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The Impact of Open-Cast Diabase Mining at Niedźwiedzia Góra Quarry in Southern Poland on the Surrounding Forest Ecosystems

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ABSTRACT

Open-cast mining of rock materials provides many essential resources for industry and construction; however, it also significantly impacts the natural environment surrounding the mining sites. The most severe environmental threats posed by open-cast mining of rock materials include land occupation and often associated deforestation, changes in the hydrological regime of the area, emissions of gaseous and particulate pollutants into the atmosphere, noise emissions, and many others. This study aimed to investigate the extent and scope of the impact of a quarry located in southern Poland on the growth and degree of defoliation of trees in the surrounding forest ecosystem, and to examine how dust deposition on the forest floor changes. Additionally, the study examined how the quarry affects the development of natural forest regeneration and the species composition of ground vegetation. For this purpose, two 140 – meter transects were established in the field, divided into four plots, with the centers located at 10, 50, 90, and 130 meters from the quarry edge. On these plots, the diameter at breast height (DBH) and height of the trees were measured, and their degree of defoliation was assessed. The understory trees were inventoried (divided into three height categories), and the contents of Al and Fe (in addition to silicon, these elements are present in diabase in the highest concentrations) in the litter was determined to assess dust deposition. Furthermore, phytosociological surveys were conducted in the plots, and each plant was assigned an appropriate light indicator value (Ecological Indicator Value). The study showed significant differences in the concentrations of Al and Fe in litter between plots, and a clear decreasing trend in the concentration of these elements with increasing distance from the quarry was observed. Trees closer to the quarry had smaller DBHs and a higher degree of defoliation, although these differences were not statistically significant. The number of understory plants in the highest height class decreased with increasing distance from the quarry. The phytosociological surveys indicated that the light requirements of plants increased with distance from the quarry. Overall, this study found that open-cast mining activities affected the surrounding forest ecosystems, and that the greatest threat posed by the quarry operations was the dust deposition on the forest floor. This phenomenon could possibly be significantly reduced by implementing a properly shaped ecotone zone.

Keywords: open-cast mining, ecological impact, forest ecosystems

INTRODUCTION

Open-cast mining in Poland provides approximately 40 different mineral resources (Kasztelewicz and Kozioł, 2015) essential for the proper functioning of the Polish economy. This is made possible by the operation of over 6.000 mining facilities, which annually extract about 350 million tons of rock minerals and over 60 million tons of lignite (Szuflicki et al., 2017). The most well-known and largest open-cast mining centers in Poland are the lignite mines in Bełchatów, Konin, and Turów. However, there are also many smaller mining centers throughout Poland that extract other rock materials. In 2015, Poland extracted as much as 232.2 million tons of natural aggregates (Kozioł et al., 2016). Despite the valuable resources obtained, mining is often a source of numerous environmental threats. The most significant impacts of open-cast mining on the natural environment include land occupation and deforestation, emissions of gas and dust pollutants, landscape degradation, effects on groundwater and surface water (cone of depression), and noise emissions (Singh et al., 2010; Lapčik and Lapčikova, 2011).

