BALTICA
2025 38(6)
ISSN: 0067-3064

DOI Link: https://doi.org/10.59879/BT7pG
Vol.38, Issue.6, Part.1, June 2025, PP. 62-98
Received April 2025 Accepted May 2025 Published June 2025

Environmental assessment of blasting in a copper quarry

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Abstract: Blasting is done to make the planned work more efficient and economical. It is used especially in mining, ore extraction, material fragmentation in construction, asphalt as gravel, road and railway filling, cement and concrete production as raw material, etc. The aim is to reduce the size of the rock, loosen it and shift it from the area where it is located. After these processes, smaller sizes are obtained by separating, breaking and grinding the ore or rock. However, bad and inefficient blasting causes fragmentation, cracks and splashes in the rock, air shock, dust and ground shaking. These effects cause dust in the environment, pollution of water resources, noise and vibration. In addition, vegetation, wildlife, displacement, soil degradation, erosion and groundwater pollution after a sudden impact, allows heavy metals and chemicals to leak from cracks in the rock. In this study, the effects of factors such as vibration (ground shaking), air shock effect, flying rock dust (dust emission) resulting from blasting in a copper mine on human health and the environment were examined and compared according to the limit values specified in the legislation and the studies conducted. It was determined that there was no negative physical effect on people and the environment, but there were psychological effects. These effects can be reduced by blasting in accordance with the legislation and by the person performing the blasting being careful. Environmental problems can be reduced or prevented by controlling issues such as blasting in accordance with the legislation, checking local regulations, adjusting blasting timers with reducing substances, dust suppression technique, water management systems, reclamation of mine sites, monitoring of air and water quality.

Keywords: blasting, copper quarry and fly rock, environmental assessment, vibration, air shock

Introduction

Blasting is widely used to break hard rocks during the construction of engineering structures such as derivation tunnels, underground and aboveground mines, subways, and hydroelectric power plants [1–5]. It is also widely preferred in sectors that include metallic mining, construction infrastructure, industrial establishments, and quarrying and require downsizing. In addition, as stated by Hudaverdi et al. [6], Ozacar [7], Yu et al. [8], Bayat et al. [9], and Abbaspour et al. [10], blasting is an integral part of the various stages of road construction, including tunnel excavation. Blasting is a widely used method in mining, quarrying, and civil engineering projects aimed at effectively breaking rock masses [11,12]. However, as noted by Zou et al. [13], Koopialipoor et al. [14], Ocak and Bilgin [15], and Singh et al. [16], it causes environmental challenges such as tremors, air shocks, rock rolling/scattering, and toxic gas formation.

These adverse environmental effects arising from blasting are caused by the fact that the explosive energy used to manage it with controlled blasting and to reduce its effects as a result of blasting is not used effectively for the intended areas such as shredding and excavation. This excess energy leads to various undesirable consequences such as dust/smoke, ground vibration, air explosion/pressure, and rock ejection. These consequences not only pose a risk to safety and health but also have negative effects on the environment [17,18]. Addressing these issues enables optimization of blasting techniques to minimize energy waste [19]. Research highlights the importance of not only ensuring the safety and effectiveness of blasting operations but also protecting the immediate environment and communities [20,21].

In projects where blasting is inevitable, such as quarries, the main purpose of blasting is to minimize negative environmental impacts. In addition, it is aimed to achieve optimum efficiency by providing security measures and the desired fragmentation. Then, it is necessary to reduce the hazards such as seismic activity, air explosion, tremors, ejecting rock, recoil, and noise caused by blasting and to take the required measures. The fact that most of the explosive energy (approximately 25-30%) is not used for purposes such as fragmentation and ejection in blasting leads to various undesirable environmental effects after blasting, including energy, dust/smoke, refraction, ground vibration, air explosion/air pressure, and ejecting rock [11]. These conditions pose a risk to the safety, health and welfare of individuals and can also damage structures and equipment near the blasting site [4,5]. To mitigate such damages, it provides for the optimization of blasting techniques, the use of better shredding strategies, and appropriate safety measures to protect both people and infrastructure around blasting operations [22]. When blasting is performed near houses, factories, or offices or is poorly planned, the severity of these effects increases even more [23]. For this reason, there are different approaches to determining blasting plans that optimize the desired results and minimize unwanted effects. In addition, it is ensured that the blasting process developed with the help of artificial intelligence causes fewer environmental problems with the programs developed by various researchers [4,18,24,25].

When determining the explosive parameters and blasting route, it may sometimes be necessary to perform blasting near historical buildings, residential areas, or industrial areas [26–28]. Although blasting in an area far from the quarry site does not cause vibration, the psychology of the people living in the region is disrupted, and mining activities are interrupted or even stopped. Whether blasting creates problems or damages the environment depends on the size of the impact or the speed of the particles. Analyzing these parameters is possible with a complete and harmless blast [29]. Thus, reducing the blasting to a harmless level prevents environmental complaints. In relation to environmental sensitivity, population growth, and urbanization have further increased the physical and psychological effects of blasts. With these effects, it is not possible to conduct an economical and safe explosive operation [30].

The main purpose of blasting is to use it as an economical and fast method in production and mining processes [31]. The basic working principle of this method is based on the fact that explosive substances cause a chemical reaction by creating a shock wave. After the reaction, the chemical components in the explosive move rapidly into the rock and show their effects. These effects begin to dissipate around the hole with ignition. The stress waves then propagate in all directions and produce tensile stress, and the blast occurs. With the blasting effect, high pressure and large gases move towards the cracks, and unwanted environmental effects such as vibration and noise occur [29,32]. One of the effective ways to minimize the environmental impacts of the blast is to examine the side effects it causes one by one. For example, factors such as the evaluation of ground vibration [24,33,34], flyrock prediction [8,17,35], explosion-induced air impact design [36,37], air pressure prediction [38], flyrock prediction [33,39,40], and minimization of dust generated by the blast [41–44]can be verified through a systematic review. These methods are important in terms of reducing and controlling the environmental impacts of the blasting process.

Blasting operations disrupt geological formations and lead to changes in the structural integrity of rock formations. This can lead to problems such as fracture, displacement, and weakening of rocks, which can affect the stability of the surrounding slopes, geological structures, and groundwater dynamics. Fracture and displacement of rock formations due to blasting can create new pathways for groundwater flow and potentially alter aquifer charge and discharge patterns. In addition, slope stability may be significantly affected by blasting operations, especially in areas with steep terrains or where blasting is carried out near slopes [45].

To analyze the vibrations that occur during blasting, it is important to pay attention to design parameters such as measurement distance and explosive charge amount. If the slice thickness (B) is designed at high levels, it causes the blasting energy to be at high levels and thus the rock to break. However, this may cause excessive ground tremors. When the bottom drill length (U) is large, it can create a smooth ground and cause vibrations to be felt at high levels [46]. When the slice thickness and bench height (H) are high, it can lead to the thickening of the colon to be fractured during the blast; therefore, benches should be classified according to the bench height. Tightening distance (T) that confines the explosive to the blasting colon and causes ground tremors is a significant parameter. It is stated that having a slice thickness ratio >1 with the distance between holes (S), which is another parameter, will increase the severity of fragmentation and reduce ground tremors [31,47]. By carefully evaluating these parameters, it is important to control environmental impacts and prevent undesirable consequences.

In this study, the environmental effects of blasting operations in a copper mine and their negative effects on human health were discussed.

Material and metod

In the study, the effects on the environment and human health after the explosions made during the operation of a copper mine were addressed. It is known that the energy used to break down or loosen the rock during blasting and the remaining energy part after these processes cause many environmental problems. To keep the possible environmental effects at minimum levels, the blasting design should be done well. A poorly designed blasting causes the rock not to be fragmented properly and infinity planes to develop within the rock. After this and many similar effects, environmental effects such as vibration value (ground shaking), air shock effect, flyrock, and dust emission occur.

Vibration values (Ground shaking)

Ground shaking is an inevitable consequence of the rock-blasting process. The reason why ground shaking is more important than factors such as air shock and dust formation is that it can be felt even at very long distances. While the main purpose of the blasting is to break the rock loose or push it away, at least some of the energy released during the detonation and applied to the rock is converted into inefficient residual energy in the form of seismic waves and air shocks. This energy decreases to a negligible level as it moves away from the blasting source and can travel a long distance until it is completely extinguished [48,49]. Vibrations can lead to damage to residences, industrial facilities, and other structures as well as rock formations in areas close to the source of the blast and problems in rock slope stability. First of all, the new energy arriving at the environment disrupts the status in the environment and leads to displacement. A total movement or material displacement is not seen during the wave movement. The particles that form the environment do oscillation and turning movements in their balance positions. The transport of seismic waves depends on the distance traveled, the formation, frequency, discontinuities, the source structure, and the elasticity of the environment. Ground shakes cause damage to structures by acting as earthquakes [50]. In the planning of blasts, the relationships of distance, charge, geological structure, and ground shakes should be taken into consideration. The effect of vibrations on environmental structures is measured with air shock and vibration measurement devices [51]. The U.S. Bureau of Mines Bulletin (USBM) analyzed ground vibrations in 656 open quarry mining operations based on vibration responses of various types of homes. Following the analysis, they calculated vibrations. As a result of these studies, it was calculated according to Equation 1:

$$PPV=1.090\times SD^{-1.82}\ [mm/s] \quad (1)$$

The potential "Ground Shake" effect following a blast was published in the Official Gazette dated 06.04.2010 and numbered 27601, which includes "the Regulation on the Evaluation and Control of Environmental Noise" [52]. According to the regulation, the ground shake value for the dominant frequency of the seismic waves must be 5.00 mm/s for 1.0 (Hz).

Air Shock Impact

In cases where necessary measures are not taken during blasts; reaction-induced gases that are released into the atmosphere fast and prematurely cause a significant level of noise. In conditions where measures are not taken, the noise level reaches high levels and turns into air shock waves. It is argued that another factor in the formation of shock waves is the rapidly acting rock mass. The moving rock mass creates shock waves functioning like a piston (Ratcliff et al., 2011; Siskind, 2000). Shock waves mostly cause psychological problems in humans, and they worry that the blast will harm them. Shock waves travel in the atmosphere and lead to vibrations in the windows and loose frames, causing people to believe that the blast is huge. The most prominent damage is window breakage. In addition, in window breakages, the property owners have deficiencies such as not fixed windows and loose frames and window cases. It is also observed that higher levels of shock waves cause damage to chimneys and cracking of plaster in walls. In addition, it is necessary to analyze whether there is a geological phenomenon that could lead to gas discharge by examining the blast mirror before drilling. In the presence of such a geological formation, less explosive material should be placed in the region [29,53]. According to the USBM (United States Bureau of Mines) RI 8485 Report, data collected on structural responses and aboveground mining air shock (noise) damage include equations developed to monitor the responses of the residents [54]. The noise values that may arise from the explosion are given in the "Blasting Designs and Blasting-Induced Environmental Impacts Guide" and are calculated according to the formula in Equation 2.

$$P=37{,}1\times SD^{-0.97}\ [dB(A)] \quad (2)$$

The P in Equation 2 is expressed as air shock (noise) level and SD (scaled distance).

Flyrock

Flyrock occurs when the explosive is not sufficiently buried and confined in the rock mass [55]. These are rock fragments that are caused by the high pressure developing in the blast reaction

 ISSN: 0067-3064

explosives not well confined, load distance being inadequate (hole diameter being less than 20 times), mirror (bench front face), or tightness distance being less than 80% of the load distance, the tightening material being dusty, having a low size with a diameter of a few mm, and being wet material. In such cases, the rock fragments are displaced and transported during a blast from the mouth of the hole[55]. To prevent and reduce this issue, it is essential to use holes of appropriate diameter and length to ensure a balanced and homogeneous distribution of explosives within the rock. Proper hole geometry must be calculated, with appropriate charging in the holes, leaving a stemming length at least equal to the burden (charge) distance, and using suitable materials for stemming. Additionally, the use of delayed detonation techniques is required [56].

The formula for flyrock is defined in the literature as $L_{max} = 260 * (d)^{\frac{2}{3}}$ In this formula, L_{max}: represents the maximum distance (m) that rocks can be projected in the worst-case scenario, and d refers to the hole diameter, expressed in inches. Another calculation formula is provided in Equation 3:

$$SDOB_m = \frac{l_s + 0{,}0005 * m * d}{0{,}00923 * (m * d^3 * \rho_e)^{0{,}333}} \quad (3)$$

In this formula: $SDOB_m$ represents the scaled depth of burial in the metric system ($m/kg^{0{,}333}$), ls is the stemming length (m), d is the hole diameter (mm), m refers to the contributing explosive column (charge) length, and ρe is the explosive density (g/cm^3). The maximum value of "m" is 8 if the hole diameter is less than 100 mm (4 inches) and 10 if it is greater than or equal to 100 mm (4 inches) (Equation 4).

$$m_m = \frac{1000 * l_c}{d} \quad (4)$$

In the formula, mm represents the length of the contributing explosive column (charge) in terms of hole diameter, lc represents the length of the explosive column (charge) in meters, and d is the hole diameter in millimeters (Equation 5).

