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Research Article

Environmental Impacts of Rock Blasting From Newmont Ahafo Mining In Asutifi North District, Ghana

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ABSTRACT

The Newmont Ahafo Mine located at Kenyasi in the Ahafo Region of Ghana is primarily involved in gold mining using an open pit mining method. The process involves high levels of rock blasting. Blasting in surface mining is generally associated with several negative environmental impacts including excessive noise, ground vibration, structural damages and air pollution. This study was conducted to assess the environmental impact of rock blasting on the inhabitants of Kenyasi in the Asutifi North District of the Ahafo Region. This was done by determining the frequency of rock blasting vibration and its environmental impact on the surrounding communities. Primary and secondary data were obtained through questionnaires, fieldwork and historic data obtained from the Newmont Ahafo Mine. The rock blasting vibrations, overpressure, frequency and dust concentration levels in sampled air from various locations, i.e. at the blasting sites and its surrounding communities were measured. The concentration of the measurements at the blast sites exceeded EPA standards whereas the concentrations measured in the communities were below. Results from the administered questionnaires show that 83.3% of the respondents believed blasting has an environmental impact on the community but can be regulated to minimize its impact. The study has shown that most of the blasting vibration frequencies were less than 40Hz which can be considered as low according to international standards.

Keywords: Rock blasting; Environmental; Impacts; Newmont Ahafo mine; Ghana

INTRODUCTION

Blasting in surface mining globally constitutes diverse activities and operations that bring about high levels of noise, ground vibration and suspending particles in the environment within which it is practiced. During the extraction of mineral in surface mining, the process is characterized by rock blasting that produces vibration and noise. This is attributed to the various means through which rocks are blasted using diverse methods. After the blasting process, machines of various sizes and capacities are used in transporting, crushing and grading of quarry materials. These processes are often characterized by noise, vibration and dust causing related health and environmental pollution [1].

In the research of Banez [2], mining was defined to be a process through which one obtains various resources that are associated with quarry. These resources come in the form of rocks. Since mining involves the extraction of rocks that have metal deposits, the process involves high levels of blasting and vibration which has the potential of causing harm within the mining site and its surrounding communities. During the mining process, marble, slate, limestone, granite, perlite, phosphate rock, rock salt and ironstone are normally extracted depending on the nature of the operations of the mining site. This is due to the fact that the type of stone or rock determines the operations at the site [3]. Mining is a matter of concern to many countries and communities across the globe.

In the study of Banez [2], blasting in surface mining is carried out through diverse means or methods. The type of method and the equipment that are normally used in the blasting process affect the process. There are instances that require explosives to blast or break rocks in the process of gold mining. This requires some form of drilling into the rock in order to get the needed holes to insert the explosives for the blasting and this produces a high level of vibration which can be detrimental to humans. Various methods or processes are used to detonate the explosives, an example being the electric firing.

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Mining, irrespective of the type, can pose negative impacts on the environment as well as individuals in the surrounding communities, especially those staying within 1km from the mining site [4]. There is also excessive vibration from the blasting of the rocks which has negative impacts on buildings and people [5].

The Newmont Gold mining site in Kenyasi involves rock blasting which is associated with ground vibrations. However, the effects of the excessive vibrations emitted from the mining site have not been analyzed to determine the environmental impact on structures and individuals in the surrounding communities.

According to Langer [6] notes that the effects that are associated with mining are not new in all regards. Way back in the 1890s, concerns were raised in relation to the effects that mining especially rock blasting has on the environment within which they operate. Over the years these effects have been persistent. Issues that relate to smoke, loss of land, quality of water and all manner of environmental issues have been raised but much has not changed [7]. Years have gone but the effect of mining globally continues to be of much concern to public advocates.

It is a known fact that excessive noise is related to the general activities of all industries that are associated with the extraction of minerals [8]. Activities that are associated with rock blasting and excavating of rocks coupled with transporting of supplies in and out of the mining environments cause a lot of environmental pollution. Furthermore, excessive ground vibrations associated with rock blasting have an adverse impact on structures which may cause cracks or collapse of buildings in the nearby communities [9]. The process of blasting the rocks in the mining process leads to vibrations that affect the structural integrity of most buildings in the environment within which the mine operates. Again, the shock waves which usually accompany the blasting have a devastating effect on buildings in surrounding communities which are by themselves not built to withstand the vibrations [7]. In a typical rural environment, houses are built with mud and bricks. The buildings easily develop cracks and in the long run collapses. When the collapse occurs, people staying in the house may be injured or sometimes may even die [10]. The impact of excessive ground vibrations on farmlands may lead to crop failure [9].

In this regard, several studies have been conducted on the impacts of mining activities on near-by communities but there has been no known study at Newmont Kenyasi mining site to determine the environmental impact of rock blasting on nearby community residents. It is for this reason and among others that the present study sought to assess the impact of rock blasting on the environment as well as on the inhabitants of Kenyasi in the Asutifi North District of the Ahafo Region.

MATERIALS AND METHODS

Study area

The research work was conducted at Newmont Ahafo Mine in Kenyasi in the Ahafo Region of Ghana. The Newmont Ahafo Mine is located along the Sefwi Volcanic Belt, a northwestern-southwest volcanic belt in western Ghana. The mine is located at about 307 kilometers northwest of the national capital, Accra. Commercial production at Ahafo started in 2006. Ahafo has two main ore zones: Ahafo South and Ahafo North. Mining is currently underway in Ahafo South (Newmont Mining Corporation, 2018).

The Ahafo mine is operated in ten host communities in the Asutifi North and Tano North districts of the Ahafo region. Host communities are; Ntotroso, Kenyasi N°1, Kenyasi N°2, Gyedu, Wamahinso, Susuanso, Terchire, Yamfo, Afirisipakrom and Adrobaa. Traditional leaders and other key actors play an important role in local communities. Through frequent engagement with these stakeholders, they work to create sustainable development programs and shared value over the long term. Community Information Offices, located in the 10 host communities, provide daily information on operations, as well as business and employment opportunities. Community members also report complaints and grievances, which are processed through a formalized reporting mechanism (Newmont Mining Corporation, 2018).

The Newmont Ahafo Mine is primarily involved in gold mining using an open pit mining method. The process involves high levels of rock blasting. Blasting is associated with excessive noise and high vibration levels that could adversely affect residents and structures at the host community.

Research design

A cross-sectional survey design based on the use of questionnaires was adopted to achieve some of the specific objectives. Primary data on blast vibration was collected on the field using geophones to monitor the blast vibrations from January 2018 to August 2018. Also, Secondary data on vibration statistics from the Ahafo mine for four years spanning 2014 to 2017 was obtained from the company.

Study population

The study population involved the inhabitants of two host communities (Kenyasi No.1, and Kenyasi No. 2) close to Newmont Ahafo mine. The study population considered were adults of sound mind who have resided in the two selected communities for at least three months as at the time of the study. The estimated population of the two selected communities as per the 2010 population and housing census is about 7,000.