Land occupation involves the transformation of existing terrain (habitat loss) and, in the case of forest areas, the premature removal of forest stands. Land-use change often results not only in habitat loss and deforestation but also in the emission of carbon stored in the soil into the atmosphere (Houghton et al., 2012). Changes in water management related to open-pit mining usually take two forms. The first is the hydrological depression cone, which involves the lowering of groundwater levels in the affected area, significantly impacting regional groundwater and surface water resources (Harnischmacher and Zepp, 2014). This is due to the interception of aquifers in the mine and the necessity of pumping out seeping waters to allow safe extraction of the mined materials. As a result, there are often changes in moisture conditions and habitat transformation, affecting species with high moisture requirements (Miatkowski et al., 2005) and necessitating forest stand reconstruction in forest areas (Principles of Forest Management, 2023). Besides the impact on flora, changes in effective infiltration, water flow in streams, and the efficiency of water supply points are also observed within the depression cone area (Jończyk and Szczepiński, 2004). The pumped-out water is usually deposited outside the open-pit area, where it can form artificial watercourses, causing waterlogging of the terrain and, in the case of water rich in mineral salts, altering the chemistry of surface waters (Zhao et al., 2017). A significant threat to the natural environment, including forest ecosystems within the reach of mining industry activities, are dust and gas emissions, with dust emissions being more significant in open-cast mining (Ptak and Merenda, 2016). Direct deposition of dust on the leaves of both woody and herbaceous plants can disrupt transpiration, induce leaf necrosis, increase plant stress levels, and, in extreme cases, drastically reduce biodiversity by eliminating less-resistant species (Katiyar and Dubey, 2000; Saha and Padhy, 2011). Dust settling on the soil can also affect its chemical properties, particularly its pH and heavy metal content (Farmer, 1993).

The aim of the conducted research was to demonstrate the changes in growth parameters and the degree of defoliation of trees, and how the level of pollutant deposition changes with distance from the edge of the mine to the interior of the surrounding forest stand. Additionally, the study aimed to elucidate how the composition of understory vegetation and natural regeneration in the examined forest ecosystem changes depending on the distance from the mine.

MATERIALS AND METHODS

Study site

The study area covered the beech forests of the Krzeszowice Forest District in the Małopolskie Voivodeship of Poland, located in the immediate vicinity of the active Niedźwiedzia Góra quarry in Tenczynek (Fig.

Figure 1. View of the Niedźwiedzia Góra quarry

1). The quarry itself was established in 1902 (Tarkowski et al., 2012), and extracts aggregates using open-cast methods with blasting techniques to detach the rock. The primary resource extracted at the quarry is diabase (a variety of basalt) from the late Carboniferous period. Diabase is mainly used in the form of crushed stone and gravel for road substructures, railway ballast, asphalt and concrete admixtures, and as decorative stone (Delić-Nikolić et al., 2021). The chemical composition of diabases from Niedźwiedzia Góra is dominated by SiO_2 (49.69–53.2%), Al_2O_3 (15.1–17.5%), and FeO and Fe_2O_3 (totaling 8.2–15.7%) (Wolska, 1984).

The soil in the study area is Dystric Cambisol developed on loamy sands, deeply underlain by clay-stone formations, with an average slope inclination of 16° facing SE-SW. The forest stand covering the area is a 90 – year-old beech (*Fagus sylvatica* L.) stand with beech contribution not exceeding 30%, aged 150 and 70 years. Additionally, there are individual occurrences of pedunculate oak (*Quercus robur* L.), small-leaved lime (*Tilia cordata* Mill.), Scots pine (*Pinus sylvestris* L.), hornbeam (*Carpinus betulus* L.), and sycamore maple (*Acer pseudoplatanus* L.).

Data collection

Field research was conducted in September 2022. Two transects, T1 and T2, were established in the field, each 140 meters long, oriented east-west, perpendicular to the quarry edge, with the shorter side on the eastern end directly adjacent to the quarry edge (Fig. 2). Each transect was divided into four research plots measuring 20 × 20 meters, separated by 20-meter gaps (Fig. 3). The plots were designated as p10, p50, p90, and p130, corresponding to the distance of their centers from the quarry boundary, i.e., 10, 50, 90, and 130 meters, respectively.