The formula for the maximum flyrock distance is given as:

$$L_{max} = 11 * (SDOB_m)^{-2{,}167} * d^{0{,}667} \quad (5)$$

The Ministry of Environment and Urbanization's General Directorate of EIA, Permit, and Inspection published a guide in 2018 titled "Blasting Designs and Environmental Effects of Blasting." According to the guide, the burden distance (the distance from the bottom of the hole to the bottom of the bench face) should not be less than 22 times the hole diameter. The stemming length must be equal to the burden distance, and aggregate (crushed rock) should be used as the stemming material. Before drilling holes, it is necessary to check the bench face for geological faults, open joints, clay seams, fractures, and crushed zones. If faults are present, less explosive material should be placed in the affected hole(s), the hole(s) should be charged in stages, or the holes should be abandoned. It is noted that, with the necessary precautions, rock projection over long distances can be prevented. Additionally, if the aforementioned measures are implemented, the maximum distance that fragmented rocks can be projected during blasting is expected to be no more than four times the bench height.

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Dust

In addition to vibration, air shock, and rock ejection, another environmental impact of blasting—often overlooked—is the generation of dust and toxic gases [57]. Dust refers to solid particles smaller than 1 mm in diameter that can remain suspended in the air or settle over time.

During rock blasting, a large amount of rock mass can be mobilized, leading to internal grinding and subsequent dust emissions. In large and open quarry mining operations, dust emissions from blasting are generally negligible and short-lived compared to other sources of dust. However, the formation of dust is a significant issue that should not be underestimated, as it affects not only the economic lifespan of machinery and equipment but also the health of workers. Although dust generation during the blasting process is unavoidable, it can be controlled through appropriate measures. Dust formation can be mitigated during staged blasting. To prevent dust, wetting procedures are carried out, including loading and preparing the holes, followed by wetting the cleared area before blasting. Dust suppression is achieved by spraying pressurized water near the blasting holes just before detonation using tankers equipped with pressurized water jets.

During blasting, in addition to toxic gases, dust particles that can harm the environment and local residents may also be generated. For every cubic meter of rock mass broken, approximately 500 grams of dust can be released into the atmosphere. Silicates constitute the majority of airborne dust. Micron-sized silicate particles can adhere to lung alveoli with each breath, potentially causing scarring in the lungs over time. The accumulation of silica dust in the lungs can also lead to cancer, bronchitis, and tuberculosis. Moreover, depending on the type of mineral produced, particles of nickel, beryllium, uranium, cadmium, and iron can become airborne, contributing to the risk of heart disease and Alzheimer's disease. Therefore, it is crucial to implement measures to prevent dust generation and ensure the use of personal protective equipment [57].

Results and Discussion

Information about the study area

A copper mining operation, including both underground and surface mining, is planned in the Köprübaşı area of Mutki district, Bitlis province. The project involves the production of 250,000 tons of copper annually using blasting methods. In the open quarry mining areas, the benches will be designed with sufficient width to allow safe and efficient movement of trucks during forward and reverse maneuvers, as well as turns. The bench height is planned to be 12 meters, the bench width 15 meters, the bench slope angle 55°, and the overall slope angle 27°. Access to the underground mine will be provided through adits, with four adits already opened in the mining area. The cut-and-fill method will be employed for underground mining activities, and loosening blasts will be used to extract copper ore. Surface mining operations will be conducted for six months each year, with work occurring 26 days per month, 8 hours per day, and in a single shift. Underground mining operations will be conducted year-round, with three shifts per day, operating 30 days per month and 22.5 hours per day. A total of 40 people will be employed during the land preparation and production phases. The copper mine is approximately 39 km from the Bitlis city center, 24 km northeast of Mutki district, 1.7 km east of Kayran, and about 1.5 km from Yazıcık neighborhood. The project area consists of "forest, meadow-pasture, rocky and stony areas, shrubland, and scrubland" (Figure 1).

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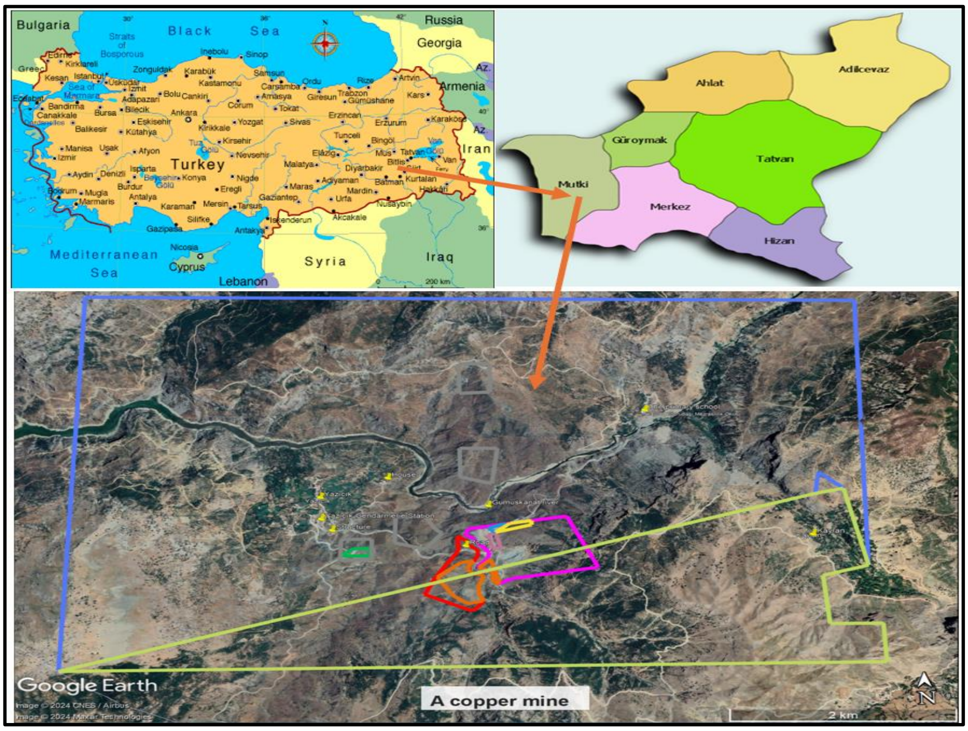

Figure 1. Location map

The project site is located on the L47-a3 sheet of a 1/25000 scale topographic map. The positions of the working area have been determined using GPS, and the coordinates of UTM-system points have been transferred onto the relevant sheet (Figure 2) and a Google Earth image (Figure 3).

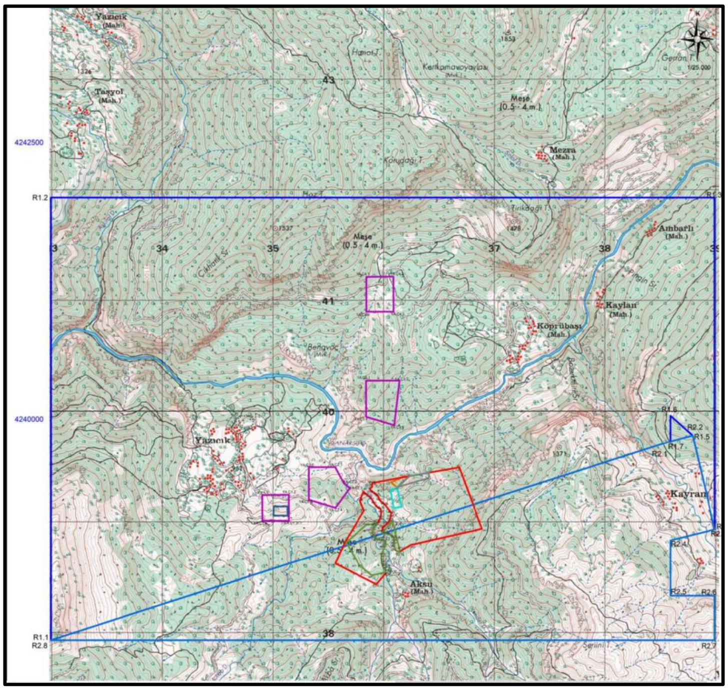

Figure 2. Location of the study area on the 1/25000 scale topographic map

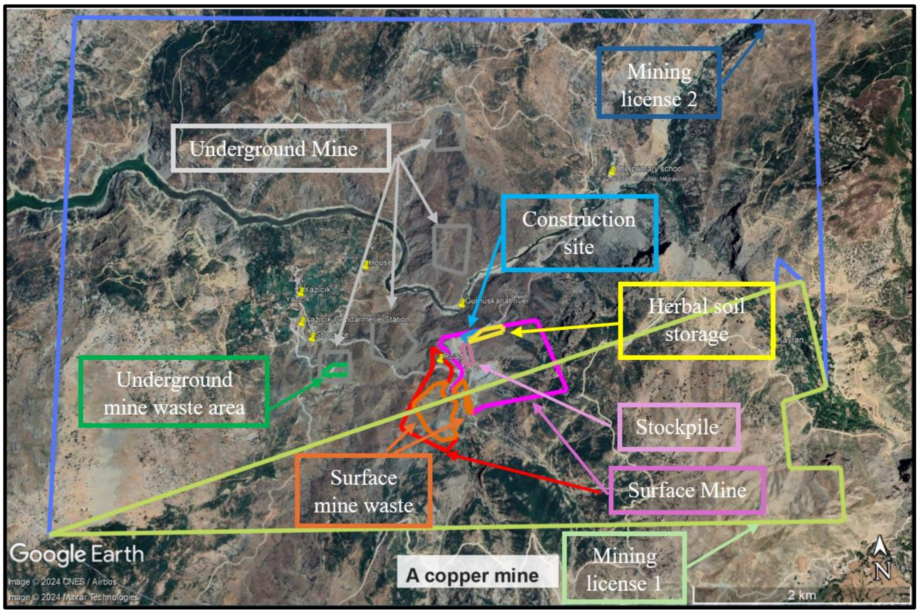

Figure 3. Google Earth (satellite) location of the project site *Geological assessments of study area*

The copper mining site is located in the western part of Bitlis Province, including Mutki District, and encompasses part of the Eastern Taurus Mountains. The geographical arrangement of the region has become distinct due to Middle Miocene tectonic movements. In the region described as the Bitlis-Hakkari Taurus, the Southeastern Anatolia Plateau gradually rises and transitions into the marginal fold belt. To the north of this belt, in an area he termed the Front Thrust Zone, the Bitlis Metamorphic Belt is situated with a sudden uplift. North of the Bitlis Metamorphic Belt, there is a sudden extension into the Muş Basin. In all these belts, the main topographic features are oriented approximately east-west, in accordance with the region's tectonic structure. The geological formations in the area surrounding the copper mine include the Kızılağaç Formation, which is the youngest formation and is of Cenozoic age. This formation consists of interbedded conglomerates, mudrocks, micritic limerocks, sandrocks, calcareous clays, and shales [58]. Serpentinites are the most common rock type forming the Guleman Ophiolite, with sections that are relatively well-preserved and exhibit a dark green to black color, being massive and fine-grained, and of Mesozoic age [58]. The Çırrık Formation, found on the northern slope of Çırrık Mountain, consists of gray-black, medium to thick-bedded, bituminous, fossil-bearing, recrystallized limerocks with intercalations of yellow-gray calc-schists, graphite-schists, and quartzites. This formation is of Paleozoic age [58]. The Çeşme Formation is composed primarily of dolomite and green schist blocks, including felsic metavolcanic rocks, meta-agglomerates, and meta-quartz porphyry. It overlies the Meydan Formation and is of Upper Paleozoic age [58].

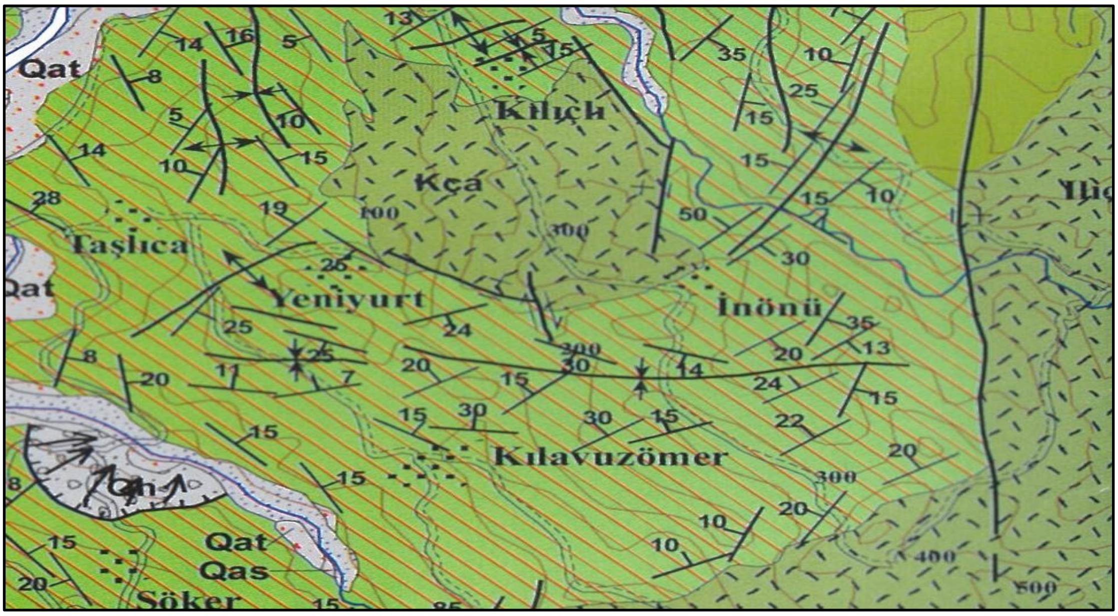

Figure 4. Geological map of the project area and its surroundings

The study area has been evaluated in terms of tectonic structure and seismic activity. The Eastern Anatolia Region is one of the areas in Turkey with ongoing seismic activity. The general tectonic structure of this region is characterized by the Bitlis Thrust Zone, which results from the collision between the Arabian Plate and the Anatolian Plate and is moving northward. This movement leads to frequent earthquakes and seismic activity in the region. The geological structure and tectonic mobility of the Eastern Anatolia Region create conditions that facilitate the release of blasts and the occurrence of earthquakes. Therefore, regional measures and ongoing work must address earthquake risks. Updated earthquake preparedness plans play a crucial role in managing seismic risks in the area (Figures 4 and 5).