Sample and sampling technique

The sample size of the study was 323 respondents and was obtained from community members of Kenyasi No.1 and Kenyasi No.2. The sample size was calculated based on the population of 7,000 [11]. The sample size was calculated at 95% confidence level and 5% margin of error. The sample size was arrived at using equation 1;

$$SS = \frac{Z^2 * p * (1-p)}{c^2} \quad (1)$$

where:

Z =1.96 for 95% confidence level

p =50% which is 0.5 (percent)

c =confidence interval or margin of error which is 0.05

From the sample size of 323, a total of 62% represent 200 respondents for Kenyasi No.2, whereas 38% represents 123 respondents for Kenyasi No.1. The difference in respondents for the two communities in the surrounding is due to the closeness of both communities to the blasting sites (i.e. Kenyasi No. 2 is closer to the site than Kenyasi No. 1). The research employed probability sampling techniques such as cluster sampling, stratified sampling and simple random sampling technique to select the subjects for the study. First of all, cluster sampling was used to put the various communities into clusters according to the known suburbs. These localized locations were further stratified into households and popular community meeting places. This was done by way of stratified sampling. From the strata that were noted, a simple random sampling technique was conducted to select the sample size. This was done with 'yes' and 'no' coded papers in a covered container. Based on the probability of being selected or otherwise, the population was made to pick a folded paper from the container. Those who chose the papers with the 'yes' inscriptions formed part of the study. Those who selected the 'no' cards were excluded from the study.

Data collection methods

Two major sources of data were used to obtain data for the study. These include primary and secondary data. Primary data was obtained by monitoring blast vibration generated at selected blast monitoring points using Geophones. The blasts vibration generated were collected on the field between January 2018 and August 2018. Furthermore, in relation to measuring of dust concentration in the study area, the researcher used a Dust Measuring Device KM 3887. This served as the instrument for detecting accurately the levels of suspended air particles (i.e. air pollutants) for air quality assessment at the locations where the measurements were done and were compared to the EPA standard of air quality of 70µg/m^3.

Primary data was also gathered through the use of questionnaires. Data were obtained from the host communities' members on the environmental impact of rock blasting on the surrounding communities.

A questionnaire was structured to collect information on demographic characteristics on age, gender, occupation, etc. from the respondents of the study as well as data on the environmental impact of rock blasting on the surrounding communities. These questions were both open and close-ended. Secondary data were collected from the mining company on the vibrations generated from rock blasting levels recorded by the environment department between 2014 and 2017. The vibrations statistics obtained were combined with the field data collected for 2018 and then compared to the standard vibration limit (2.0In/sec particle velocity and 0.5psi). Questionnaires were administered to the sampled population and this was done with the aid of research assistants. They were made to know the essence of the research before the administration of questionnaires in order to prevent misrepresentation of answers. The aim was to prevent or avoid any avenue that could compromise the quality of responses. The research team established a good rapport with respondents throughout the questionnaire distribution and collection periods to enable them feel comfortable to give independent and accurate information. The questionnaire was pre-tested before its administration to respondents.

Also, generated blasting vibration and suspending air particles (i.e. dust) data from Newmont Ahafo Mine between 2014 and 2018 were obtained. These data were compared to the standard vibration and dust limits in order to determine the environmental impact on the host communities.

Measuring blast vibration

Determining ground vibration

The vibration of the blast is generated in the ground by a dynamic source of sufficient energy. It is composed of different types of waves of different characteristics and meanings, collectively called seismic waves. These seismic waves propagate radially from the vibration source and decrease rapidly as the distance increases. Four interdependent parameters were used to define the amplitude of the ground vibrations at the location. These are:

Displacement -the distance that a particle moves before returning to its original position, measured in millimetres (mm).

Velocity –displacement rate of particle change is determined in millimetres per second ($mm.s^{-1}$).

Acceleration –velocity rate of particle change is determined in millimetres per second squared ($mm.s^{-2}$) or acceleration due to gravity.

Frequency -the oscillations number per second in which a particle undergoes is determined in Hertz (Hz).

The parameter used to determine impulsive generated vibration of the particle velocity and frequency in sinusoidal motion is given in equation 2;

$$PV = 2\pi fa \qquad (2)$$

where PV, f and a represent particle velocity, frequency and amplitude, respectively.

The peak particle velocity also known as the highest value of particle velocity was of significance to the study. This was measured in three mutually independent directions that are perpendicular to one location as a way of ensuring that the actual peak value is captured. The directions are transverse, vertical and longitudinal. This kind of maximum single-plane measurement is the worldwide recommended standard. Also, it is the basis of all recognized investigations of satisfactory vibration levels with respect to human perception and structural damage.

Determining airborne blast vibration

Anytime an explosive occurred, it produces transient airborne pressure waves. When rocks are blasts, airborne pressure waves are generated from five major sources namely:

(i) movement of rocks from the face,

(ii) ground-induced vibrations,

(iii) the release of gas by natural cracks,

(iv) the release of gas by shutdown, and

(v) explosive charges insufficiently confined.

When these waves pass a given position, the pressure of the air increases very rapidly to a value greater than the atmospheric or ambient pressure. It then falls more slowly to a value below atmospheric pressure before returning to the ambient value after a series of oscillations. The maximum pressure above atmospheric pressure is called peak overpressure. The pressure waves include energy over a wide range of frequencies. Energy above 20Hz is perceptible to the human ear in the form of sound, while that below 20Hz is inaudible. However, it is perceived as a concussion. The sound and the concussion are together called air overpressure, measured in decibels (dB) or pounds per square inch (p.s.i.) based on required range frequency. The decibel scale expresses the logarithm of the ratio between a level and a given base value. In acoustics, this reference value is taken as being equal to 20×10^{-6} pascals, which is considered as the threshold of human hearing.

Vibration criteria

The residential type structures damaged were classified as follows:

Threshold damage –this is the occurrence of building cracks or the increasing of already existing cracks on plaster or drywall surfaces as a result of the blast vibrations.

Minor damage –this is the occurrence of large cracks that lead to the collapsing of plaster on drywall surfaces or bricks or concrete blocks cracks.

Major or structural damage –this is a damage caused to the structural elements of the building.

EPA vibration limit

The researcher used the Environmental Protection Agency (EPA), DIN, and United States Bureau of Mine (USBM) vibration limits as the reference point to determine high and low vibrations from the blasting site of Newmont Ahafo Mine (Table 1).

Determining peak particle velocity (PPV)

The peak particle velocity (PPV) was measured to determine its potential damage. Peak particle velocity corresponds to an indicator of a structural damage, largely depending on parameters such as the distance between the blast and measuring point, the characteristics of the medium and the maximum charge [12].

The formula proposed by USBM was used to determine the PPV in equation 3;

$$V = K * \left(\frac{D}{\sqrt{W}}\right)^{n} \quad (3)$$

Where V and W represent peak particle velocity (mms) and charge per delay (kg), respectively. The factor of K is the scale distance SD in $m/kg^{1/2}$.

