's random index (*RI*), being a reference value dependent on the number of alternatives *n* (2).

$$CR = \frac{CI}{RI} \tag{2}$$

The Leopold matrix is a method that facilitates the identification of relationships and their intensity between environmental components and specific activities.

Through a calculation of the product of the impact forces and the weights assigned to individual environmental components, and then summing them, a cumulative value can be obtained to assess the overall environmental impact of a given project (Sobczyk, 2016; Sobczyk et al., 2014). The magnitude of the impact is assessed on a scale from 0 to 5 points (Kowalska and Sobczyk, 2015). The weights of the indicators are assigned using the expert-based Analytic Hierarchy Process (AHP) method. An example of a Leopold matrix layout is presented in Table 1. For a specific problem, the Table is filled in based on expert opinions.

Tab. 1 Exemplary Leopold matrix

Components of Environment	Effects on the environment		
	Impact 1	Impact 2	Impact n
Anthroposphere	value 1	value 2	value 3
Lithosphere	…	…	…
Biosphere	…	…	…
Landscape aesthetics	…	…	…

The following factors of a potentially harmful impact on individual components of the environment were selected in the analysis using the Leopold matrix: land occupation, deforestation, exhaust emissions, particulate matter, waste generation, chemical hazard, biological hazard, noise pollution, mechanical vibration, and ionizing radiation.

Field measurements

The investigative programme includes measurements at six points in situ located near the mine. Their locations are presented in Fig. 1. The first measurement point was situated in proximity to old residential buildings. The main road is located approximately 15 meters to the east and north of the measurement point. Both heavy-duty vehicles and passenger cars operate quite regularly on the road. The second measurement point was positioned directly adjacent to the entrance gate of the mining facility. From this location, aggregate is transported to customers by trucks and tractors. The main road, situated 10 meters from the entrance gate, is also used by road sweepers, mining loaders, and passenger vehicles. It was observed that drivers waiting for their turn to load often remain in front of the gate with their engines idling. The third, fourth, and fifth research points were established within a forested area aligned with the direction of the entrance gate. These measurement sites are located at distances of 15 meters, 50 meters, and 100 meters from the main road, respectively. The sixth measurement site was designated near single-family residences, directly adjacent to the main road, which is used only by passenger vehicles. Mechanical loader operations from the mining facility are audible from this location.

Fig. 1 Area of research: 1- 5 measuring points (Google Maps)

The experimental scheme included the execution of 10 measurement series at each measurement point. The dates and times of data collection are presented in Table 2. Based on the results obtained from the Leopold matrix, three significantly harmful factors were identified: exhaust emissions, dust emissions, and noise. As previously established, these factors harm the environment, with particular emphasis on the anthroposphere, biosphere, and atmosphere.

Tab. 2 Date and time of measurements

Day	Date & Time	Day	Date & Time
1	08 November, Time: 11:30 - 13:30	6	04 December, Time: 13:00 - 15:00
2	09 November; Time: 12:30 - 14:30	7	05 December, Time: 11:00 - 13:00
3	12 November; Time: 10:30 - 11:30	8	07 December, Time: 14:00 – 16:00
4	12 November; Time: 12:00 - 14:00	9	09 December, Time: 11:00 - 14:00
5	02 December, Time: 11:00 - 13:00	10	10 December, Time: 13:00 - 15:00

During the investigations, the noise level (dB), carbon dioxide emission (CO_2), and PM 2.5 particulate matter concentrations (μg/m^3) were recorded (Tab. 7). In the next stage, statistical analyses were conducted on the collected measurement data, and correlation relationships between traffic intensity and the emission levels of individual factors, were determined (Tumidajski and Saramak 2009). The traffic volume on the main road was determined by counting the number of mechanical vehicles passing along it.