One of the regions with significant seismic activity in Turkey is the Eastern Anatolia Region. The general tectonic structure of Eastern Anatolia is primarily influenced by the collision between the Arabian Plate and the Anatolian Plate, with movement occurring along the Bitlis Thrust Zone to the north. The collision is dominated by the right-lateral North Anatolian Fault and the left-lateral East Anatolian Fault converging at the Karlıova triple junction. Additionally, this collision results in dominant northwest-trending right-lateral strike-slip faults and northeast-southwest-trending left-lateral strike-slip faults in the eastern part of the Karlıova triple junction. Other significant tectonic features in the Eastern Anatolia Region include the east-west trending Muş-Van Lake and Pasinler Basins.

The project involving changes to the production volume and blasting methods for both underground and surface copper mining is situated within the 1st earthquake zone according to the Turkish Earthquake Zone Map prepared by the Department of Earthquake Research, General Directorate of Disaster Affairs, Ministry of Public Works and Settlement.

Special support systems used in mines prevent the collapse of gallery voids. In underground mines, shelters should be constructed to serve as the safest place for workers to take refuge in emergency situations when surface access is not possible. When determining the location of these shelters, it is crucial to thoroughly assess the seismic activity and potential destructive effects of underground transmission lines, cracks, and pipelines.

ISSN: 0067-3064

For the copper mining operation area, the following earthquake-related measures for underground mines are listed (Figure 6):

➢ Special support systems are installed to prevent the collapse of gallery structures.

➢ Safe rooms should be constructed in underground mines.

➢ Emergency sirens must be installed and activated during an earthquake.

➢ Personnel should move from emergency exits to the assembly area and take refuge in the pre-determined safety triangle.

➢ Employees should be informed about earthquake preparedness and the necessary safety measures.

The landslide conditions of the copper mine and its surroundings have been assessed based on data provided by the Bitlis General Directorate of Disaster Affairs. According to the map shown in Figure 7, the mine and its surrounding area are situated to the west of the landslide zone within the Environmental Impact Assessment (EIA) area. The distance between the landslide areas and the mining site indicates that there is no significant landslide risk.

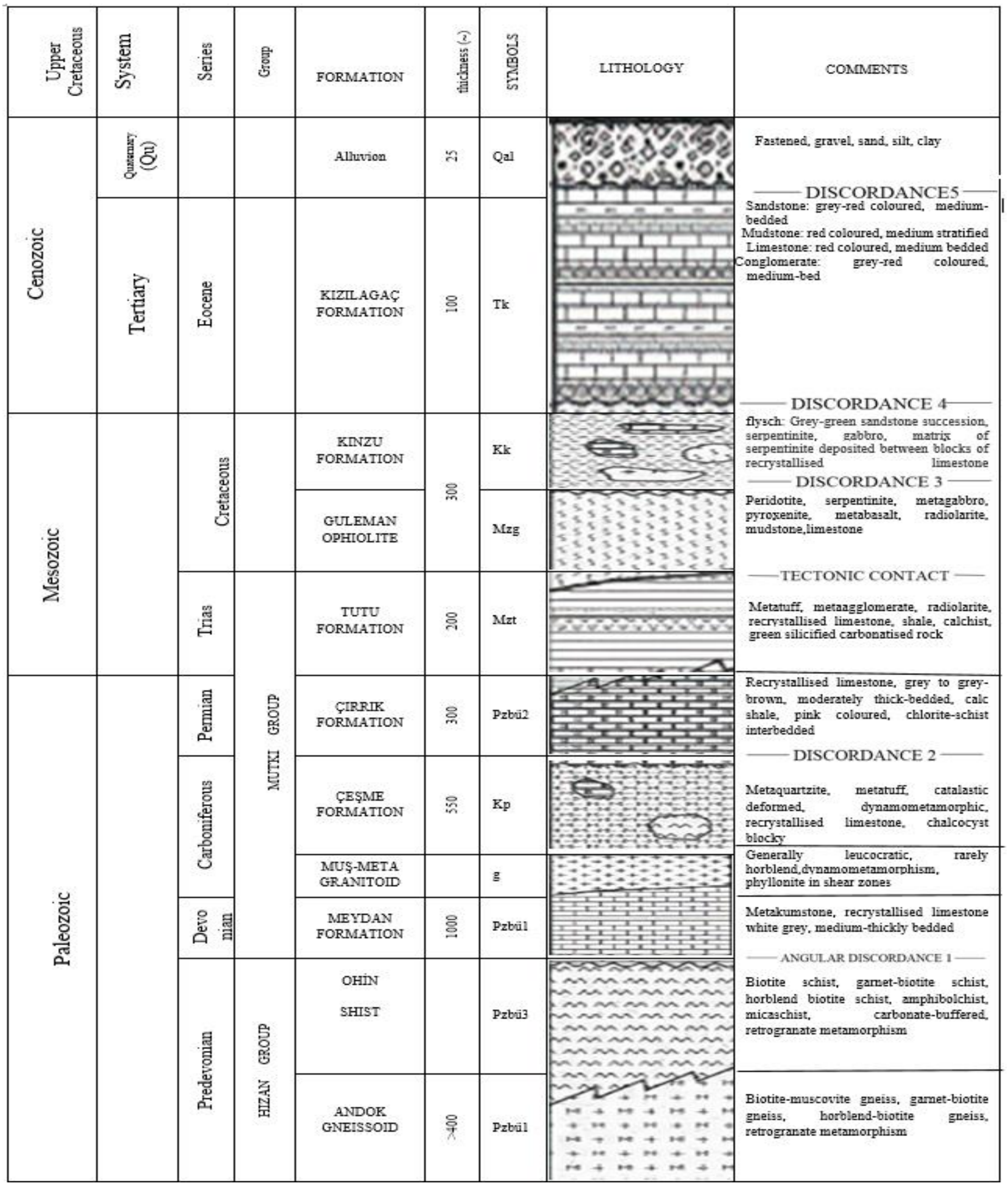

Figure 5. Stratigraphic section of the study area

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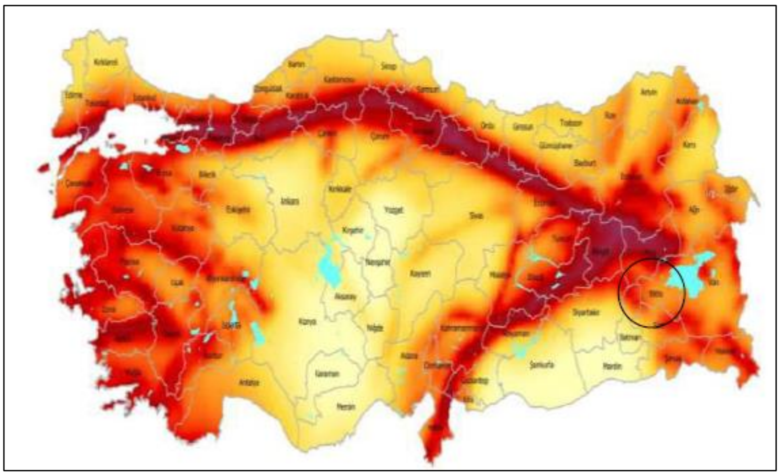

Figure 6. Earthquake map showing the study area

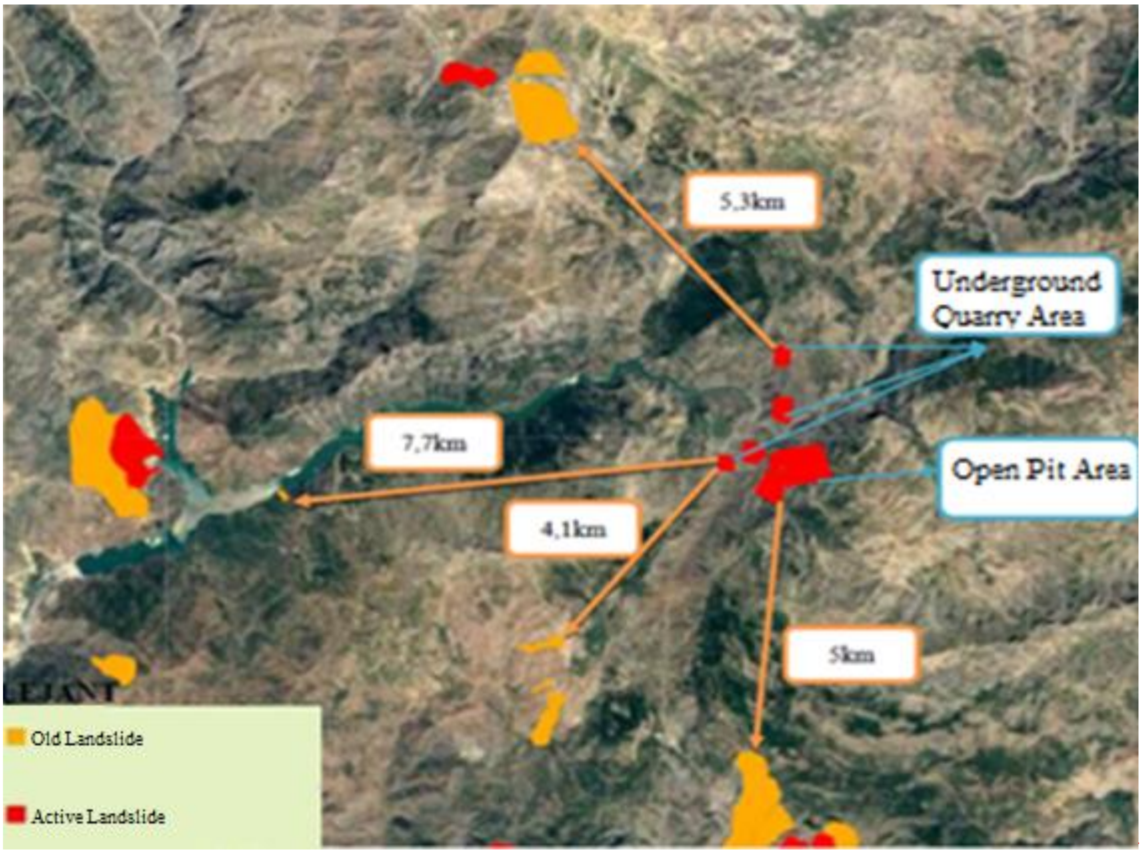

Figure 7. Old landslide zones around the copper mine

Environmental assessment of blasting

Copper mining activities are conducted using both underground and open quarry mining methods. This study focuses on open quarry mining activities. The work plan for such activities typically includes: the excavation of any overburden, drilling of holes in the benches using a drill rig, conducting blasting operations, removal of material using various machinery and equipment, and transportation to the crushing and screening plant. Among these stages, blasting is the most crucial as it is necessary for the excavation of rock. In Turkey, the impacts of open quarry mining

ISSN: 0067-3064

generally include topographic disruption, loss of fertile soil, contamination of water sources, a decrease in groundwater levels, and the occurrence of landslides. Additionally, blasting operations can lead to negative effects such as air shock, dust, rock ejection, and vibration in the surrounding area and nearby settlements.

In open quarry mining operations, the benching production method is commonly used. This method is based on the excavation and loading of material resulting from drilling and blasting benches in a specific sequence. The geological and structural properties of the rock to be blasted are the most important parameters. Although the inherent properties of the rock cannot be altered, several adjustable parameters in bench blasting can control the blasting process, including bench height, hole diameter, pattern of blast holes, the amount and type of explosive used, and the firing system.