In each research plot, measurements were taken for all trees with a diameter at breast height (DBH) > 7 cm: Tree height was measured using trigonometric methods with an accuracy of 0.25 m using a Suunto PM-5 clinometer, DBH was measured with an accuracy of 0.1 cm using a caliper, and defoliation degree was assessed using an estimated method for loss of assimilative apparatus with an accuracy of 10%. Additionally, a phytosociological survey was conducted in each plot using the Braun-Blanquet method in the C layer in a 100 m² area located centrally within the research plot. Identified plants were then assigned corresponding light indicators (L) according to Ecological Indicator Values (EIV). An inventory of understory young trees (DBH < 7 cm, height: 0.5–2.5 m) was also conducted in 100 m² subplots located centrally within the plots, divided into three height categories: 0.5–1 m (1), 1.01–1.5 m (2), and 1.51–2.5 m (3). From each corner of every research plot, samples of the top litter layer were collected (a total of 4 samples from each plot). Litter was collected from an area of 0.04 m². The litter samples were dried at 55 °C, mineralized in 60% $HClO_4$ solution and analyzed for Al and Fe contents using a Thermo Fisher ICP-OES iCAP 6000 spectrometer.

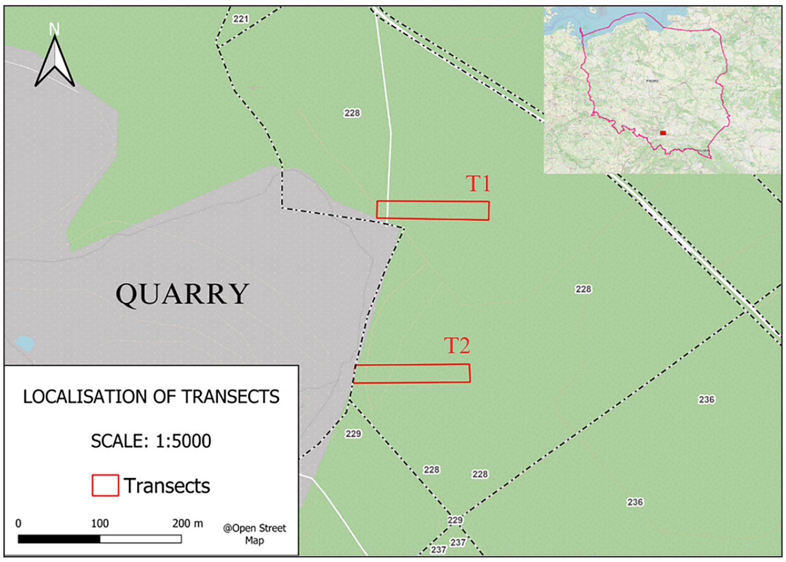

Figure 2. Study site localization and transect placement

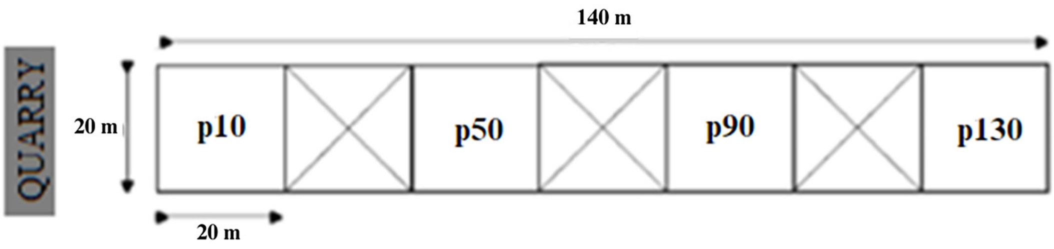

Figure 3. Plot placement and dimensions (for both transects)

Statistical analysis

For analysis purposes, plots at the same distance from the quarry edge – p10, p50, p90, and p130 (distances of 10, 50, 90, and 130 meters, respectively) – were analyzed collectively. The values of DBH, height, defoliation degree, Al and Fe contents, and understory tree count for each plot were tested for normal distribution using the Shapiro-Wilk test ($\alpha = 0.05$). The Al and Fe content values showed a normal distribution, while the other parameters' values did not conform to a normal distribution. For Al and Fe contents, Levene's test was used to assess the homogeneity of variances, followed by Tukey's HSD test to determine the significance of differences between the plots. For DBH, height, defoliation degree, and undergrowth density, the non-parametric Kruskal-Wallis test was applied to determine the significance of differences in these parameters between the different plot groups. For EIVs, the weighted mean for each plot group was calculated, where the weight was the percentage cover of the plot for a given plant species.