Fig. 2 Measuring devices

The field investigations were conducted following the guidelines included in the relevant regulations of the Ministry of the Environment and the procedures specified in standards related to the measurement of CO_2 and PM2.5 (Regulation Minister of Env. 2011, Regulation of Minister of Env. 2007, Report of Insp. Of Env. Prot 2009). The environmental studies were carried out under the following atmospheric conditions:

- air temperature: 5°C – 7°C,
- wind speed: below 10 km/h,
- air humidity: 70% – 80%,
- atmospheric pressure: 1015 hPa – 1030 hPa.

Results

Results obtained using the AHP method

To obtain an objective assessment of the mining industry's impact on various environmental components, a specific analysis involving a panel of twenty experts was conducted. The panel comprised academic researchers and graduates in the field of mining and environmental engineering. Each expert provided an independent quantitative and qualitative evaluation. The results of the pairwise comparison of criteria are presented in Table 3. Table 4 contains the computed average values for each criterion.

Tab. 3 Results of the pairwise comparison of criteria

Components of Environment	Ant	Lit	Bio	Land	Atm	Hyd
Anthroposphere (Ant)	1	7.00	5.00	1.00	3.00	7.00
Lithosphere (Lit)	0.14	1	0.33	0.14	0.33	1.00
Biosphere (Bio)	0.20	3.00	1	0.33	1.00	3.00
Landscape aesthetics (Land)	1.00	7.00	3.00	1	3.00	7.00
Atmosphere (Atm)	0.33	3.00	1.00	0.33	1	5.00
Hydrosphere (Hyd)	0.14	1.00	0.33	0.14	0.20	1

Tab. 4 Average weights determined based on respondents' opinions

Components of Environment	The average of ten measurements
Anthroposphere	0.23
Lithosphere	0.22
Biosphere	0.2
Landscape aesthetics	0.18
Atmosphere	0.11
Hydrosphere	0.06

The results of investigations indicate that the mining plant activity has the greatest impact on the anthroposphere (0.23) and the lithosphere (0.22), which can be attributed to several factors. The impact extends well beyond the surface area of the plant, which operates extraction activities across Silesia and Malopolska provinces. The formation of waste heaps, the transport of excavated material, and the migration of particulate matter caused by wind contribute to pollution and degradation of the lithosphere. The long-range migration of dust particles negatively affects the anthroposphere. These particulate matters, especially particles below 2.5 microns (PM2.5), can enter the bloodstream and cause numerous respiratory diseases. People living near the plant are exposed to exhaust fumes due to the operation of heavy machinery. The multi-faceted nature of underground extraction activities also contributes to rock mass tremors, which can extend beyond the boundaries of the local municipality. In 2020, Brzeszcze experienced numerous and intense tremors that caused concern among residents.

The biosphere (0.20) is equally vulnerable to the occurrence of all harmful activities. During the study, the presence of birds (pheasants) and mammals (hares) was observed, particularly at the fifth measurement point. Air pollution—especially noise—frightens wildlife, forcing animals to migrate deeper into the forest in search of tranquility. Another important environmental component negatively affected by the mine is landscape aesthetics (0.18). The occupation of land by the mining plant is not the only aspect of its intrusion. Dust migration, which settles on buildings and tree leaves, affects areas far beyond the boundaries of the coal mine. Additionally, waste generated by drivers of heavy machinery significantly contributes to the degradation of landscape aesthetics. The mine's negative impact on the atmosphere (0.11) is primarily associated with transportation, mainly the emission of dust and exhaust gases. The extent of their migration depends on wind direction and speed. The smallest, yet still relevant, impact concerns the hydrosphere (0.06), because mining waste infiltrates groundwater. The Vistula River is located in close proximity.

Results obtained using the Leopold matrix

To obtain a comprehensive assessment of the plant's environmental impact, ten potentially harmful factors were selected. These factors may represent the primary sources of associated risks. Each factor was assigned a rating from 0 to 5 for the respective environmental components. The results are presented in Tables 5 and 6.