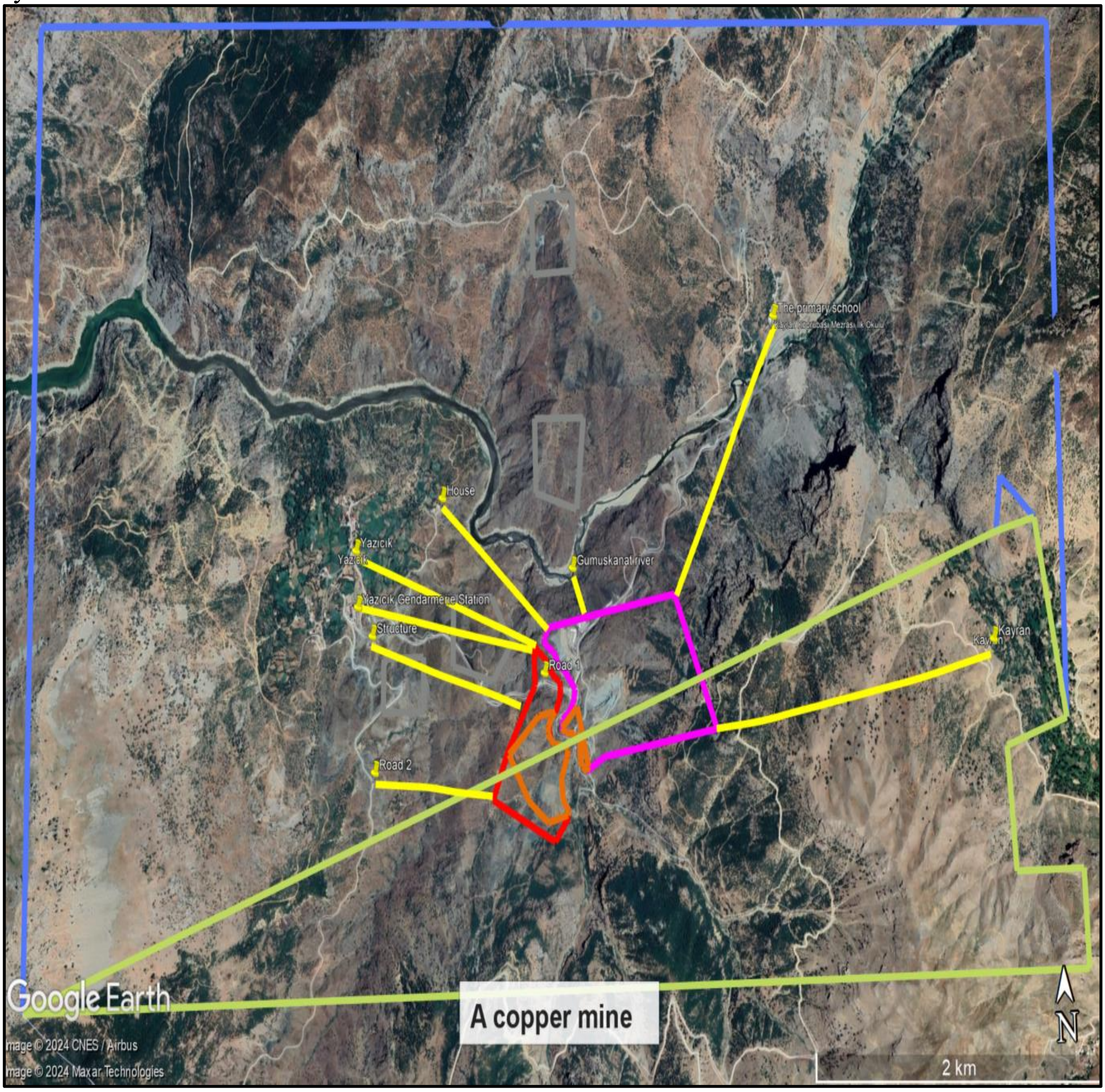

Figure 8. Houses, roads, schools, etc. in the vicinity of the project area

The distance between holes, the distance to the bench face (slice thickness), and various hole patterns such as square or staggered arrangements can be chosen based on the rock and explosive properties. Additionally, the firing system, which controls the timing and quantity of explosives, is crucial for managing adverse effects such as seismic shock, rock ejection, and air shock. The benching production method is suitable for systematic production in quarries due to its ease of implementation and its ability to facilitate production during the preparation phase. The advantages of this method include obtaining clean material during production, reduced vibration, noise, dust, and gas emissions as a result of firing, minimal impact on nearby settlements, and the production of material suitable for manufacturing.

Figure 8 provides a Google Earth image showing nearby homes, roads, schools, and other areas, while Table 1 lists the distances.

The copper open quarry mine is planned to extract 25,000 tons of material per year from a project area of 2,375.87 hectares, with 9.73 hectares designated as the project area (Environmental Impact Assessment (EIA) Area). The copper ore will be sold as run-of-mine (ROM). The mine will operate with a single shift of 8 hours per day, 26 days per month, and 6 months per year. The planned bench parameters for the open quarry mine are: bench height of 10 meters, bench width of 15 meters, bench slope angle of 55°, and a general slope angle of 27°. During production, 8 benches are planned to be created. Limerock will be extracted from areas accessible by machinery, and in areas where machinery cannot operate, blasting will be used. The blasting pattern will be staggered/square, with delayed blasting techniques. ANFO will be used as the explosive, with a hole diameter of 89 mm, a hole inclination of 60°, and 54 holes to be drilled. The drilling parameters are as follows: hole length of 10 meters, hole depth of 0.411 meters, stemming length of 0.9 meters, and a hole-to-hole distance of 1.13 meters. Each hole will contain 59.05 kg of ANFO and 1 kg of dynamite.

Table 1. Approximate air-line distances to houses, roads and river areas around the study area (distances to settlements are taken according to the mine licence area).

Interlocality ve Transportation	Distance (m)
Road 1	10
Gumuskanat River	220
Road 2	718
House	845
Structere	950
Yazıcık Gendarmerie Station	1069
Yazıcık Neighbourhood	1170
The primary school	1347
Kayran Village	1689
Mutki District	24000
Bitlis Province Centre	39000

In the copper mine, evaluations for blasting excavation production regarding vibrations (ground shaking), air shock, rock ejection, and dust have been conducted using empirical formulas. The instantaneous charge amount to be used in blasting has been set at 61.05 kg, with a specific charge value of 0.41 kg/m^3.

Vibration Values (Ground Shaking

The vibration values have been evaluated according to Article 25 of the "Regulation on the Assessment and Management of Environmental Noise" published in the Official Gazette No. 27601 on June 4, 2010. The regulation states that the ground vibration levels caused by blasting in

ISSN: 0067-3064

mines, quarries, and similar activities must not exceed the limit values specified in Annex VII (Table 2) of this regulation, particularly in areas with very sensitive uses.

Table 2. Maximum Permissible Values of Ground Vibrations Caused by Vibration Due to Blasting in Mines, Quarries and Similar Areas Outside the Nearest Very Sensitive Area of Use.

Vibration Frequency (Hz)	Maximum Allowable Rate of Vibration P (mm/sec)
1	5
4-10	19
30-100	50

The calculated ground vibration values based on the locations and distances of houses, roads, and other structures surrounding the copper mine (see Figure 5 and Table 1) are presented in Table 3. The vibration values calculated in Table 3 have been evaluated according to Article 25 of the "Regulation on the Assessment and Management of Environmental Noise". In Table 1, the planned copper mine license boundaries include Road 1, Gumuskanat River, Road 2, House, Yazıcık Gendarmerie Station, Yazıcık Neighbourhood, The Primary School, Kayran Village, Mutki District, and Bitlis Province Centre. The closest distances of these locations are determined as follows: 10 m, 220 m, 718 m, 845 m, 1069 m, 1170 m, 1347 m, 1689 m, 24,000 m, and 39,000 m. Based on these distances, the vibration speeds are calculated as follows: 695.67 mm/s, 2.51 mm/s, 0.29 mm/s, 0.22 mm/s, 0.18 mm/s, 0.14 mm/s, 0.12 mm/s, 0.09 mm/s, 0.06 mm/s, and 0.00 mm/s.

In Table 3, the calculated vibration values, if they occur within the 1-10 Hz frequency range specified in Table 2, are below the standard limit (5 mm/s) at any settlement. Therefore, damage to buildings is not anticipated. Table 4 provides the types of buildings that could be damaged due to blasting based on the vibration speed at the building foundation. The study indicates that Road 1, located 10 meters from the blasting area, has a vibration speed of 695.67 mm/s, which is considered to have a high likelihood of causing damage.

Table 3. Vibration values of houses, river and roads around the copper mine

Interlocality ve Transportation	D (m)	W (kg)	P (mm/s)
Road 1	10	61.05	695.67
-	20	61.05	197.03
-	30	61.05	94.20
-	40	61.05	55.80
-	50	61.05	37.18
-	89	61.05	13.02
-	100	61.05	10.53
Gumuskanat River	220	61.05	2.51
-	300	61.05	1.43
-	500	61.05	0.56
Road 2	718	61.05	0.29
House	845	61.05	0.22
Structere	950	61.05	0.18
Yazıcık Gendarmerie Station	1069	61.05	0.14
Yazıcık Neighbourhood	1170	61.05	0.12
The primary school	1347	61.05	0.09
Kayran Village	1689	61.05	0.06
-	2000	61.05	0.05
-	5000	61.05	0.01
-	10000	61.05	0.00
Mutki District	24000	61.05	0.00
Bitlis Province Centre	39000	61.05	0.00

Table 4. Types of Buildings That May Be Damaged Due to Blasting Based on Building Foundation Vibration Velocity Values (Forssblad, 1981)

Building Type	Vibration Rate (mm/sec)
a-Very old historical buildings that are about to collapse	2
b- Plastered briquette, adobe, masonry brick building	5
c- Reinforced concrete buildings	10
d- Industrial buildings with very solid structures such as factories	10-40

According to Table 4, vibration values for Road 1 and Gumuskanat River pose a risk when evaluated by building type. However, since these building types are not included in the restriction classification, they do not constitute a problem within the scope of the study. Post-blasting ground vibration values have been compared based on their impact distances and direct influence levels. In addition to direct effects, ground vibrations can also have indirect effects on both structures and the environment through their impact on people. This effect has been compared by various researchers according to limit values and impact levels (Table 5).

The area known as Road 1 has been identified as having ground shaking values that exceed the limit values specified by researchers in Table 5, affecting people and vehicles to the extent of causing physical harm. In the Gumuskanat River area or nearby areas, it has been determined that people experience shaking to levels that can be strongly felt following blasting.

Table 5. The effects of ground shaking on people and its evaluation

Types of impact	ISSE(2015)	Konya and Walter (1991)	Oriard and Emmert (1980)	Road 1	Gumuskanat River	Road 2
Hardly felt	-	-	0.25 mm/s		2.51 mm/s	0.29 mm/s
Felt	0.51 mm/s	0.51mm/s	-		2.51 mm/s	-
Easily Felt	-	-	1.5 mm/s		2.51 mm/s	-
Strongly Felt	-	-	2.5 mm/s		2.51 mm/s	-
Can cause problems	-	5.1 mm/s	-	965.67 mm/s	-	-
Disturbing	-	-	10.2 mm/s		-	-
Very uncomfortable	-	-	25.4 mm/s		-	-
Tolerance limit	-	17.8 mm/s	30.5 mm/s		-	-
Risk onset of physical harm	-	-	50.8 mm/s		-	-

The likelihood of people in the Road 2 area experiencing ground shaking after blasting is low [6]. People's exposure to ground shaking in various studies is generally considered a matter of personal perception. This perception can vary depending on whether a person is inside or outside a building during the event, with being inside typically resulting in a stronger perception. If people living in the blasting area and its surroundings do not welcome this situation, blasting activities may not be carried out or may be discontinued (Society of Explosives Engineers, n.d.). In addition, the response of people to blasts conducted against their will and the subsequent effects can vary significantly. These factors include the duration and timing of ground vibrations (whether during the day or night, during working hours or outside them), the frequency of blasts, prior notification to the local community, and the health, temperament, and age of individuals. These aspects are crucial factors influencing the effects of blasting. According to ANSI S3.29-[59], which is developed by ANSI, vibrations lasting less than 1 second are evaluated based on the number of

ISSN: 0067-3064

blasts conducted during the day, timing (night or day), and location (residential, office). The assessment examines the PPV values tolerated by people within buildings and the levels of impact experienced (Table 6).

It has been determined that structural damage and perceptual effects on people occur when the PPV value is between 5-50 mm/s. However, even at levels significantly below those causing structural damage, people can still perceive vibration levels.

Table 6. PPV values that people can tolerate inside buildings (American National Standards Institute (ANSI), [59]

Number of events per day	1	12	26
Nighttime, residence	0.2 mm/s	0.09 mm/s	0.07 mm/s
Day time, residence,	12.70 mm/s	6.35 mm/s	4.30 mm/s
Workplace and office environment	18 mm/s	8.90 mm/s	6.10 mm/s

The perception of vibrations in humans starts at very low levels, with a threshold of 0.02 mm/s. At a PPV value of 50 mm/s, physiological damage can occur, while structural damage begins at 5 mm/s. After blasting, people may experience fear and anxiety even at very low ground vibration levels due to the possibility of structural damage and injuries. This fear leads individuals to search for cracks in their buildings out of concern for potential damage. Often, this can result in increased complaints and concerns as individuals may come across existing cracks that they do not remember or have not previously noticed, attributing them to the blasting events [60].

Air Blasting Shock

The air blasting effects of the copper mine, calculated based on the distances of nearby residences, tourism areas, and their proximity to the surface mining area, are shown in Table 7 and the effects at different levels of air blast are illustrated in Figure 9.

As shown in Table 7, considering the closest settlement, Road 1 (see Figure 5), is 10 meters from the copper surface mining license boundary, the calculated air blast value for this location is 157.63 dB. According to this result, the air blast value for Road 1 exceeds the 140 dB threshold (Figure 9), indicating potential issues with air blast in this area. For the settlements of House, Yazıcık Gendarmerie Station, Yazıcık Neighbourhood, The Primary School, and Kayran Village, the air blast levels are at the threshold of pain and complaint initiation. If there are changes in the instantaneous-specific charge values, these areas may also face problems.

The effect of air blast resulting from blasting can also be calculated using the following equations:

Severe Impact Zone: $D < 5 * \sqrt{W}$

Moderate Impact Zone: $5 * \sqrt{W} < D < 10 * \sqrt{W}$

Light Impact Zone: $10 * \sqrt{W} < D < 15 * \sqrt{W}$

Here; D: Effective Zone Range (m) and W: Amount of Explosive Used in a Delay Interval (Instantaneous Charge) (kg) are indicated.