K and n in the study represent the site constants which vary from site to another. K depicts the line intercept (SD=1) on the log-log graph. This is the initial energy transferred from the explosive to the surrounding rocks. Lastly, n represents the slope factor responsible for the attenuation rate of the PPV induced by the spreading geometric and the impact of rocks features.

Determining air blast overpressure

Air blast turbulences spread as compression waves in air. It can travel for a long distance under conditions such as poor blast design and certain weather conditions [12]. The overpressure is calculated in either decibel (dB) or Pascal (Pa) using equation 4.

$$P_{dB} = 20log\,(P/P_0) \quad (4)$$

Where P and P_0 represent measured and reference pressures. A reference pressure of $2.0{\times}10^{-5}$ Pa was used. Air blast is an atmospheric pressure wave emanating from an explosion in the air. The wave consists of audible (acoustic) which has a higher frequency (i.e. between 20 - 20,000Hz) and sub-audible (infrasound) which has a low frequency content (i.e. below 20Hz). Audible air blast (Acoustic) is classified as noise, whereas air blast at frequencies below 20Hz is called a concussion.

Air blast regulatory limits

The recommended maximum safe air blast permitted at residential structures is 0.014 psi (134 dB). This set of criteria was based on the major superficial type of damage affecting residential-type structures. The safe maximum air blast levels are thus recommended to be 134 dB at 20Hz high pass system. These recommended levels provide 90-95% of annoyance acceptability and 95-99% non-damage probability as shown in Table 2.

Blast vibration regulatory limit

Ground vibrations related to rock blasting result in several deleterious problems. The United States Bureau of Mine (USBM)

Table 1: EPA blasting vibration limits for newmont ahafo mine.

	Overpressure reading dB(L)	Overpressure Limit (Mincom) dB(L)	Vibration reading (mm/s)	Vibration limit (Mincom) (mm/s)
SKBMP1 (Subika bypass)	<88	117	2.28	2
		2nd shot		
SKBMP1 (Subika bypass)	109.1	177	0.81	2
Comment: SKBMP1 vibration for the first shot exceeeded mincom guideline of 2 mm/srecording 2-28 mm/s				

Table 2: Overpressure unit conversion (dB and psi) and effects on human annoyance and structural damage. (Source: Nicholls et al., 1971).

mi		
dB	Pa	Effect
180	206842.7	Structural damage
170	6550.01	Most windows break
160	2068.42	
150	655	Some windows break
140	206.84	OSHA* maximum for impulsive sound
130	65.5	USBM TPR 78 maximum
		USBM TPR 78 safe level
120	20.68	Threshold of pain for continuous sound
110	6.55	Complaints likely
100	20.684	OSHA maximum for 15 minutes
90	0.65	
80	0.2	OSHA maximum for 8 hours

RI 8507 reveals that peak particle velocity corresponds to the best description of the single ground vibration [13]. The safe maximum velocity of particles around 2 in/sec (50 mm/s) is recommended for all buildings [14]. Most modern blasting seismographs express the vibration data according to the USBM limiting criterion. In general, at lower frequencies, the ground vibration should not exceed 12.7 mm/s, but at higher frequencies, the limit can increase to 50 mm/s [15].

Table 3 depicts the blasting level set of smooth criteria recommended by the USBM–RI 8507 which was employed in the present study. Any seismic record for any component (longitudinal, transverse, vertical) for the particle velocity at a particular predominant frequency below any part of the solid line graph in Figure 4 is considered safe. However, any value above any part of the solid line graph increases the possibility of human annoyance and residential damage. Figure 1 presents the criteria of the German standard DIN 4150 (DIN 4150, 1986), also taken into account in this study. DIN 4150 proposes three lines of vibration limits as a function of time for different types of structures [12,16]. Line 1 represents buildings meant for industrial and commercial purposes. Line 2 represents residential building. Line 3 represents structures not listed in 1 and 2 because of their particular susceptibility to vibration; and having great intrinsic values such as construction that are under a preservation order. The low frequency part of the seismic waves plays an important role. In addition, the potential damage caused by the vibrations induced by the blast on the structures is conditioned by the speed of the particle and the low frequency part of the seismic waves. Potential damages in the low frequency range (<40 Hz) are considerably higher than those in the high frequency range (> 40 Hz). This is due to resonance effects in the natural frequency range (5-16 Hz).

Measurements and methods

For this research, three shots were recorded at Newmont Ahafo Mines using the Nonel initiation system. Three Deltaseis seismographs model and the two Instantel seismographs model were used. The seismographs come with microphones which were used to measure sound and air blast overpressure. The instruments were installed at blast monitoring locations. The threshold release of each seismograph is selected according to its location.

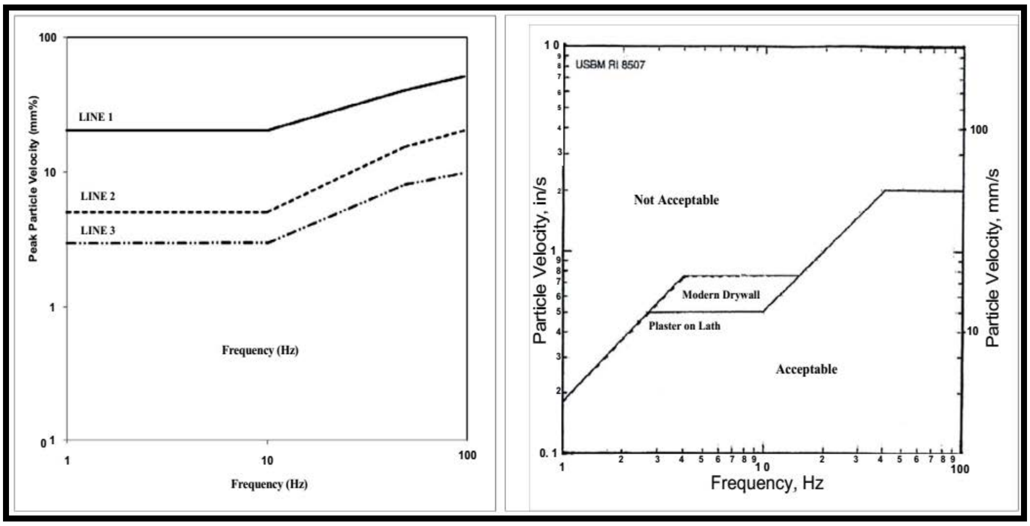
Measuring dust concentration

Determination of the concentration of dust particles

In measuring the dust (i.e. suspending particle in the air) concentrations, filter papers were designed by the researcher. These filters have pore sizes that were noted to be less than 10 microns. These were used to collect particulates. These were first stabilized in a desiccator for 24 hours. The filters were weighed with an electronic balance (AG104 Mettler Toledo) as M_1. The filters were then fitted into the PM10 samplers which draw air at a rate of 5.000 m^3 per minute and then sent to the field. Loaded filters with PM10 were removed and conditioned in a desiccator for 24 hours to ensure no moisture effect on the air particulate weight before re-weighing (M_2). The study considered eight (8) site locations. Four (4) of these locations were sited at the rock blasting site and the other four (4) in the selected communities. The mass concentration of the sampled particulates was then calculated using the equation 5;

Table 3: Safe level blasting criteria: Thresholds of PPV values at different frequencies. (Source: DIN 4150, 1986; Siskind, Stagg, Kopp & Dowding, 1980).