Tab. 5 Intensity of impact of specific factors on environmental components

	Effects on the environment										
Components of Environment	Weighted average	Land occupation	Deforestation	Exhaust emission	Particulate matter	Waste generation	Noise pollution	Mechanical vibration	Biological hazard	Chemical hazard	Ionizing radiation
Anthroposphere	**0.23**	3	3	4	5	4	5	2	4	4	2
Lithosphere	**0.22**	5	5	1	1	4	0	3	1	1	1
Biosphere	**0.2**	4	4	4	5	4	5	2	4	4	2
Landscape aesthetics	**0.18**	5	5	1	3	5	0	1	1	1	1
Atmosphere	**0.11**	2	5	5	5	3	0	0	2	1	1
Hydrosphere	**0.06**	1	2	1	1	1	0	1	4	4	2

Based on the data presented in Table 5, it can be seen that the highest impact (rated 5) on environmental components includes the following:

- Particulate matter – affects the anthroposphere, biosphere, and atmosphere;
- Land occupation – impacts the lithosphere, landscape aesthetics, and biosphere;
- Deforestation – affects the lithosphere and landscape aesthetics;
- Noise pollution – impacts the anthroposphere and biosphere;
- Exhaust emissions – affect the atmosphere;
- Waste generation – impacts landscape aesthetics and the lithosphere.

For field investigations, the following harmful factors characterized by very high intensity of impact were selected: particulate matter, noise pollution, and exhaust emissions.

Tab. 6 Sum of respective actions and environmental elements

	Effects on the environment											
Components of Environment	Weighted average	Land occupation	Deforestation	Exhaust emissions	Particulate matter	Waste generation	Noise pollution	Mechanical vibration	Biological hazard	Chemical hazard	Ionizing radiation	**Sum**
Anthroposphere	0.23	0.69	0.69	0.92	1.15	0.92	1.15	0.46	0.92	0.92	0.46	**8.28**
Lithosphere	0.22	1.1	1.1	0.22	0.22	0.88	0	0.66	0.22	0.22	0.22	**4.84**
Biosphere	0.2	0.8	0.8	0.8	1	0.8	1	0.4	0.8	0.8	0.4	**7.6**
Landscape aesthetics	0.18	0.9	0.9	0.18	0.54	0.9	0	0.18	0.18	0.18	0.18	**4.14**
Atmosphere	0.11	0.22	0.55	0.55	0.55	0.33	0	0	0.22	0.11	0.11	**2.64**
Hydrosphere	0.06	0.06	0.12	0.06	0.06	0.06	0	0.06	0.24	0.24	0.12	**1.02**
SUM	**1**	**3.77**	**4.16**	**2.73**	**3.52**	**3.89**	**2.15**	**1.76**	**2.58**	**2.47**	**1.49**	**28.5**

Analysis of the obtained results (Table 6) leads to the conclusion that, in principle, every analyzed component of the environment is subject to negative impacts caused by factors associated with mining activities. It has been demonstrated that the anthroposphere (8.28) is the most exposed to harmful effects generated by the mining operation. The most significant threats resulting from the plant activity are undoubtedly dust pollution (1.15) and noise (1.15). These harmful factors primarily originate from transportation activities. Heavy vehicles contribute to increased noise levels and serve as sources of dust emissions. Wind speed and direction also play a considerable role, facilitating the spread of particulate matter far beyond the premises of the mine.

With regard to the lithosphere (4.84), the greatest negative impact results from land occupation (1.1) and deforestation (1.1). The former mainly refers to the designation of land for buildings, waste heaps, railway tracks, and the broader infrastructure necessary for resource extraction. Removal of trees, on the other hand, results in erosion and soil degradation. The operation of the mine has a particularly negative impact on the biosphere (7.6). Similarly to the anthroposphere, the major threats here also arise from dust pollution (1.0) and noise (1.0).

In terms of landscape aesthetics (4.14), the most significant negative impacts are related to waste generation (0.9), deforestation (0.9), and land occupation (0.9). It has also been determined that dust pollution (0.55), exhaust emissions (0.55), and deforestation (0.55) exert the strongest impact on the atmosphere (2.64). The presence of the first two factors is undoubtedly linked to the transportation of raw materials and the formation of waste heaps, and this negative impact is intensified under windy conditions. Noise (0.0) and mechanical vibrations (0.0) were found to have no harmful impact on the atmosphere.