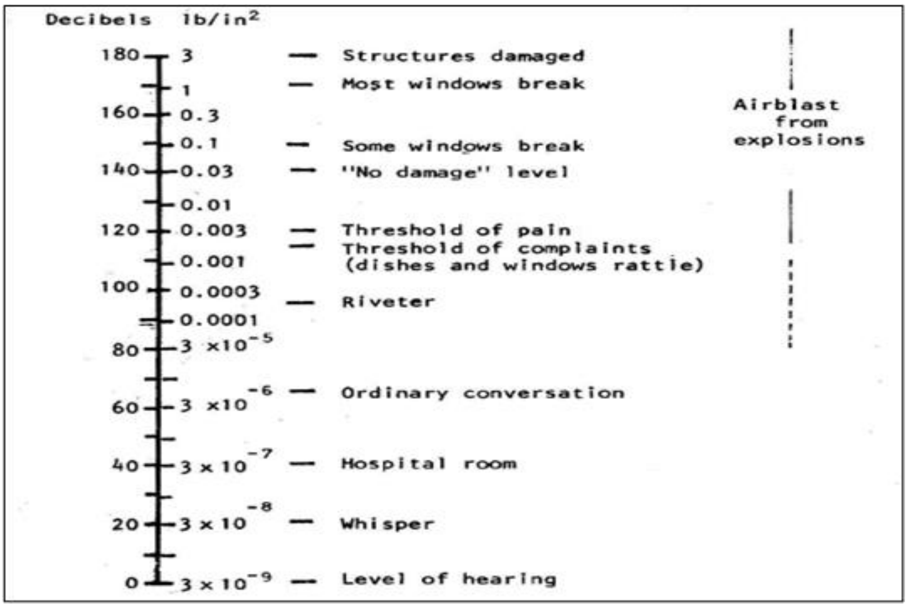

Figure 9. Response of people and structures to different levels of noise (sound waves)

According to the calculations based on these equations results are follows;

Severe Impact Zone:	$D < 5 * \sqrt{W}$	**0 – 39 m**
Moderate Impact Zone:	$5 * \sqrt{W} < D < 10 * \sqrt{W}$	**39 – 78 m**
Light Impact Zone:	$10 * \sqrt{W} < D < 15 * \sqrt{W}$	**78 – 117 m**.

As seen from the calculations, the air shock impact zones calculated based on the amount of explosive per delay (61.05 kg) are severe between 0 and 39 meters, moderate between 39 and 78 meters, and light between 78 and 117 meters. Beyond 117 meters, the air shock dissipates. From these calculations, it is understood that the area near the work site, specifically Road (Road 1) located at the closest distance of 10 meters (Table 7), will be severely affected by air shock. Other areas are not at risk of exposure as the air shock dissipates beyond 117 meters.

As stated in the regulation, considering that the working hours during the day should be less than 20%, the L scale and the U.S. regulations have been recommended based on scientific studies, technical reviews, and regulatory compliance. The high "Low Frequency Content" of the noise after blasting causes the "Blasting Air Shock (Noise)" to dissipate within a few seconds. According to this, the maximum allowable noise level in the environmental impact assessment catalog is given as 133 dB(A). Hoek and Bray [61] permit up to 140 dB(A) for building damage assessments.

Table 7. Air shock values of houses and roads around the copper mine

House- Road etc.	D (m)	W (kg)	P (mb)	P (dB)
Road 1	10	61.05	15.02	157.63
-	20	61.05	7.67	151.79
-	30	61.05	5.18	148.38
-	40	61.05	3.92	145.95
-	50	61.05	3.15	144.07
-	89	61.05	1.80	139.22
-	100	61.05	1.61	138.23
Gumuskanat River	220	61.05	0.75	131.59
-	300	61.05	0.55	128.98
-	500	61.05	0.34	124.67
Road 2	718	61.05	0.24	121.63
House	845	61.05	0.20	120.25
Structere	950	61.05	0.18	119.27
Yazıcık Gendarmerie Station	1069	61.05	0.16	118.27
Yazıcık Neighbourhood	1170	61.05	0.15	117.51
The primary school	1347	61.05	0.13	116.33
Kayran Village	1689	61.05	0.10	114.42
-	2000	61.05	0.09	112.99
-	5000	61.05	0.04	105.51
-	10000	61.05	0.02	99.89
Mutki District	24000	61.05	0.01	92.73
Bitlis Province Centre	39000	61.05	0.01	88.86

The data obtained after blasting shows that Road 1 has a noise level of 157.63 dB, which is above the threshold value for air shock. Air shock measurements were taken at a distance of 10 meters from the blasting area, very close to Road 1. Therefore, this does not pose a problem for the conducted blast. It is anticipated that the reason for the higher air shock values in some blasts compared to the threshold is due to careless tamping and formation characteristics.

The calculated and measured air shock (noise) damage effect value will be below 133 dB(A) at distances of 10 meters and further. Therefore, "controlled blasting for excavation and loosening purposes will be ensured" with the maximum instantaneous charge, and "there will be no adverse air shock (noise) effects."

Table 8. Effects of noise levels on people and structures

Sound Pressure (dB)	Identification / Sampling
20	Whispering
40	Quiet neighbourhood / living room
60	Normal speech
80	Intensive workplace
100	Heavy traffic
110	Creation of window / crockery cluttering
120	Pain threshold (highest permissible level in many blasting noise norms)
140	Air raid siren / Sudden sound (upper limit for damage initiation/noise according to USBM and OSM norms)
150	Breaks in some window panes

Noise has effects on people not only in terms of physical hearing loss but also psychologically, physiologically, and in terms of productivity. Noise is defined as an adverse condition characterized by sound levels [62]. The degree of impact on individuals based on noise levels is provided in Table 8.

During the blasting process, people are exposed to very short-term effects. During this process, individuals are primarily affected physiologically and psychologically rather than physically. Evaluating the physiological effects of noise is challenging [63,64]. Psychologically, the effects of noise are characterized by fear, anxiety, fatigue, and a slowdown in mental activities. To limit the impact of noise, legal regulations have been established worldwide. Country-wide limit values are set at 80, 85, or 90 dB. For impulsive and/or sudden noise, the highest sound pressure levels or maximum limit values are considered in noise standards (International Institute of Noise Control Engineering (I-INCE-97-1), 1997; National Institute for Occupational Safety and Health (NIOSH), 1998). The U.S. Army Firearms Unit has set the maximum permissible level for any instantaneous noise to 140 dB for noise protection. According to the Australian and New Zealand Environment Council (ANZEC) (1997) criteria, air shock values for human comfort are evaluated according to Table 9.

Table 9. Australia and New Zealand Environment Council (ANZEC) (1997) Noise environmental protection criteria regulation (Boladz vd., 2013)

Upper blasting limits	Monday-Friday 7.00-18.00	Sundays and holidays 7.00-18.00	Other time zones 18.00-7.00
Upper limit of blasting at a certain time	125 dB L	120 dB L	90 dB L
Repeated upper limit blasting in the amount of 9-10	120 dB L	115 dB L	-

The U.S. Bureau of Mines (USBM) and the Office of Surface Mining Reclamation and Enforcement (OSMRE) have established regulations for impulsive sounds from blasting, such as air shocks, under U.S. law. They have set noise upper limits and damage threshold values. According to USBM, structural responses and damages caused by air shock effects have been studied. After examination, safe limits for residential areas are set at 105 dB C, 129 dB L (6 Hz), 133 dB L (2 Hz), and 134 dB L (0.1 Hz). Generally, many studies have accepted 140 dB L as a safe limit, although it is considered disturbing from a human perspective. The maximum safe level of 134 dB has been associated with a 95-99% probability of no damage and a 95-90% probability of acceptable disturbance. A threshold of 120 dB has been set for human discomfort, based on fears caused by structural vibrations being considered a disturbance for people [54]. In the study, Road 1 at 157.63 dB, Gumuskanat River at 131.59 dB, Road 2 at 121.63 dB, and House at 120.25 dB exceed the 120 dB threshold, indicating that people in these areas are experiencing discomfort.

According to the OSMRE (Office of Surface Mining Reclamation and Enforcement), environmental impacts of blasting are evaluated in terms of noise and vibration limits, focusing on human perception and building damage. The damage limit for buildings is similar to USBM, with a threshold value of 129 dB. This value represents the lowest probability of surface damage in residential structures and has been set considering subjective human responses. According to OSMRE, if noise levels are kept below 120 dB L, discomfort is considered minimal. In Turkey, the Environmental Impact Assessment Regulation (2010) for noise has been considered. This regulation does not address instantaneous noise from blasting but covers human noise perception levels. Many researchers have proposed different threshold values for the effects of air shock on people. People perceive the effects of vibration and air shock as blasting noise. The reason is that air shock is felt through the reaction of large surfaces (such as ceilings and windows). Responses to smaller but noisy blasts are more frequent compared to large-scale controlled blasts. It has been noted that air shock amplitudes below 128 dB are less likely to disturb people and animals. Persson et al.[65] discussed estimated air shock threshold values. According to this, 120 dB is considered the pain threshold for continuous sounds; air shocks above 130 dB cause oscillation and complaints on large surfaces; 150 dB may cause some glass breakage; 170 dB can break most glasses; and 180 dB is associated with structural damage. Chernaik [66] measured noise levels around open quarry blasting between 128-140 dB. He believed that noise levels would decrease with increasing distance and decreasing charge per delay, and he used a maximum charge of 20 kg per delay. This was expected to keep air shock within permissible limits. Since the closest village was 0.5 km from the blasting site, it was thought there would be no significant noise issues at this distance, with an expected noise level of about 40 dBA. It was believed that there would be no physical damage to buildings but some stress on people. Cihangir et al. [67] measured air shock and vibration in 49 blasts at a limerock quarry, with air shock records ranging from a maximum of 132.4 dB to a minimum of 104.9 dB. Considering the 140 dB threshold for noise annoyance in some standards, they concluded that staying below this limit would not cause environmental discomfort.

Flyrock

When applying the formulations from the methodology section to the copper surface mining data:

According to the Lundberg formula, if d=89 mm = 3, inches, the safety distance for flyrock is calculated to be

$$L_{max} = 260 * (d)^{\frac{2}{3}} = 260 * (3{,}50)^{\frac{2}{3}} = 599{,}3 \text{ m} \cong 600 \text{ m}.$$

The distances calculated using the formula $L_{max} = 260 * d^{2/3}$ represent the worst-case scenario distances, as controlled conditions are not specified. It is important to establish these distances as the "safety distance" before blasting to prevent loss of life and property. However, considering that such blasting will be carried out under controlled conditions, it is considered that the distances calculated using the second formula, the scaled depth of burial ($SDOB_m$) formula, should be regarded as the typical flyrock distances.

According to the formula for maximum flyrock distance based on the scaled depth of burial; d= 89 mm, l_s=0,9 m, ρ_e = 0,82 g/cm^3 for ANFO, m= maximum value, taken as 8 when the borehole diameter is less than 100 mm (4 inches); The maximum flyrock distance is calculated as:

$$SDOB_m = \frac{l_s + 0.0005 * m * d}{0{,}00923 * (m * d^3 * \rho_e)^{0.333}} = \frac{0{,}9 + 0{,}0005 * 8 * 89}{0{,}00923 * (8 * 89^3 * 0{,}82)^{0{,}333}} = \frac{1{,}256}{1{,}5299} = 0{,}821$$

$$L_{max} = 11 * (SDOB_m)^{-2{,}167} * d^{0.667} = 11 * (0{,}821)^{-2{,}167} * 89^{0{,}667} = 336{,}750 \cong 337 \text{ m}.$$

The guidelines for blasting designs and environmental effects caused by blasting, as outlined by the Ministry of Environment and Urbanization's General Directorate of Environmental Impact Assessment, Permit, and Inspection in 2018, specify that the loading distance (the distance between the bottom of the hole and the face of the bench) must not be less than 22 times the hole diameter, and the charging length must always be equal to the loading distance. Aggregate (crushed rock) should be used as the charging material, and before drilling, the presence of geological faults, open joints, clay veins, fractures, and crushed zones on the face of the bench should be checked. If faults are found, measures such as using less explosive material in the faulty section, staging the charging of the hole(s), or canceling the faulty hole(s) should be taken. It is stated that, with these precautions, rocks will not be ejected over long distances and the typical distance rocks may be ejected during blasting will be a maximum of 4 times the bench height. Considering the total bench height of 11 meters, the typical distance for flyrock is calculated to be 4 * 11 = 44 meters.

Upon careful examination of the adverse situations, the ejection distances obtained from multiple flyrock calculations (43-337-600 m) are provided. Considering the distances of the houses from the limerock quarry provided in Table 1, it is understood that the closest location, Road (Road 1), Gumuskanat River, and other settlements, which are within 10 meters, could be directly and/or indirectly affected. Therefore, it is anticipated that the copper open quarry could cause damage to these structures in terms of rock ejection.

However, it has been observed that part of the road around the limerock quarry falls within the permit boundary. It is noted that during operations at the quarry (especially blasting), there will be a risk for those passing through the road. Studies need to be conducted to determine what measures should be taken to eliminate these risks, which will help in reducing or eliminating potential issues.

If explosives are not adequately confined within the rock mass, gases with high pressure after the reaction will be released into the atmosphere in less time than required to separate from the cracks within the rock. The high-speed discharge of gas causes cracks, fractures, and movement within the rock. When the movement of rocks results in ejection into the air, it can cause damage to structures and harm people from an environmental perspective.