US Bureau of Mines R1 8507			Structure	DIN 4150-3		
Structure	PPV (mm/s)			PPV (mm/s)		
	<40 Hz	≥40 Hz		10 Hz	10-50 Hz	50-100 Hz
Modern homes dry	18.75	50	Industrial buildings	20	20-40	40-50
Wall interiors			Residential buildings	5	May-15	15-20
Older homes	12.5	50	More sensitive buildings than above	3	03-Aug	08-Oct



Limit of the potential damage for:
LINE 1: Industrial Building
LINE 2: Residential Building
LINE 3: Sensitive Building

The safe limit for
~~~~~ Modern Homes
[redacted]es

Figure 1: Recommended safe levels for blasting vibration by DIN 4150 and USBM.
~~~~~

$$PM10 = \frac{M_2 - M_1}{FR*T} \quad (5)$$

Where, M_2, M_1, FR and T represent mass of filter and particulate matter, mass of filter, flow rate and time.

Assessing the impact of blasting activities on the environment

There was a random inspection of civil works and farms located within the surroundings of the blasting sites of Newmont Ahafo Mine so as to determine the various environmental impacts of the rock blasting activities especially on structures and farmlands. In doing this, the researcher listed the various potential environmental impacts of the blasting activities using a checklist. Upon visiting the nearby communities' civil works (structures and buildings), any sign of the various environmental impacts of that blasting that the researcher spotted was ticked using the checklist. The impacts that the researcher looked out for were cracks in buildings, collapse of buildings, waste farmlands, etc. There were follow up questions that were contained in the questionnaire to confirm the cause of the damage on the structures, building and farmlands from the community members.

Data analysis

In general, the collected responses were analyzed with the Statistical Package for Social Sciences, (SPSS) version 23.0. The responses obtained from completed questionnaires were first of all checked for accuracy and consistency. In the case of open-ended questions, they were grouped based on the responses given by the respondents. Regression analysis was done to determine the relationship and effects of blasting and vibrations on buildings and finally the relationship between mining activities and waste farmlands.

RESULTS AND DISCUSSIONS

Demographic characteristics of respondents

Table 4 summarizes the distribution of demographic data of the respondents. In relation to sex, 187(58%) of respondents were females while 136(42%) were males. A large number, 100(31%) of the respondents were within the ages of 26-36 years. A total of 183(57%) of the respondents were married. Majority of the respondents, 174(54%) were Christians. Out of the 323 respondents, 152(47%) were Senior High School graduates. A total of 96(30%) respondents were farmers, 75(23%) traders while 75(23%) work at the mining company.

The demographic data of the respondent indicated that majority of them were educated. 152(47.05%) had SHS education and 33(10.22%) had tertiary education.

Level of rock blasting vibration for the past four years

This section presents the analysis of rock vibration levels recorded from Newmont Ahafo site between 2014 and 2018. The seismograph used to measure the blasting data is made up of a data acquisition and storage device, an air overpressure transducer and a 3-axis speed transducer. Soil vibration and air explosion data recorded as sounds and waves were printed from the company records, as shown in Figure 2. Figure 2 below shows a seismograph of ground vibration and Airblast.

The air-blast overpressure, full waveform as well as summary of

Table 4: Demographic characteristics of the respondents. source: field data (2018)

Variable	Frequency	Percentage
Sex		
Male	136	42
Female	187	58
Total	323	100
Age		
15-25	60	19
26-36	100	31
37-47	90	28
48-58	73	23
Total	323	100
Marital Status		
Married	183	57
Single	76	24
Divorced	53	16
Widow	11	3
Total	323	100
Religion		
Christian	174	54
Muslim	64	20
Traditionalist	85	26
Total	323	100
Educational Status		
Tertiary	33	10.22
Secondary	152	47.05
Primary	84	26.1
No Education	54	16.72
Total	323	100
Occupation of Respondents		
Farmer	96	30
Trader	75	23
Teacher	32	10
Mine Worker	54	17
Non-Employed	66	20
Total	323	100

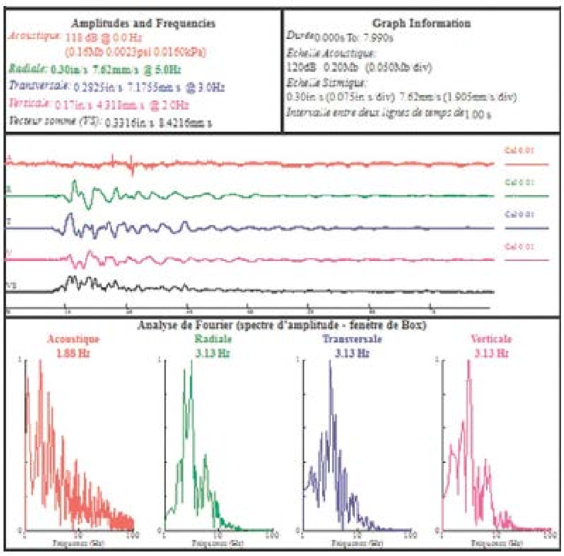


Figure 2: Ground vibration and airblast.

peak values of ground movements are illustrated in Figure 2. The overpressure, frequency and vibration levels from each blasting pit between 2014 and 2018 were obtained from the Newmont Ahafo Mine and the five highest vibrations recorded in each month with their corresponding frequencies and overpressure values are presented in Tables 5-9.

The field data collected during the period of 2018 was compared to the historic data obtained (between 2014 and 2017). Figures obtained in 2018 were relatively higher. Investigations revealed that blasting was performed in a relatively newer pit such that the blast was closer to the surface. This implies that the impact of vibration reduces as the pit goes deeper. In theory, it implies

Table 5: Highest rock blasting vibration levels recorded in each month for 2014.