Among all environmental components analyzed, the hydrosphere (1.02) is the least negatively affected by the mine. Wastewater from the mine entering surface water or groundwater poses biological (0.24) and chemical (0.24) hazards, which represent the most significant threats to this environment.

Results on emissions of particulate matter, CO2 and noise

For the subsequent stage of research, three factors were identified as having the potentially greatest negative impact on the environment – based on the analyses presented in Sections 3.1 and 3.2. – were selected: exhaust gas emissions, particulate matter emissions, and noise generation. These factors are particularly detrimental to the anthroposphere, biosphere, and atmosphere. The measurements were conducted at the locations indicated in Figure 1, with ten measurement series performed at each site. The results are presented in Table 7.

Tab. 7 Results of measurements

Number of trials	Measurement points	Parameters				Number of trials	Measurement points	Parameters			
		L_{Aeq}[db]	Ø PM 2.5 (μg/m^3)	Ø CO_2 (ppm)	Number of vehicles			L_{Aeq}[db]	Ø PM 2.5 (μg/m^3)	Ø CO_2 (ppm)	Number of vehicles
Serie 1	1	59.3	63	533	5	Serie 6	1	60.7	59	527	6
	2	70.4	80	543	7		2	58.8	59	532	2
	3	64.3	73	536	8		3	52.7	50	519	3
	4	54.5	57	522	6		4	49.3	39	512	4
	5	49.1	52	509	6		5	46.7	38	505	5
	6	58.7	56	534	5		6	52.9	47	529	2
Serie 2	1	51.5	50	515	1	Serie 7	1	55.8	55	527	4
	2	62.2	54	533	5		2	61.9	55	530	4
	3	52.6	55	520	3		3	56.9	54	529	5
	4	47.9	40	509	3		4	52.1	51	523	5
	5	43.7	35	507	2		5	48.3	40	501	5
	6	57.6	47	526	6		6	58.1	43	525	5
Serie 3	1	58.3	61	530	4	Serie 8	1	54.9	52	521	4
	2	61.5	61	529	2		2	59.1	50	526	2
	3	61.2	72	533	5		3	53.4	51	523	4
	4	48.5	47	516	4		4	47.1	38	511	2
	5	44.9	38	501	3		5	42.7	31	490	1
	6	63	65	543	7		6	57.4	53	528	4
Serie 4	1	61.4	54	531	5	Serie 9	1	54.8	47	522	3
	2	70.4	61	535	6		2	69.3	65	537	6
	3	56.8	48	520	4		3	60.6	62	536	6
	4	51.3	41	518	5		4	48.2	46	516	3
	5	47.2	35	508	4		5	47.9	39	506	5
	6	58.4	47	533	5		6	51.7	39	520	2
Serie 5	1	56	58	523	3	Serie 10	1	56.2	51	531	4
	2	73.1	83	549	8		2	68.1	67	537	5
	3	55.6	70	527	5		3	55.9	55	529	4
	4	49.8	36	516	4		4	48.1	45	519	3
	5	49.5	38	504	7		5	44.7	34	503	3
	6	57.1	49	529	6		6	57.9	42	523	5

In addition to the analysis of permissible limits for the examined parameters, a series of correlation analyses was also conducted between these parameters and the traffic intensity, which is one of the main sources of carbon dioxide, particulate matter, and noise emissions. Specifically, the study investigated the relationships between the number of vehicles operating on the road and the levels of generated noise, particulate matter emissions, and CO_2 emissions, as well as the interdependencies among dust, CO_2 emissions, and noise. The results of calculations are presented in Table 8.

Discussion

Table 8 presents the values of the linear correlation coefficients between the examined parameters, where: NoC – number of cars, PM2.5 – particulate matter, LAeq – noise pollution, and CO_2 – exhaust emission.