In some cases, flyrock can result in flyrock distances reaching up to 700 meters, potentially causing fatal accidents for people. Often, ejecting rocks not only pose a risk to people but also damage machinery and equipment. In quarries, particularly with gallery blasting, it is not suitable for controlled blasting, as it tends to create flyrock issues.

In the study, preventing flyrock involves eliminating or reducing the factors that could lead to ejection, which significantly contributes to preventing or mitigating damage. Flyrock primarily results from a mismatch between the geomechanical properties of the blasted rock and the blasting energy. Along with this main cause, factors such as overloading the blast holes with explosives, incorrect bench width selection, rock structure with excessive discontinuities, delayed blasting, improper filling, and incorrect blasting design must be identified and appropriate blasting design should be implemented. To prevent flyrock, it is crucial to address the problems arising from incorrect calculations and designs by implementing the specified measures. After blasting, one should wait 1 minute in the safely selected area, inspect the site before immediately entering, anticipate potential hazards such as loose rock even if no flyrock occurs, select the appropriate slice thickness for the amount of explosive used, place filling material in areas with weak planes or mud-like weak rocks, and use suppressors such as sandbags, conveyor belts, and wire meshes [68].

Dust Emission Amount

During mining operations, dust formation sources include stripping, removal, loading, storage, unloading, crushing, screening, and transportation processes. The factors provided use the coefficients from the Ministry of Environment and Urbanization's Regulation on the Control of Industrial Air Pollution dated December 20, 2014, and numbered 29211 (SKHKKY). According to Annex-12 of the Regulation on the Control of Industrial Air Pollution, under Article 2, the dust emissions from excavation, crushing, and classification facilities are calculated using the controlled emission factors listed in Table 7. Measures such as watering, using closed transport systems, keeping materials moist, and loading/unloading without scattering, as specified in Annex-

1, must be taken to minimize dust emissions. All calculations in the study were performed using both controlled and uncontrolled emission factors (Table 10).

Table 10. Dust emission factors in the production process (SKHKKY)

Dust Formation Sources	Dust Emission Factors (kg/ton)	
	Uncontrolled	Controlled
Dust formation due to blasting	0.8	-
Dust formation due to dismantling	0.025	0.0125
Dust formation during material loading	0.010	0.005
Dust generation during the total round-trip transport distance (kg/km-araç)	0.7	0.35
Unloading of the transported material	0.010	0.005
Storage of transported material	5.8	2.9

Dust Amount After Surface Activities in a Copper Mine

Dust formation in mining is categorized into two parts based on surface and underground operations. In surface activities, dust formation sources result from the extraction of ore and waste. Table 11 provides the sources of dust formation during the ore and waste processes.

Table 11. Sources of dust formation in the ore and tallow.

Causes of dust generated during ore extraction	Causes of dust generated during the tallowing process
Blasting	Removal of tallow
Ore dismantling	Loading tallow into lorries
Loading on trucks	Transport to the storage area
Transport to the storage area and for sale	Discharging to the storage area
Discharge to storage area	Storage of tallow
Storage of the ore	

The amount of dust generated during ore extraction due to blasting has been calculated based on the data provided in Table 12, and the results have been obtained.

The amount of dust released into the environment after each blasting operation is 0.16 kg. Considering that the dust from each blast dissipates within 10 seconds and is spread over an area of 83.6 m^2:

0.16 kg/patlatma x 1 patlatma (10 sn x 83.6 m^2) x 1000gr /kg= 0.19 g/s. m^2

Table 12. Amount of dust emission from blasting

Factors used for blasting	Data used for blasting
Load distance	1.37 m
Distance between holes	1.13 m
Number of holes	54 hole
Blasting surface area	83.6 m^2
Dust emission	0.16 kg/ blasting
Blasting surface area = Load distance x Distance between holes x Number of holes	
Blasting surface area = 1.37x1.13mx54	
Emission factor = (PM ≤ 30 µm)= $0.00022xA^{1.5}$	
Emission factor = (PM ≤ 30 µm)= $0.00022x83.6^{1.5}$	
Dust emission =0.16 kg/ blasting	

Dust Emissions During Copper Ore Extraction:

For the surface copper mining operation, an annual production of 25,000 tons is planned. With a 25% recovery rate, 6,250 tons of copper is produced, and 18,750 tons of waste is generated. The controlled and uncontrolled dust emission quantities during copper extraction are shown in Table 13.

In mining operations, dust is generated during ore handling and transportation, and waste produced during ore processing also contributes to dust formation. The sources and amount of dust generated during this process are provided in Table 14.

Table 13. Amount of dust generated during controlled and uncontrolled processes during copper extraction

6 month 26 day/ 8 hour	
Annual amount of material to be purchased	6250 ton/ year
Amount of material to be purchased monthly	1041.6 ton/ month
Amount of material to be purchased daily	40.06 ton/day
Amount of material to be purchased hourly	5 ton/hour
A total of 500 m of road was used between the quarry areas within the mine and the stockpile area.	
- Distance to and from the Stockpile Approx: 1000 m (500 m x 2)	
- Considering that 1 truck carries 25 tonnes of material; Number of trips: (26,7 tonnes/day) /(25 tonnes x 2 vehicles): 2 trips)	
Total Dust Emission Flow Rate in Controlled Condition (kg/hour)	
Loading of Ore	0,005 kg/ton x 5 ton/hour = 0,025 kg/hour
Transport of Ore	0,35 kg/km- vehicle x (2 vehicle 8 hour) x (1 kmx2 expedition) =0,17 kg/hour
Ore Discharging	0,005 kg/ton x 5 ton/hour = 0,025 kg/hour
Ore Storage	1,1 ha x 2,9 kg toz/ha day x 1day/24hour = 0,13 kg/hour
Total Dust Emission Flow Rate in Uncontrolled Condition (kg/hour)	
Loading of Ore	0,010 kg/ton x 5 ton/hour = 0,050 kg/hour
Transport of Ore to Crushing and Screening	0,7 kg/km- vehicle x (2 vehicle /8 hour) x (1 kmx2 expedition) =0,34 kg/hourt
Ore Discharging	0,01 kg/ton x 5 ton/hour = 0,05 kg/hour
Ore Storage	1,1 ha x 5,8kg toz/ha day x 1day/24hour= 0,26 kg/hour

Table 14. Amount of dust generated during removal and disposal of rust

6 month 26 day/ 8 hour	
Amount of material to be purchased annually	18.750 ton/year
The amount of material to be purchased monthly	3125 ton/month
The amount of material to be purchased daily	120 ton/day
The amount of material to be per hour	15 ton/hour
- Round Trip Distance from Quarry Area to Final Haul Road Approx: 1000m (500 m x 2)	
- Considering that 1 truck carries 25 tonnes of material; Number of trips: (84 tonnes/day) / (25 tonnes x2 vehicles): 2 trips)	
Total Dust Amount Generated by Dust Emission Flow in Controlled Condition (kg/hour)	
In the process of tallow load	0,005 kg/ton x 15 ton/hour = 0,075 kg/hour
During transportation of tallow to the landfill	0,35kg/km vehicle x (2 vehicle /8hourt) x (1kmx1 expedition x2 vehicle) =0,17 kg/hour
Discharging tallow to the Storage Area	0,005 kg/ton x 15 ton/hour= **0,075 kg/hour**
Storage of tallow in the Storage Area	1,26 ha x 2,9 kg toz/ha day x 1day/24hour = 0,15 kg/hour
Total Amount of Dust Generated by Dust Emission Flow in Uncontrolled Condition (kg/hour)	
During the tallow load process	0,01 kg/ton x 15 ton/hour = 0,15 kg/hour
During transportation of tallow to the landfill	0,7kg/km- vehicle x (1 vehicle /8 hour) x (1kmx2 expedition x2vehicle) =**0,34 kg/hour**
Discharging tallow to the Storage Area	0,01 kg/ton x 15 ton/hour= **0,15 kg/hour**
Storage of tallow in the Storage Area	1,26 ha x 5,8 kg toz/ha day x 1day/24hour = 0,3 kg/hour

ISSN: 0067-3064

The study calculates the causes and amounts of dust formation during surface mining operations under both controlled and uncontrolled conditions and presents these in the relevant tables. All surface dust activities are shown in Table 15 (Figure 10).

Table 15. Total dust emission flow rate as a result of surface activities (kg/hour)

(Dust emission flow rate after all above ground activities) (kg/hour)	Controlled	Uncontrolled
During the ore loading process	0.025	0.05
During the ore transport process	0.17	0.34
In the process of discharging ore	0.025	0.05
During the ore storage process	0.13	0.26
Allow loading	0.075	0.15
Transport of tallow to the storage area	0.17	0.34
Discharging tallow to the storage area	0.075	0.15
Storage of tallow in the storage area	0.15	0.3
Total	0.82	1.64

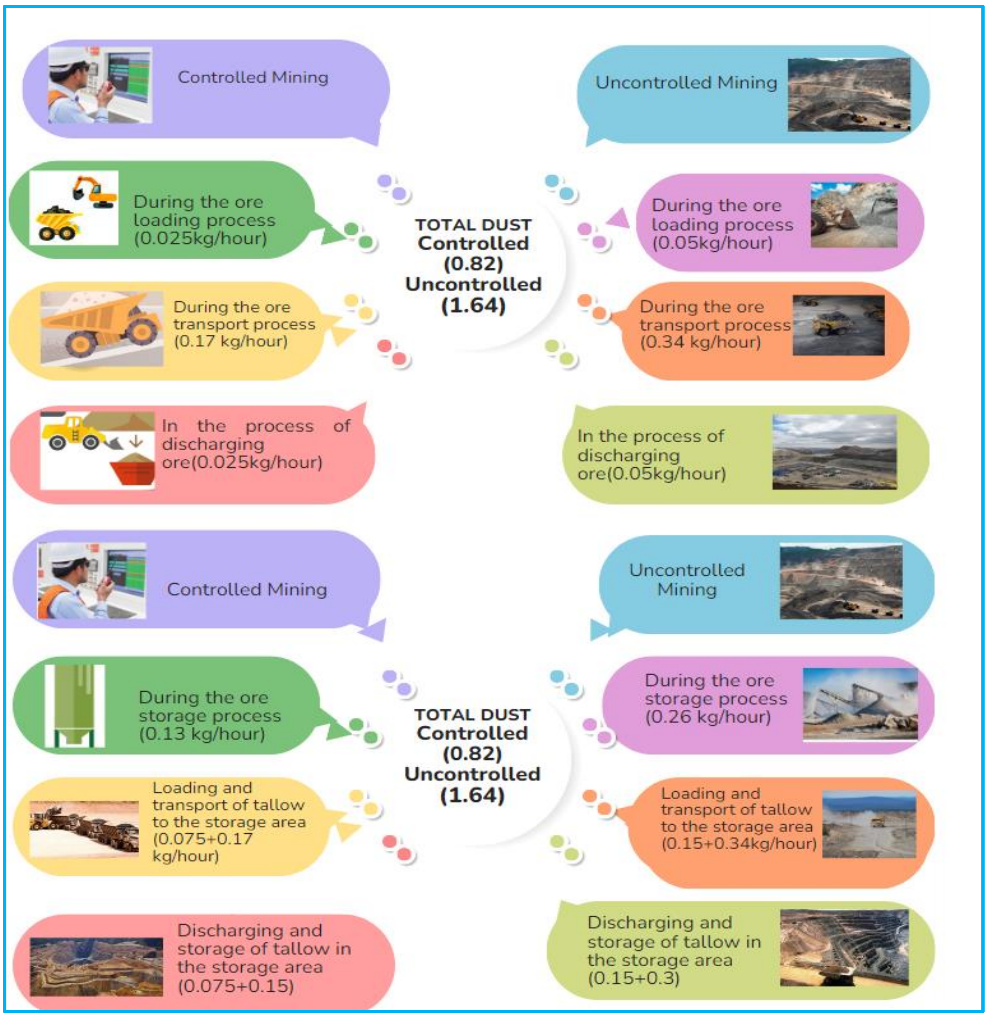

Figure 10. Amount and causes of dust generated after surface activities.

 ISSN: 0067-3064

The reasons for and amounts of dust formation following surface mining operations, under both controlled and uncontrolled conditions, are shown in percentage distribution graphs in Figure 11. The comparison of dust amount generated in both scenarios is shown in Figure 12.