RESULTS

The median diameters at breast height (DBH) of trees in plots with centers located at distances of 10 m, 50 m, 90 m, and 130 m were 33.9 cm, 34.45 cm, 43.35 cm, and 43.45 cm, respectively. However, no statistically significant differences were found between the DBH of trees in the successive groups of plots. An increasing trend in DBH with increasing distance from the excavation site was observed. The median tree heights in plots with centers located at distances of 10 m, 50 m, 90 m, and 130 m were 25.5 m, 28.0 m, 29.5 m, and 25.25 m, respectively. No statistically significant differences were found between the heights of trees in the successive groups of plots. The median defoliation rates of trees in plots with centers located at distances of 10 m, 50 m, 90 m, and 130 m were 20%, 25%, 20%, and 15%, respectively. While no statistically significant differences were found between the defoliation rates of trees in the successive groups of plots, a decreasing trend in defoliation rates was observed with increasing distance from the excavation site. Trees at the end of the transect showed greater variability in DBH (interquartile range: 39.8 cm) than trees at the beginning of the transect (interquartile range: 24.3 cm). In the case of height and defoliation rates, the variability was similar (interquartile range for height: 12.25 m at the beginning of the transect and 12.75 m at the end; for defoliation rates: 20% at both the beginning and the end of the transect). Results of DBH, height, and defoliation rate are presented in Table 1.

The average contents of Al and Fe in the litter collected from the plots decreased with increasing distance from the excavation site (Fig. 4). For Al content, the p10 plots differed statistically significantly from the other plots, with an average of 1894.728 ppm for p10. In the

Table 1. Medians and interquartile ranges (IQR) for DBH, height, and defoliation degree for each plot. The letter "a" denotes homogenous groups

Plot	Median DBH	IQR of DBH	Median height	IQR of height	Median defoliation dgr.	IQR of defoliation dgr.
p10	33.90^a	24.30^a	25.50^a	20.00^a	20.00^a	12.25^a
p50	34.45^a	36.70^a	28.00^a	20.00^a	25.00^a	13.00^a
p90	43.45^a	35.10^a	29.50^a	10.00^a	20.00^a	13.50^a
p130	43.45^a	39.80^a	25.25^a	20.00^a	15.00^a	12.75^a