Tab. 8 Values of the linear correlation coefficients between the examined parameters in individual locations

Point 1	NoC	LAeq	CO2	PM 2.5	Point 2	NoC	LAeq	CO2	PM 2.5
NoC		0.902	0.774	0.55	NoC		0.932	0.894	0.765
LAeq	0.902		0.808	0.627	LAeq	0.932		0.871	0.818
CO2	0.774	0.808		0.578	CO2	0.894	0.871		0.943
PM 2.5	0.55	0.627	0.578		PM 2.5	0.765	0.818	0.943	
Point 3	**NoC**	**LAeq**	**CO2**	**PM 2.5**	**Point 4**	**NoC**	**LAeq**	**CO2**	**PM 2.5**
NoC		0.908	0.861	0.733	NoC		0.954	0.716	0.613
LAeq	0.908		0.878	0.728	LAeq	0.954		0.752	0.668
CO2	0.861	0.878		0.753	CO2	0.716	0.752		0.755
PM 2.5	0.733	0.728	0.753		PM 2.5	0.613	0.668	0.755	
Point 5	**NoC**	**LAeq**	**CO2**	**PM 2.5**	**Point 6**	**NoC**	**LAeq**	**CO2**	**PM 2.5**
NoC		0.972	0.558	0.662	NoC		0.9	0.554	0.55
LAeq	0.972		0.562	0.687	LAeq	0.9		0.734	0.725
CO2	0.558	0.562		0.534	CO2	0.554	0.734		0.922
PM 2.5	0.662	0.687	0.534		PM 2.5	0.55	0.725	0.922	

The relationship between the number of cars (NoC) and noise levels (LAeq) shows a very strong positive correlation ($rs \geq 0.9$) in all measuring points. The highest value was recorded at the 5^{th} measurement point (0.972). The intensity of traffic, measured by the number of motor vehicles, was found to be the predominant source of noise emissions. It is characterized by high and harmful intensity, affecting both the anthroposphere and the biosphere.

The relationship between the number of motor vehicles (NoC) and CO_2 emissions in locations 1, 2, 3, and 4 shows a strong positive correlation ($0.7 \leq |rs| < 0.9$), with the highest at point 2 (0.894). The reason was that location point 2 was the closest to the main road, right next to the entrance gate. At points 5 (0.558) and 6 (0.554), an average correlation was observed ($0.4 \leq |rs| < 0.7$), which can be attributed to their greater distance from the main source of pollution emissions.

The relationship between the number of motor vehicles (NoC) and particulate matter emissions (PM 2.5) at locations 1, 4, 5, and 6 shows an average positive correlation was recorded ($0.4 \leq |rs| < 0.7$). These are the locations furthest from the primary emission source. In contrast, at locations 2 and 3, a strong positive correlation was identified ($0.7 \leq |rs| < 0.9$), with the highest value at location 2 (0.765). This measuring point was located directly at the entrance gate, near the customer supply area, where material may become airborne, especially under increased wind conditions.

The relationship between noise levels (LAeq) and CO_2 emissions exhibits a strong positive correlation at locations 1, 2, 3, 4, and 6, with the highest at point 3 (0.878). This indicates a very strong relationship between the number of recorded vehicles and noise levels, which confirms the results of other investigations (Ruskić et al., 2022). Only at the measuring point 5, which is the farthest from the main pollution source, an average correlation value was observed (0.562). The relationship between noise levels (LAeq) and particulate matter emissions (PM 2.5) presents a strong and positive correlation, especially at points 2, 3, and 6. The remaining measuring points showed average correlations. The relationship between particulate matter emissions (PM 2.5) and CO_2 emissions shows varying results. Very strong correlations were observed at measuring points 2 and 6, strong correlations were found at locations 3 and 4, while average correlations can be observed in points 1 and 5.

Analyzing the results presented in Table 8, it can be observed that the highest values of the examined parameters (LAeq, CO_2, PM 2.5) were recorded at point 2. This indicates that this area was the most exposed to emissions of the above pollutants. It can also be concluded that these emissions were primarily generated by road traffic. The lowest values of LAeq, CO_2, and PM 2.5 were observed at points 4 and 5, which may suggest that the trees acted as a natural barrier against the pollutants under investigation. The deeper into the forest, the lower the level of pollutant emissions. To confirm this hypothesis, additional research was conducted at measurement points 3, 4, and 5. For this purpose, 12 grams of leaves were collected from trees, then placed in small containers, and soaked in water for 30 minutes. In the final stage, the leaves were filtered. The study focused on the thickness and colour of the liquid (Figs. 3a, 3b, 3c).