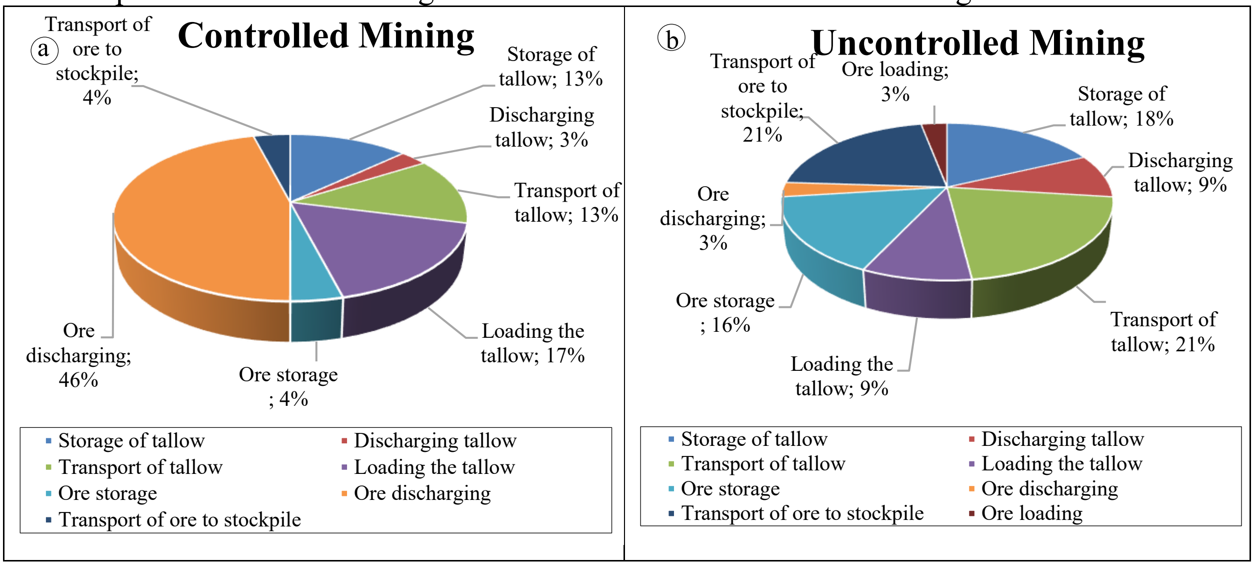

Figure 11. Stages and quantities of dust formation under a) controlled and b) uncontrolled conditions in the surface production process

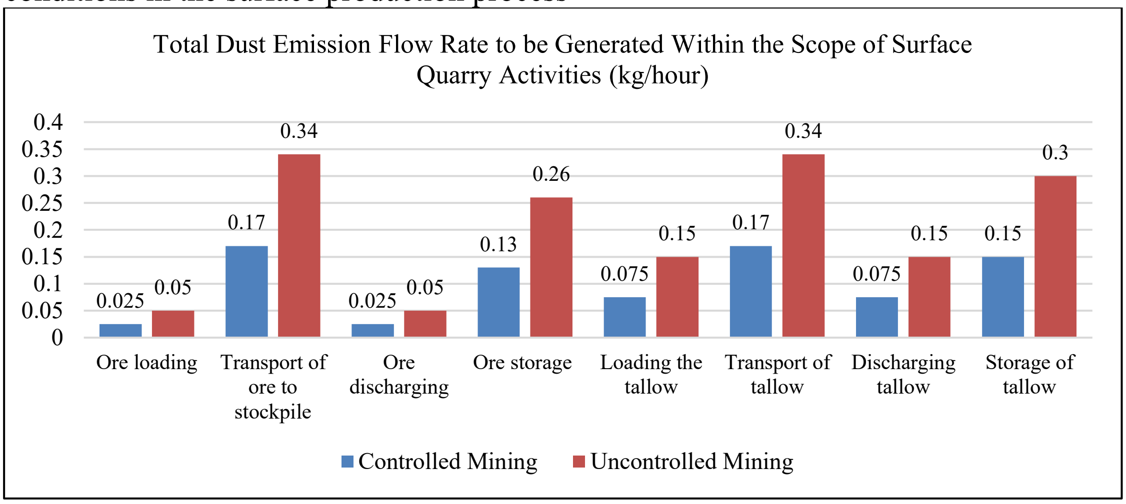

Figure 12. Dust formation processes and quantities under controlled and uncontrolled conditions in the surface production process

Dust Quantities After Underground Mining Activities in a Copper Mine:

Due to the moist conditions underground, only a small amount of dust and harmful gases are released during blasting, and these are not included in the calculations. These dust and gases are removed through ventilation or air supply. The dust amount is determined based on the amount of ore and waste. The amount of dust is determined based on the ore and waste quantities. In the study area, it is planned to produce 225,000 tons of copper ore annually, with 75% of the produced ore obtained from waste.

Dust Emissions During Copper Ore Production:

Blasting operations are conducted in the underground mine with modifications to the blasting pattern. The dust emission value during excavation has not been calculated. Table 16 provides the amount of dust emissions during the operation of the underground copper mine.

Table 16. Amount of dust emission during underground copper quarry operation

12 month/ 30 day/ 24 hour	
Amount of material purchased in 1 year	56.250 tonnes/year
Amount of material purchased in 1 month	4687,5 tonnes/ month
Amount of material purchased in 1 day	156,25 tonnes/ day
Amount of material purchased in 1 hour	6,9 tonnes/ hour
A total of 2000 m of road was used between the underground quarry routes and the stockpile area.	
-Approximate distance between stockpile routes round trip: 4000 m (2000 m x 2)	
-Considering 25 tonnes of material that 1 truck can carry; Number of trips: (156,25 tonnes/day)/(25 tonnes x 3 vehicles): 2 trips	
Total Dust Emission Flow Rate in Controlled Condition (kg/hour)	
Loading of Ore	0,005 kg/ton x 6,9 ton/hour = 0.03 kg/hour
Transport of Ore	0,35 kg/km- vehicle x (3 vehicle/24 hour) x (4 kmx2 expedition) =0,35 kg/hour
Ore Discharging	0,005 kg/ton x 6,9 ton/hour = 0,03 kg/hour
Ore Storage	1,1 ha x 2,9 kg toz/ha day x 1day/24hour = 0,13 kg/hour
Transport of ore to crushing and screening	0,7kg/km- vehicle x (3 vehicle /24 hour) x (4kmx2 expedition) =0,7 kg/hour
Ore Discharging	0,01 kg/ton x 6,9 ton/hour= 0,06 kg/hour
Ore Storage	1,1 ha x 5,8 kg toz/ha day x 1day/24hour = 0,26 kg/hour

In the work area, an annual total of 75,000 tons of slag is generated. The slag is stored within the work area and is evaluated as a byproduct or waste material following production activities. Table 17 provides the quantities of dust generated during the collection and disposal of the slag.

Table 17. The amount of dust generated during the removal and disposal of rust is given.

12 month/30 day/ 24 hour	
Amount of material to be purchased annually	168.750 ton/year
The amount of material to be purchased monthly	14062, 5 ton/month
The amount of material to be purchased daily	468,75 ton/day
The amount of material to be per hour	20,8 ton/hour
-A total of 50 m road will be used between the Underground Quarry Areas and the Paste Area.	
-Approx. 100 m (50 m x 2) to and from the Paste Area	
-Considering that 1 truck carries 25 tonnes of material; Number of trips: (468,75 tonnes/day)/(25 tonnes x 3 vehicles):6 trips	
Total Dust Amount Generated by Dust Emission Flow in Controlled Condition (kg/hour)	
In the process of load the tallow	0,005 kg/ tonnes x 20,8 tonnes /hour = 0,1 kg/hour
During transport of tallow to the storage area	0,35kg/km vehicle x (3 vehicle / 24 hourt) x(0,1km x6 expedition) =0,02 kg/hour
Discharging the tallow to the storage area	0,005 kg/ tonnes x 20,8 tonnes /hour= **0,1 kg/hour**
Storage of tallowt in the storage area	1 ha x 2,9 kg dust/ha day x 1day/24hour = 0,12 kg/hour
Total Amount of Dust Generated by Dust Emission Flow in Uncontrolled Condition (kg/hour)	
In the process of load the tallow	0,01 kg/ton x 20,8 ton/hour = 0,2 kg/hour
During transport of tallow to the storage area	0,7kg/km- vehicle x (3 vehicle /24 hour) x (0,1 kmx6 expedition) =**0,04kg/hour**
Discharging the tallow to the storage area	0,01 kg/ton x 20,8ton/hour= **0,2 kg/hour**
Storage of tallow in the storage area	1ha x 5,8 kg toz/ha day x 1day/24hour = 0,24 kg/hour

The total amount of dust calculated after underground mining activities is provided in Table 18. The percentage distribution graphs of dust generation causes and amounts under controlled and uncontrolled conditions are shown in Figure 13. Figure 14 presents a comparison of the dust quantities generated in both scenarios.

Table 18. Total dust emission flow rate during copper ore underground mining activities (kg/hour)

Total Dust Emission Flow Rate to be Generated within the Scope of Underground Quarry Activity (kg/hour)	Controlled	Uncontrolled
Ore Loading	0.03	0.06
Transport of Ore to StockpileShipping of Ore to Stockpile	0.35	0.7
Ore Discharging	0.03	0.06
Ore Storage	0.13	0.26
Loading the Tallow	0.1	0.2
Transport of Tallow	0.02	0.04
Discharging of Tallow	0.1	0.2
Storage of Tallow	0.12	0.24
Total	0.88	1.76

The flow diagram showing the dust formation processes, quantities, and necessary measures under controlled and uncontrolled conditions during the underground production process is provided in Figure 15.

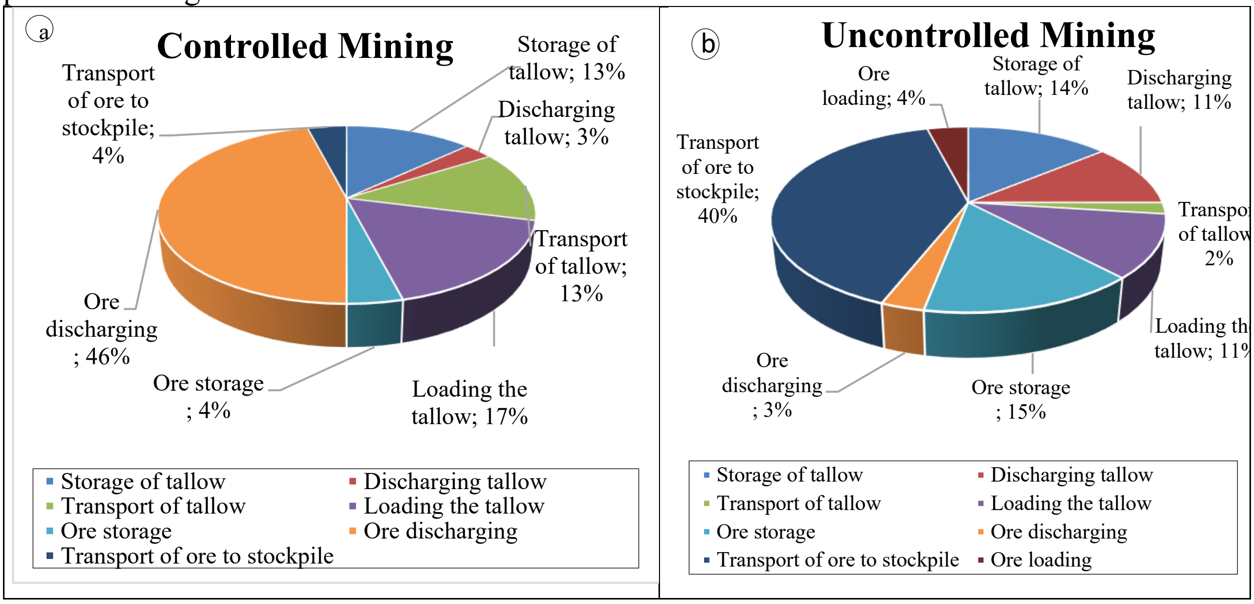

Figure 13. Dust formation processes and quantities under a) controlled and b) uncontrolled conditions in the underground production process

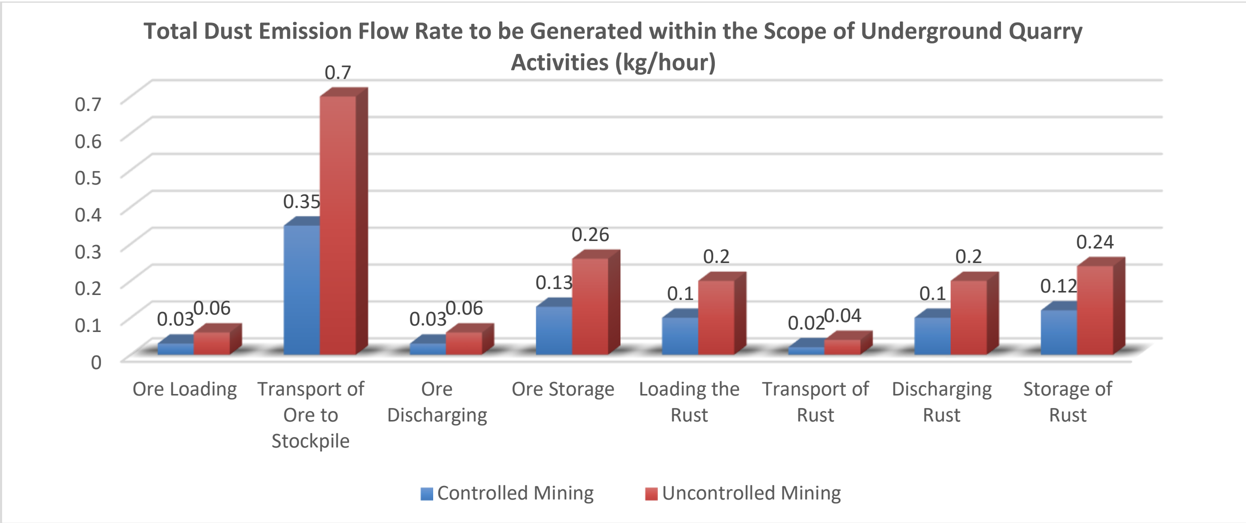

Figure 14. Dust formation processes and quantities under controlled and uncontrolled conditions in underground production process