Month	Overpressure (EPA Limit <88dB)				Frequency (EPA Limit = 20Hz)				Vibration (EPA Limit = 2.0mm/s)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
Jan	121.9	115.2	112.8	120	7.4	13	3.5	10	2.24	2.27	2.32	2.8
Feb	105.5	121.9	115.2	94	4.3	7.4	13	100	1.61	2.24	2.27	3.42
Mar	91.5	91.5	123.7	98.8	64	100	7.4	13	1.85	2.16	2.83	2.93
Apr	108.4	97.5	91.5	115.6	8.4	-	85	2.3	1.19	1.22	1.28	1.46
May	107	116.4	107	108.4	-	-	2.9	10	1.9	2.28	2.56	3
Jun	106	113.5	97.5	124.5	11	5.7	73	12	2.92	3.25	3.76	4.09
Jul	94	94	120	136.2	57	64	-	8.3	2.79	2.92	4.35	4.98
Aug	108	91.4	95.9	106	3.7	100	23	3.1	1.94	2.09	2.19	2.37
Sep	88	88	95.9	91.5	-	-	-	100	1.24	1.27	1.36	1.41
Oct	97.5	91.5	91.5	91.5	6	100	34	47	1.35	1.49	1.52	1.89
Nov	91.5	94	94	91.5	73	57	73	100	1.83	2.3	3.05	4.19
Dec	91.5	94	88	94	24	3.1	-	73	0.49	0.69	0.84	3

Table 6: Highest Rock Blasting Vibration Levels Recorded in each Month for 2015. (Source: Author's Construct, 2018).

Month	Overpressure (EPA Limit <88dB)				Frequency (EPA Limit = 20Hz)				Vibration (EPA Limit = 2.0mm/s)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
Jan	91.5	91.5	91.5	91.5	73	64	100	28	1.81	1.82	2.04	2.24
Feb	114.2	95.9	94	94	16	17	27	11	0.19	0.24	0.39	0.98
Mar	91.5	91.5	91.5	98.8	30	100	-	3.5	0.58	1.25	1.25	1.67
Apr	<88	<88	<88	<88	-	-	-	100	<0.13	<0.13	<0.13	2.22
May	98.8	94	100	91.5	100	64	2.6	57	0.4	0.4	81	0.93
Jun	<88	<88	95.9	91.5	-	-	64	85	<0.13	<0.13	0.18	1.1
Jul	91.5	91.5	94	91.5	39	27	67	100	1.05	1.2	1.35	1.57
Aug	91.5	91.5	95.9	113.1	54	25	58	57	0.25	0.56	0.59	1.09
Sep	<88	<88	<88	<88	-	-	-	-	<0.13	<0.13	<0.13	<0.13
Oct	<88	<88	<88	91.5	-	-	-	85	<0.13	<0.13	<0.13	1.7
Nov	<88	<88	91.5	91.5	-	-	12	100	0.51	0.64	0.79	3.1
Dec	100	101.1	97.5	108.4	-	4.3	8.7	5.6	0.15	0.15	0.19	0.19

Table 7: Highest Rock Blasting Vibration Levels Recorded in each Month for 2016. (Source: Author's Construct, 2018).

Month	Overpressure (EPA Limit <88dB)				Frequency (EPA Limit = 20Hz)				Vibration (EPA Limit = 2.0mm/s)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
Jan	104.2	91.5	94	107.5	3.1	21	4.5	7.1	0.18	0.22	0.36	0.92
Feb	91.5	101	100	110.9	34	3.9	10	1.9	0.31	0.4	0.5	0.85
Mar	91.5	97.5	91.5	91.5	34	28	100	64	1.07	1.1	1.22	1.53
Apr	91.5	91.5	102.8	91.5	28	43	-	20	0.89	0.97	1.21	1.28
May	<88	<88	95.9	91.5	-	-	12	100	<0.13	<0.13	0.38	1.4
Jun	<88	<88	97.5	101.9	-	-	6.9	6	<0.13	<0.13	0.33	0.53
Jul	<88	<88	<88	<88	-	-	-	-	<0.13	<0.13	<0.13	<0.13
Aug	<88	98.8	91.5	98.8	-	8	51	23	<0.13	0.19	1.91	3.61
Sep	<88	<88	<88	104.2	-	-	-	64	<0.13	<0.13	<0.13	2.68
Oct	<88	<88	<88	<88	-	-	-	-	<0.13	<0.13	<0.13	<0.13
Nov	<88	<88	<88	<88	-	-	-	-	<0.13	<0.13	<0.13	<0.13
Dec	<88	<88	<88	113.1	-	-	-	-	<0.13	<0.13	<0.13	1.41

Table 8: Highest Rock Blasting Vibration Levels Recorded in each Month for 2017.

Month	Overpressure (EPA Limit <88dB)				Frequency (EPA Limit = 20Hz)				Vibration (EPA Limit = 2.0mm/s)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
Jan	<88	<88	<88	91.5	73	-	-	-	<0.13	<0.13	<0.13	0.99
Feb	<88	<88	<88	91.5	-	-	-	-	<0.13	<0.13	<0.13	1.15
Mar	<88	<88	<88	<88	-	-	-	-	<0.13	<0.13	<0.13	<0.13
Apr	<88	<88	<88	108.4	-	-	-	8.3	<0.13	<0.13	<0.13	0.15
May	91.5	91.5	94	91.5	16	13	11	64	0.6	0.66	0.96	1.31
Jun	<88	<88	<88	<88	-	-	-	-	<0.13	<0.13	<0.13	<0.13
Jul	<88	<88	101.9	91.5	-	-	26	57	<0.13	<0.13	0.9	1.02
Aug	98.8	94	94	94	30	11	85	64	1.32	1.82	1.94	2.84
Sep	<88	109.5	100	88	-	26	46	27	0.72	0.78	1.61	2.17
Oct	91.5	91.5	91.5	91.5	100	73	51	100	0.47	0.77	1.05	1.95
Nov	98.8	88	<88	98.8	10	-	-	46	0.77	1.17	1.31	1.36
Dec	88	<88	91.5	91.5	51.2	-	100	64	1.12	1.33	1.47	2.08

Table 9: Highest rock blasting vibration levels recorded in each month for 2018.

Month	Overpressure (EPA Limit <88dB)				Frequency (EPA Limit = 20Hz)				Vibration (EPA Limit = 2.0mm/s)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
Jan	<88	<88	91.5	<88	-	-	65	-	1	1.39	1.72	2.33
Feb	107	95.9	97.5	91.5	4.7	21	64	47	0.78	0.83	1.29	2.33
Mar	95.9	94	94	94	51	85	100	85	2.32	2.77	3.39	3.56
Apr	103.5	91.5	91.5	95.9	3.6	100	100	47,0	1.08	1.09	1.27	1.37
May	97.5	<88	<88	97.5	5.2	100	-	20	1.11	1.34	1.46	1.49
Jun	<88	91.5	88	88	100	100	27	85	0.54	0.89	2.82	2.97
Jul	132.2	119.7	124	131.5	100	3.9	30	3.9	4.32	4.66	5.75	21.44
Aug	<88	<88	<88	<88	23	100	100	24	0.67	1.44	1.48	1.64
Sep	<88	<88	<88	<88	13	85	100	85	1.47	1.91	2.14	2.24

Table 10: Air blast measurements and ground vibration results.