Fig. 3a. Sample 3

Fig. 3b. Sample 4

Fig. 3c. Sample 5

The liquid obtained from the leaves collected at measurement point 3 showed the highest density, had a tar-like consistency, and a significant amount of sediment was observed at the bottom of the container. The colour of the liquid was the darkest compared to the other measurement points. The cleanest water sample came from measurement point 5. The liquid in this sample was thin, with a minimal amount of sediment on the surface and at the bottom of the container. The colour of the water was the lightest among all the measurement points, though not entirely colourless. The permissible upper limits for PM 2.5 particulate matter concentrations in the atmosphere include, among others, the average daily value, which is set at 15 µg/m³ according to WHO guidelines. In UE, there weren't defined daily limits, while average yearly limits equal 10 µg/m³. In the case of Poland, the average yearly limit of PM 2.5 concentration was set at 20 µg/m³ (Regulation of the Minister of Environment, 2007). The recorded measurement results were compared against these standards. The lowest value was observed at measurement point 5, where a concentration of 31 µg/m³ was observed on the eighth day. The highest value was recorded on the fifth day at point 2, reaching 83 µg/m³. It is generally accepted that the concentration of carbon dioxide in fresh outdoor air ranges from 340 to 450 ppm. Specific standard (EN 13779:2007) defines acceptable indoor CO_2 levels, considering air quality to be good when concentrations remain below 800 ppm. The values obtained during the study did not exceed this threshold. However, when compared with the values expected for outdoor air, the measured concentrations did surpass the recommended limit. The lowest recorded value was 490 ppm at measurement point 5 on the eighth day, while the highest—549 ppm—was observed at point 2 on the fifth day. The above-cited Regulation of the Minister of the Environment dated June 2007 (Regulation of the Minister of Environment, 2007) specifies acceptable noise levels. For example, over 16 hours, the permissible limit is 65 dB. The conducted research focused on short-term average noise levels, specifically five-minute intervals. To provide a partial assessment of noise emissions, the collected data were compared to these regulatory standards. Out of 60 measurements, the 65 dB threshold was exceeded five times at point 2. The recorded values were as follows: 73.1 dB (fifth day), 70.4 dB (first and fourth days), 69.3 dB (ninth day), and 68.1 dB (tenth day).

Conclusions

The results of investigations under the impact of harmful factors on environmental components indicate that the most affected elements are the anthroposphere (0.23), lithosphere (0.22), and biosphere (0.20). Furthermore, the analysis of the impact of selected factors on specific ecosystem elements using the AHP method revealed that the most intense negative impacts were associated with: suspended particulate matter, land occupation by the enterprise, deforestation, noise pollution, exhaust emissions, and waste generation. A comprehensive assessment of the environmental impact of the mine, conducted using the Leopold matrix, confirmed that the anthroposphere (8.78), biosphere (7.60), and lithosphere (4.84) are the most exposed to the negative effects of industrial activity.

The assessment of environmental impact for PM 2.5 particulate matter, noise, and exhaust emissions, carried out in the second phase of the study, demonstrated a significant and varied influence of these factors on the environment. Relevant correlation analyses indicated a direct relationship between noise intensity and the number of vehicles recorded in each study area. Measurement results showed that PM 2.5 levels exceeded permissible limits at all measurement points. Carbon dioxide concentrations also surpassed the threshold above which air can no longer be classified as fresh.

In the case of noise measurements, the obtained results at point 2 showed exceedances in several measurement series. This phase of the research confirmed the findings from the first part of the investigations, reinforcing that the three factors selected for analysis—suspended particulates, noise, and exhaust emissions—exert the most significant environmental impact.

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