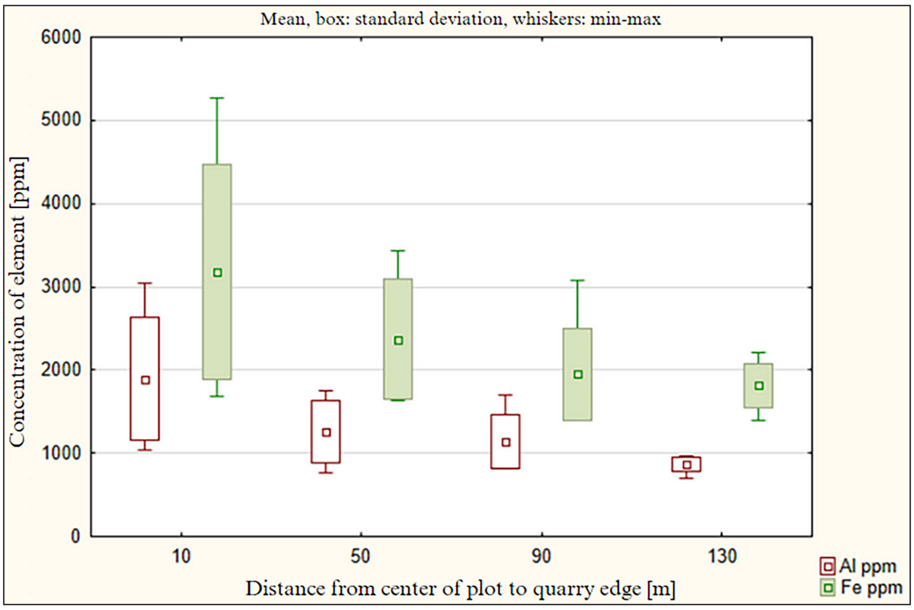

Figure 4. Concentrations of Al and Fe in the litter of each plot

remaining plots, a decreasing trend in Al content was maintained, with values of 1252.484 ppm, 1141.303 ppm, and 867.415 ppm for the subsequent plots, respectively. In the case of Fe, the p10 plots, with an average of 3173.100 ppm, differed significantly from the p90 and p130 plots, where the average Fe contents were 1947.600 ppm and 1814.850 ppm, respectively. The p50 plots did not differ significantly from the others. A clear decreasing trend with increasing distance was also noted for Fe (Table 2). The average Al content in the litter of the plots furthest from the excavation site (p130) was 45.8% lower compared to the plots adjacent to the excavation site (p10). For Fe, this value was 57.9% lower.

The number of understory young trees (DBH < 7 cm, height: 0.5–2.5 m) in successive plots was 14, 17, 6, and 12, respectively. With increasing distance from the quarry, the proportion of seedlings in height classes 2 and 3 decreased. In p10 plots, seedlings in height class 3 accounted for 50% of the total seedlings, while those in class 2 accounted for 33%. In p50 plots, seedlings in classes 3 and 2 each accounted for 41% of total seedlings. In p90 and p130 plots, however, the number of seedlings was noticeably lower, with seedlings in height class 1 accounting for 83% and 92%, respectively (Fig. 5).

Based on a phytosociological survey, the habitat was classified as Dentario-Glandulosae Fagetum association. No deviations from the characteristic floristic combination for this association were found (Pawlaczyk, 2015). The weighted means of ecological indicator values for light (EIV Ls) suggested that with increasing distance from the quarry, the light preference of the plants present increased. The difference in the light indicator between the first and last group of plots was 31.7%. For the successive plots, the average EIV Ls were 2.24, 2.83, 2.73, and 2.95, respectively (Table 3).

DISCUSSION

The observed decrease in DBH and height may be due to the deposition of dust from the quarry on the leaves of trees. Studies have shown that the deposition of dust on leaf blades limits their photosynthetic activity (Vardaka et

Table 2. Mean values of element concentrations in each plot. Letters "a" and "b" denote significant differences between values

Element	p10	p50	p90	p130
Al [ppm]	1894.728[a]	1252.484[b]	1141.303[b]	867.415[b]
Fe [ppm]	3173.100[a]	2369.225[ab]	1947.600[b]	1814.850[b]

Figure 5. Number of understory young trees of each height class (1, 2, and 3) in each plot

Table 3. Results of phytosociological surveys

Plot	Plot group		Transect 1		EIV L
	Species	Coverage	EIV L	Coverage	
p10	*Galium odoratum*	2	2.24	1	2.24
	Fagus sylvatica	+	*Fagus sylvatica*	+	
	Mycelis muralis	+			
	Stachys sylvatica	r			
	Viola reichenbachiana	r			
p50	*Fagus sylvatica*	1	2.83	3	2.83
	Epipactis helleborine	r	*Galium odoratum*	2	
			Convallaria majalis	1	
			Rubus idaeus	1	
			Rubus hirtus	+	
p90	*Galium odoratum*	2	2.73	3	2.73
			Fagus sylvatica	1	
			Rubus idaeus	+	
			Frangula alnus	r	
p130	*Galium odoratum*	1	2.95	3	2.95
	Rubus hirtus	+	*Fagus sylvatica*	1	
	Gymnocarpium dryopteris	+	*Frangula alnus*	+	
	Fagus sylvatica	+	*Quercus rubra*	+	
	Aegopodium podagraria	+	*Festuca altissima*	+	
	Mycelis muralis	r			