Yr	Seismograph	PPV_{MAX}	Particle Velocity (mm/s)			Ground Vibration Frequency (Hz)	Charger per delay W (kg)	Distance D(m)	Scaled distance SD (m/kg 0.5)	Air Blast (dB)	Air Blast Frequency (Hz)
			Longitudinal Peak (PVL)	Vertical Peak (PVV)	Transverse Peak (PVT)						
2014	M1	14.2	11.1	7	14.2	5	390	434	22	117	2.25
	M2	1.7	0.7	1.6	1.7	2.25	390	610	578	108	10.63
	M3	-	-	-	-	-	-	1141	-	-	-
	M4	-	-	-	-	-	-	1429	-	-	-
2015	M1	7.6	7.6	4.3	7.2	3.13	275	391	23.6	118	1.88
	M2	2.1	2.1	1.7	1.3	2.5	275	592	35.7	111	1.5
	M3	1.1	0.8	1	1.1	2.5	275	1144	69	108	2.4
	M4	1	0.6	0.6	1	2	275	1452	87.6	100	8.1
2016	M1	13.6	9.5	5.5	13.6	5.63	300	280	16.2	110	1.38
	M2	1.7	1.7	0.9	1.7	2	300	503	29.1	106	6.0
	M3	0.9	0.6	0.6	0.9	2	300	1069	61.7	108	5.0
	M4	0.6	0.5	0.5	0.6	1.63	300	1404	81.1	115	3.88

that the impact decrease with time and depth of blasting. Table 5 represents the 2014 vibration levels with their corresponding frequencies and overpressure values. According to the EPA, USBM and DIN the recommended blasting overpressure should not be <88dB, frequency should be 20Hz whereas the vibration limit should 2.0mm/s. Analysing the present data, the various vibration, frequency, and overpressure values were higher than the recommended EPA blasting reference limits. This implies that the vibrations emitted from the blasting sites have the potential of causing environmental and health problems to individuals within and around the blasting area.

Table 6 below illustrates the 2015 vibration, frequency and overpressure values emitted from the rock blasting sites of the mining company. About 3 out of 12 months (for M_3 & M_4) experienced vibration, frequency and overpressure values higher than the recommended EPA, USBM and DIN blasting reference values. The overpressure values recorded for most of the months were higher than the recommended values. This implies that the vibration emitted from the mining site has the potential of causing environmental and health problems for individuals within and around the blasting site. Table 7 illustrates the 2016 vibration levels with their corresponding frequencies and overpressure values. The findings indicated only August (3.61mm/s) and September (2.68mm/s) for M_4 recorded vibration values higher than the reference point (2.0mm/s). However, January to May recorded overpressure and frequency values above the reference points. This implies that the vibrations emitted from the blasting site were within the recommended limits and this would have less negative impact on the environment of the host community members. Table 8 presents the 2017 vibration, frequency and overpressure values for each month from the blasting sites of Newmont Ahafo Mine. The results showed that only August (2.84mm/s) and September (2.17mm/s) for M_4 recorded vibration values higher than the reference point (2.0mm/s). Most of the months also recorded overpressure and vibration frequencies within the recommended reference point. The various vibrations, frequency and overpressure values were within the recommended EPA, USBM and DIN blasting reference value. This implies that the vibration emitted from the blasting site would have less impact on the environment of the host communities.

Table 9 illustrates the 2018 vibration levels with their corresponding frequencies and overpressure values. The findings indicated that 5 out of the 9 months recorded vibration values above the reference value whereas all the months have recorded at least one overpressure and frequency value above the reference points. This implies that most of the vibration, frequency and overpressure values recorded were above the recommended EPA, USBM and DIN blasting reference values. The vibration emitted from the blasting sites, therefore, have the potential of causing environmental and health problems for individuals staying near the blasting sites.

Table 10 presents the data for each explosion. Resultant compressed air, overpressure and vector sum vector were also determined.

Vibration predictor equation

In establishing the relationship between VPP and the distance at the scale of the blasting sites, regression analysis was performed using all the pairs of data. The equation determined for the sites was used to establish the allowable explosive charge at any distance. Equation 3 is applied at this stage.

Blast vibration data was analyzed to understand the ground vibration effect resulting from blasting in the open pit. Data included part particle velocity and scaling distance from different rock blasting. The predictive equation for scale distance and PPV are;

$$V_{PPV} = 1508 * \left(\frac{D}{\sqrt{W}}\right)^{-1.92} \quad (6)$$

And

R = 0.92 ≈ 1.0

Regression analyses values of 1508 and -1.73 were used to determine K and n respectively. It was established that VPP decreases when the maximum loads by delay in the hole are decreased or when distance increases. The VPP stipulated according to the requirements must be maintained so as to determine the maximum load per pit for structures at a fixed distance.

Evaluation of damage risk

The firing frequency and measured VPP amplitudes were evaluated taking into account some established damage criteria (USBM and DIM 4150) used in the geotechnical/structural engineering as well as the mining field. All the recorded ground vibration frequency data were less than 40Hz in all below VPPs. These values exceeded the safety limits for older homes (VPP=12.50mm/s). However, they were below the safety limits for modern homes (VPP=18.5mm/s). Based on the DIN damage criteria, the VPP and frequency measurements belonged to the class of residential and more sensitive buildings (VPP =0.5mm/s and F =10Hz). It was observed that in the PPV plot as a function of frequency (Figure 3). Most of the values were below the allowable limits stipulated in the damage criteria for residential and more sensitive buildings. Some of the values that exceeded the safety limits posed environmental and health implications on residents near the blasting site.

Figure 3 depicts the particle velocity versus the scaled distance of the blasting site. It was observed that in the plot as a function of frequency, some recorded ground vibration data were greater than the allowable limits described in both damage criteria.

Overpressure results

Overpressure values ranging between 100 and 118 dB (Table 10) decreased as the measurement distance increases. This value of overpressure resulted in the vibration of windows and also noise levels that aroused panic and discomfort, but not enough

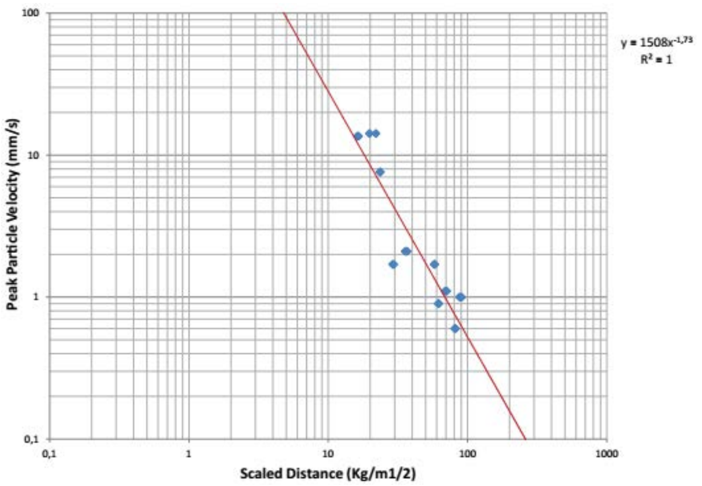


Figure 3: PV versus scaled distance.

to damage structures. Based on this knowledge, modifications should be made to the current blasting practice to ensure that the overpressure value is within allowable limits. The wind direction should also be considered during blasting so as to avoid blasting when the wind direction is towards the host community.