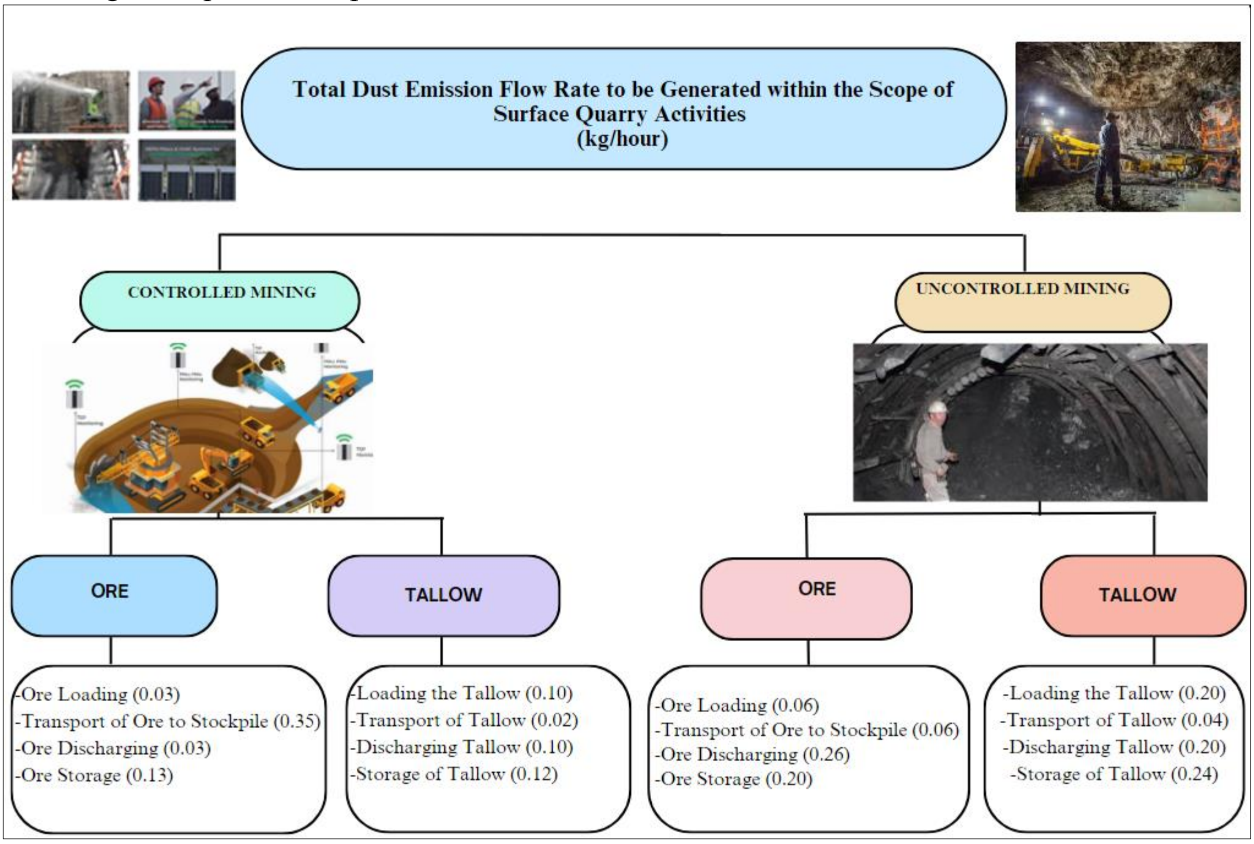

Figure 15. Dust flow diagram in underground operation process

According to the regulation published in the Official Gazette on 05.11.2013 with number 28812, Table 19 in Annex-1 provides the limit values for dust control related to activities such as the production, processing, transportation, filling, unloading, and classification of dusty materials in facilities.

The dust emissions from gases released (through chimneys) during operations such as filling, separation, screening, transportation, crushing, and grinding, when conducted in fixed installations and enclosed areas, have been compared with the limit values derived from the study.

Tablo 19. Limit values in the regulation for dust control (05.11.2013 Official Gazette and 28812 Official Gazette number of the regulation within the scope of dust control)

Dust emissions (for emission flow rates of 1.5 kg/h or less)	200 mg/Nm^3
Dust emissions (for emission flow rates between 1.5kg/h -2.5kg/h)	150 mg/Nm^3
Dust emissions (for emission flows of 2.5 kg/h or more)	100 mg/Nm^3

The total dust emissions for production under controlled conditions are 0.82 kg/hour and 0.88 kg/hour for surface and underground activities, respectively. According to Table 19, emissions within the limit of 1.5 kg/hour or lower are accepted, with a limit value of 200 mg/Nm^3. imilarly, under uncontrolled conditions, the dust emissions are 1.64 kg/hour and 1.76 kg/hour for surface and underground activities, respectively. The regulation specifies a dust emission limit of 150 mg/Nm^3 for emissions ranging between 1.5 kg/hour and 2.5 kg/hour. Potential dust emissions in the study were assessed according to the Industrial Air Pollution Control Regulation (SKHKKY). The assessment indicated that the emissions exceed the limit value of "1 kg/hour" for mass flow from non-stack sources, as outlined in Appendix 2, Table 2.1 of the Industrial Air Pollution Control Regulation published in the Official Gazette on 03.07.2009 (No. 27277). As a result, dust dispersion modeling was required in accordance with the regulation.

According to Appendix 2, Table 2.2 of the Industrial Air Pollution Control Regulation, short-term and long-term limit values that must be adhered to within the impact area of industrial facilities are specified. The regulation provides reduction values for these limits in tabular form. In this study, the most binding situation is presented for the year 2019 and beyond, as shown in Table 20.

Table 20. By the regulation on the control of industrial air pollution (SKHKKY)

Pollutant	Average duration	Unit	2014	2015	2016	2017	2018	2019-2023	2024 and after
Airborne particulate matter (PM 10)	24 hours (no more than 35 times in 1 year)	μg/m^3	100	90	80	70	60	50	50
	Annual		60	56	52	48	44	40	40
Settling dust	KVS	mg/mg^2 day	390	390	390	390	390	390	390
	UVS		210	210	210	210	210	210	210

In Table 20, it is shown that the dust emissions of PM10 and Settled Dust Parameters meet the limits set by the Industrial Air Pollution Control Regulation (SKHKKY) when production is conducted under controlled conditions. The 24-hour limit (not to be exceeded more than 35 times a year) specified in the regulation is not exceeded. The study indicates that the emitted dust does not exceed the regulatory limits, though large rock fragments are mobilized during the blasting process, followed by the grinding process within the rocks. Internal grinding creates dust in the form of airborne particles, but it has been determined that this amount is not environmentally harmful. Dust formation is an unavoidable aspect of mining activities, including blasting, truck traffic during ore transport, and ore and waste loading and hauling processes. While these activities have various negative effects on the environment, human health, and machinery, the effects are managed as long as dust levels remain below regulatory limits and are not in proximity to residential areas. However, to avoid negative impacts on personnel, machinery, and surrounding vegetation, protective measures should be implemented to ensure efficient and economical operations. Key measures include dust suppression using water systems, dust vacuuming if a closed system is available, and adhering to regulatory limits. The study found that dust formation from surface activities is managed, while dust emissions in underground operations are negligible due to the moist working conditions. As many researchers have emphasized, watering is considered the most effective method for dust suppression.

4. Conclusions

In the Köprübaşı area of Mutki district, Bitlis province, the environmental impacts of blasting activities for both underground and surface copper mining operations have been studied, focusing on their effects on the environment and people, including vibration, air shock, noise, rock ejection, and dust conditions. The findings are as follows:

- The geological structure of the area is characterized by the Çağlayan Formation, which consists of Campanian-Maastrichtian age basalt, andesite, and pyroclastic rocks, and the Fatsa Formation, composed of Maastrichtian age limerock, sandy-clayey limerock, and tuffs. The mining site has been identified as consisting of sandy-clayey limerock units.
- The closest old landslide area is situated approximately 85 meters southeast of the study area.
- The stratigraphic section of the area has been analyzed, showing the types of rocks, discontinuities, physical and lithological properties, slopes, and orientations.
- Although no landslide hazard is present within the study area, there are potential risks from old landslide sites in the vicinity. Regular monitoring and preventive measures, such as reducing slope ratios and applying shotcrete, wire mesh, and ground anchoring (bolts), are necessary. In the event of potential rainfall, additional protective measures against soil erosion should be implemented. Measures like retaining walls, embankments, terraces, and rock walls should be used to mitigate these risks.
- In the study, the vibration levels resulting from blasting activities were evaluated according to Article 25 of the "Regulation on the Assessment and Management of Environmental Noise." The assessment determined that the planned copper mining license boundaries encompass areas including Road 1, Gumuskanat River, Road 2, House, Yazıcık Gendarmerie Station, Yazıcık Neighbourhood, The primary school, Kayran Village, Mutki District, and Bitlis Province Centre. The closest distances to these areas were calculated as 10 m, 220 m, 718 m, 845 m, 1069 m, 1170 m, 1347 m, 1689 m, 24000 m, and 39000 m, respectively. Based on these distance measurements, vibration speeds were found to be 695.67 mm/s, 2.51 mm/s, 0.29 mm/s, 0.22 mm/s, 0.18 mm/s, 0.14 mm/s, 0.12 mm/s, 0.09 mm/s, 0.06 mm/s, and 0.00 mm/s.
- The calculated vibration values within the frequency range of 1-10 Hz were found not to exceed the standard limit of 5 mm/s for any of the settlement areas, indicating that damage to buildings is not expected. The calculated vibration values within the frequency range of 1-10 Hz were found not to exceed the standard limit of 5 mm/s for any of the settlement areas, indicating that damage to buildings is not expected. However, based on the vibration speed assessment at the building foundation, potential damage to certain building types was considered. For instance, Road 1, located 10 meters from the blasting area, recorded a vibration speed of 695.67 mm/s, indicating a high likelihood of damage.
- The comparison of vibration values by building type revealed that Road 1 and Gumuskanat River are at risk. However, as these areas were not assessed under the building type restriction classification, they do not present a problem within the scope of the study.
- Post-blasting ground shaking values were compared based on impact distances and levels of direct influence.

ISSN: 0067-3064

- Based on the calculated vibration values, areas of direct impact have been examined. However, in addition to direct impacts, the indirect effects of ground shaking have also been addressed. These effects have been found to particularly impact people and the environment.
- The indirect effects of ground vibration values have been examined. In the study, vibration values measured in the Road 1, Gumuskanat River, and Road 2 areas as given in Table 5 were considered as impact areas. For Road 1, the vibration value of 965.67 mm/s fully covers the impact levels listed in Table 5, including barely perceptible, perceptible, easily perceptible, strongly perceptible, potentially problematic, annoying, very annoying, tolerance limit, and physical damage risk beginning, encompassing all impact areas. It has been determined that people in or near the Gumuskanat River area are affected up to strongly perceptible levels after blasting. For the Road 2 area, it has been determined that the likelihood of people feeling ground shaking levels after blasting is low.
- The examination of the indirect effects of vibration values on people is considered a personal perception, and it has been determined that these effects are not always seen as stable.
- The impact of air shock after blasting has been examined. Considering that Road 1, the nearest to the copper open quarry mining license boundary, is 10 meters away, the air shock value is calculated as 157.63 dB for this distance. According to this result, the air shock value for the nearest settlement, Road 1, is above the 140 dB threshold, and it is evaluated that there may be issues with air shock in this area. For the settlement areas of House, Structere, Yazıcık Gendarmerie Station, Yazıcık Neighbourhood, The primary school, and Kayran Village, it has been concluded that they are at the initial pain and complaint levels, and problems may arise if there are changes in the instantaneous-specific charge values.
- The effects of air shock on people have been examined. It was determined that people perceive the effects of vibration and air shock as blasting noise. The reason is that air shock is felt through the reaction of large surfaces (such as ceilings and windows). Compared to large-scale controlled blasts, it has been found that responses to smaller but noisier blasts are more frequent.
- The flyrock distances after blasting have been determined as 43, 337, and 600 meters. Considering the distances of the houses mentioned in the study from the limerock quarry, it has been determined that Road (Road 1) at the closest distance of 10 meters, Gumuskanat River, and other settlements are directly and/or indirectly affected. No adverse effects have been observed on people in these areas. However, in some cases, rocks can be ejected up to 700 meters after fragmentation, potentially causing fatal accidents for people. Additionally, ejected rocks can also damage machinery and equipment besides humans, making necessary precautions a must for prevention of such effects.
- Dust formation in the copper production process occurs due to surface and underground operations, and the calculation has been done in two parts.
- Dust formation occurs during ore and slag acquisition processes, with separate calculations made for each part During ore acquisition, dust is generated during blasting, ore removal, loading onto trucks, storage, and transportation for sales. In the slag acquisition process, dust is generated during slag removal, loading onto trucks, transportation to the storage area, and unloading at the storage area.
- In underground operations, the likelihood of dust in the copper mine environment is lower. Underground work areas are naturally humid, resulting in very little dust; only a small amount of dust and harmful gases are released during blasting. The released dust and gases are managed by ventilating or supplying air to the blasting area to remove the dust from the area.

- The amount of dust generated by blasting does not pose a problem because it remains below the regulatory limit values and is not close to residential areas. However, to avoid negative impacts on personnel, machinery, and surrounding vegetation, protective measures should be implemented to ensure efficient and economical operations. These measures include dust suppression with a water system, dust vacuuming if a closed system is present, and ensuring compliance with the regulatory limit values.

Author Contributions: Hasan Eker: data analysis and writing; Demet Demir Şahin: formal analysis and validation.

Conflict of interest: The authors declare that they have no competing interests.
Data availability: All data generated or analysed during this study are included in this published article

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