al., 1995) and reduces the nitrogen and phosphorus contents in the assimilatory apparatus (Chaturvedi and Obaidullach, 2012), which can be a potential limiting factor for tree growth. Trees under heavy dust exposure also show a reduction in the width of annual growth rings (Brandt and Rhoades, 1973; Parn, 2006). Defoliation may also be caused by the presence of dust pollution, which, by covering the leaf blade, clogging pores, or acting phytotoxically on leaf cells, can contribute to leaf necrosis (Squires, 2016). The amount of dust in the litter decreases with increasing distance from the quarry. The transects' location in the dominant wind direction allowed for the observation of changes in the amount of deposited dust, as wind speed and direction are the most important factors determining the movement of dust from open-pit mines (Chakraborty et al., 2002; Sastry et al., 2015). Dust settles in the topsoil layer (Magiera et al., 2021) or on the tree's assimilatory apparatus, while coniferous trees are generally better at retaining dust pollutants (Chen et al., 2017). Quarry operations likely did not deteriorate the moisture properties of the soil at the studied sites. Additionally, the soils in this area contain a significant amount of silt, which enhances their water retention properties (Hawelke et al., 2015). Some researches highlight that mining activities can lead to the leaching of heavy metals from mined materials and contamination of groundwater sources (Darwish et al., 2011), and significantly change the chemical and physical properties of aboveground streams (Miliša et al., 2010)

In the case of regeneration, better light conditions resulting from the opening of the forest stand edge near the quarry likely played a more significant role than the presence of dust pollution, comparable to the dynamics of large forest gaps (Muscolo et al., 2014). This mechanism is comparable to the characteristics of beech regeneration in forest gaps, where higher regeneration density and larger tree sizes are observed both in the gap and under the canopy near the gap (Bilek et al., 2014; Sitters et al., 2019). Changes in light and moisture conditions in forest gaps not only stimulate stand regeneration development but also alter the species composition of forest floor plants (Galhidy et al., 2006). However, the coexistence of young woody plants and herbaceous plants is also strongly influenced by antagonistic interactions between them (Mores et al., 2020), which may explain the decrease in EIV L with increasing distance from the quarry. Particulate matter pollution can also be a contributing factor to slight changes in species composition between plots, as some studies have shown that dust pollution can lead to increased plant mortality and biodiversity loss (Saini et al., 2011; Sayara et al., 2016).

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CONCLUSIONS

The activities associated with the extraction of various types of mineral resources by opencast mining bring many economic benefits, while simultaneously negatively impacting the surrounding environment. The study carried out confirms that the mining activities associated with the extraction of diabase in an open-cast mine are not without impact on the surrounding forest ecosystems. The greatest impact of the operation of the mine on the surrounding forest ecosystems was observed in the 20 m strip of trees directly adjacent to the quarry. In this zone, the growing trees were characterized by lower biometric parameters and greater damage to the assimilation apparatus. A significantly higher accumulation of dust from the mine operations settling on plant organs was also observed in this zone. The changing microclimatic conditions in the transect also influenced the change in the forest floor vegetation; that is, the light conditions changed with increasing distance from the excavation site. In the plot adjacent to the quarry edge, we also observed a higher proportion of beech regeneration, which occurred in all the distinguished height classes. A practical conclusion to be drawn from the study is the recommendation that the ecotone zone of the forest wall located in the immediate vicinity of the open-cast mine should be properly built and shaped. This ecotone zone should be constructed from a rich set of different tree and shrub species forming several strips of vegetation, varying in height. A properly shaped ecotone zone would significantly minimize the negative impact of mining activities on the surrounding forest ecosystems by intercepting dust pollution, reducing noise, or minimizing microclimatic changes.

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