Frequency analysis

Ground vibration frequency

Majority of the blast frequencies were above 20Hz (Table 1). Below 20Hz, structures are usually stressed indirectly by vibrations. The foundation soil was mobilized since the foundations were not heterogeneous and consolidated. The soil in the area did not correctly redistribute stresses. The soil type in the area consists of conglomerates, gypsum silts, clays and sand.

The measured frequency of the ground vibration induced by blasting in the area represented a higher risk of potential damage. Majority of the shots had frequencies ranging from 1–5 Hz which posed a high risk of damage.

Residential structures in the area may be affected due to the low frequencies which may be critical to residential structures in general. This is because these values are in the range of their natural frequencies. The measured frequency values which are close to the natural frequencies of residential structures (20 Hz) may be very dangerous as it results in amplification of the vibration of the ground. The area is characterized by fractures which explain the low frequency recording. Generally, non-fractured rocks result in high frequencies.

High frequencies were absorbed by the soil as the soil acted as a filter and hence imposed its own frequencies. Table 10 shows the distribution of the measured frequencies.

Explosive frequency

The measured induced explosive frequencies were all below 20Hz (from Table 10) resulting in an increased risk of damage. An evaluation of the damage risk of the shots according to DIN 4150 criterion DIN standards is illustrated in Figure 5.

Assessment of atmosphere of blasting site and surrounding communities for dust concentration

Table 11 summarizes the results of the air assessment in the vicinity of the blast site and the communities for dust particles. As noted

Table 11: Concentration of dust particles in the atmosphere at blasting site and the surrounding community.

Dust Particles Concentration	Dust Concentration (μg/m³)	
Location ID	PM10	TSP
Blasting Site		
Site 1	103.5	256.4
Site 2	182.7	632.2
Site 3	121.0	239
Site 4	81.2	192.0
Surrounding communities		
Community 1	68.8	153.2
Community 2	67.4	178.1
Community 3	52.2	190.2
Community 4	54.9	234.0
EPA (Standard)	70.0	230.0
IFC/WB (2000)	150.0	700.0

above, all of the sampling sites at the blast site had dust levels that exceeded the standards recommended by the Environmental Protection Agency (EPA) of (70 μg/m³) with the concentration of highest dust (182.7μg/m³) recorded at site 2 and at least (81.3 μg/m³) at site 4. In addition, the results show that all communities around the blast site recorded a lower concentration of dust particles in the site. Ambient air showed the highest concentration of (68.8 μg/m³) in Community 1 and (52.9 μg/m³) in Community 3.

The results showed that the concentrations of dust particles within air samples collected from various locations at the blasting sites were higher than the Environmental Protection Agency (EPA-Ghana) standard of 70 μg/m³ and ranged between 81.2 and 182.7 μg/m³. Also, the concentration total for suspended particles within samples of air collected from the various locations at the blasting site were higher than the EPA standard of 230 μg/m³ and ranged from 239 to 632.2 μg/m³. These results confirm the report of earlier studies (Ferris, speizer & Spengler, 1979) that blasting activities release a high concentration of dust particles into the immediate atmosphere surrounding blasting sites.

Even though the concentrations of dust particles in the various samples of air within the blasting site were higher than the EPA standard of 70 μg/m³ for particulate matter (PM) and 230 μg/m³ for TSP, most of these values were lower than the World Health

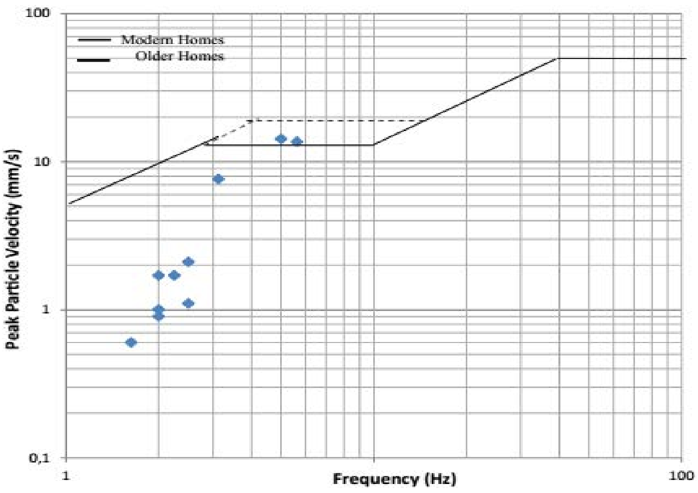


Figure 4: Evaluation of damage risk of the shots by EPA criterion.

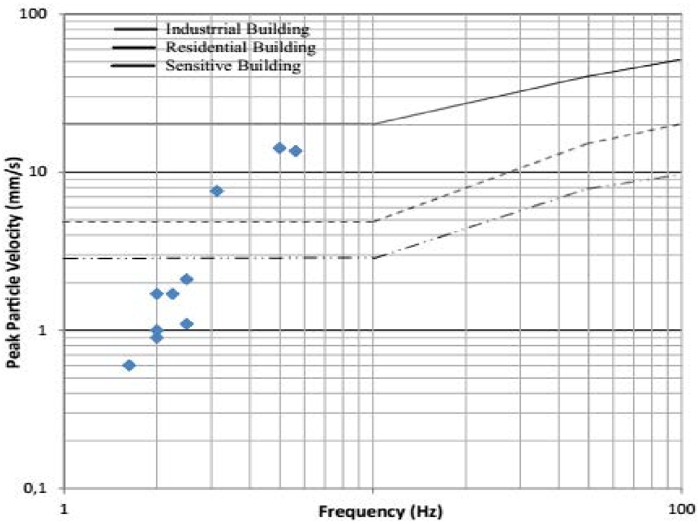


Figure 5: Evaluation of damage risk of the shots according to DIN 4150 criterion DIN standards.

Organization (WHO) standards of 150 and 500 μg/m³ for PM_{10} and TSP respectively. It is however important to note that Ghana's EPA are the regulators of environmental pollution in Ghana and since they are in charge of licensing for mining operations, they are more answerable to them as compared to WHO. It is therefore for these reasons that one should be particularly concerned when the amount of pollution that is being generated is higher than the limits that Ghana's EPA has set.

In addition, the results indicated that the concentrations of PM in the various air samples from the host communities were all lower than the EPA standard of 70 μg/m³ with half of the samples having particulate matter (PM) concentrations ranging from 67.4 to 68.8 μg/m³. This therefore requires measures to be taken to control the emissions from the blasting activities. Also, the TSP concentration from air samples from various locations within the communities were generally lower than the EPA threshold of 230 μg/m³. However, one of them registered 234.0 μg/m³ of TSP which was slightly higher than the EPA standard and therefore imply that pollution by dust particles within the host communities could also escalate if measures are not taken to control dust emission into the environment. In spite of the foregoing, the concentrations of dust particles in the host communities were mostly lower at the blasting sites, which confirms the report by Chaullya, Chakrborty and Sing (2001) that concentration of dust particles that are measured in air samples from communities around blasting sites are usually lower than the host communities.

Environmental impact of rock blasting on the surrounding communities

Plate 1, 2, 3 and 4 summarizes some environmental effect of rock blasting activities on selected buildings within the selected communities as determined by personal observation. As shown, a number of buildings in the surrounding have developed cracks due to the effect of blasting activities.

The above figures summarize data on the collapse of a building that resulted in death as reported by participants. There was no high rate of death due to collapsed buildings in the community. From the results, 258 respondents representing (80%) reported 'No" to the question; has any member of the community died in a collapsed building? Blasting activities involve blasting and crashing of rock which causes vibration in the earth [17]. The vibrations in the earth due to blasting activities create shock waves which travel along the ground causing disruption of the integrity of land for farming and eventually lead to cracks and gullies [18]. Eventually, the vibration cracks and gullies that result are reported to disturb the foundations of buildings and other structures on land causing them to crack and collapse with time [18]. Vibrations, cracks and gullies that occur in farmlands are reported to lead to erosion of the topsoil which eventually makes the land unable to support agricultural activities. In line with the various reports stated above, the findings of this study also showed that several buildings in the host communities have cracks in them while some have collapsed as shown in Figure 6 above.

Furthermore, observations from the study (Figure 6) showed that blasting activities in the host communities have adversely affected nearby farmlands and probably contributed to the reasons why they cannot support crop cultivation. In addition, the present study showed that dust particles in the atmosphere of the host communities made the environment dusty resulting in poor

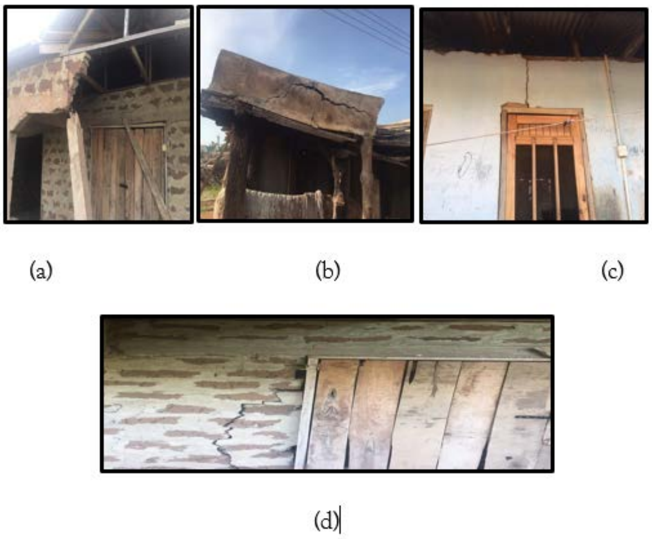


Figure 6: Environmental Impact of blasting on structures.

visibility, as reported by majority of the respondents (83.3%). In view of the foregoing, blasting activities at the Newmont Ahafo Mine could be said to have a negative effect on the environment of the surrounding communities and therefore the need for blasting to be regulated properly.

CONCLUSION

In this study, the environmental impact of rock blasting on the inhabitants of Kenyasi in the Asutifi North District of the Ahafo Region has been assessed. The results of the study showed that the level of dust concentration in the host communities was slightly lower than the EPA standards with the lowest dust particle concentration of (52 μg/m³) and the highest concentration of (68.8 μg/m³) as against the EPA standard of (65 μg/m³). However, at the quarry site, the allowed levels were very high compared to EPA standards. Dust emissions have a number of health consequences that should be taken into account.

With respect to the effects of blasting and generated vibration and other related blasting activities on buildings and farmland, the study found a significant relationship between the variables. Explosions and vibrations were linked to cracks in buildings and their collapse, leading to death, among other impacts. There was also a significant relationship between blasting activity and the quality of agricultural land surrounding the blast site. As agriculture is the main occupation of host communities, the destruction of agricultural land is a threat to their survival.

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REFERENCES

1. Fedra K, Winkelbauer L, Pantulu VR. Systems for Environmental Screening. An Application in the Lower Mekong Basin. International Institute for Applied Systems Analysis. A-2361 Laxenburg, Austria. 2005:169.
2. Banez J, Ajaon SM, Bilolo JR, Dailyn JM. Quarrying and Its Environmental Effects.

3. Mackey A, Gass SM. Second language research: Methodology and design. Routledge. 015.

4. Nene NJ. Assessment of the effects of quarrying activities on some selected communities in the lower Manya Krobo District (Doctoral dissertation, University of Ghana).

5. Nicholls HR. Blasting vibrations and their effects on structures. US Department of the Interior, Bureau of Mines; 1971.

6. Langer WH. Potential environmental impacts of quarrying stone in karst: a literature review. US Department of the Interior, US Geological Survey. 2001.

7. Patton L. Signs, toy models, and the a priori: from Helmholtz to Wittgenstein. Studies in History and Philosophy of Science Part A. 2009;40:281-289.

8. Feldman J. From molecule to metaphor: A neural theory of language. MIT press;2008.

9. https://www.grc.org/bioorganic-chemistry-conference/2011/

10. Ellis NC, Sagarra N. Learned attention effects in L2 temporal reference: The first hour and the next eight semesters. Language Learning. 2010;60:85-108.

11. https://unstats.un.org/unsd/censuskb20/Attachments/2006GHA_Report-GUID10e698e01fd242a68642ce15e0afdf19.pdf

12. Elsemain IA. Measurement and analysis of the effect of ground vibrations induced by blasting at the limestone quarries of the Egyptian cement company. College of Engineering, Assiut University, ASIUT EGYPT. 2000.

13. Nicholls HR. Blasting vibrations and their effects on structures. US Department of the Interior, Bureau of Mines; 1971.

14. Brinkmann JR. The control of ground vibration from colliery blasting during the undermining of residential areas. Journal of the Southern African Institute of Mining and Metallurgy. 1987;87:53-61.

15. Rorke AJ. Blasting impact assessment for the proposed new largo colliery based on new largo mine plan 6. AJR_NL001_2011 Rev. 2011;4.

16. Ak H, Iphar M, Yavuz M, Konuk A. Evaluation of ground vibration effect of blasting operations in a magnesite mine. Soil Dynamics and Earthquake Engineering. 2009;29:669-676.

17. Naidoo S, Muneku E. Dust exposure, respiratory symptoms and disease among informal quarry workers in Lusaka Province, Zambia. Occupational Health Southern Africa. 2015;21:12-16.

18. Akabzaa TM. Boom and dislocation: The environmental and social impacts of mining in the Wassa West District of Ghana. Third World Network. 2001.