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Noise Mapping of a Highly Mechanised Coal Mine Using Measured Noise and GPS Data

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Abstract: *This study aimed to produce a noise map by determining the noise levels in the different parts of the highly mechanized coal mine and to compare them with the Directorate General of Mines Safety (DGMS) prescribed permissible limits. A total of 497 Global Positioning System (GPS) variables were collected from the mine at varying intervals according to the International Organization for Standardization (ISO) and DGMS guidelines to measure sound pressure levels (SPL). The GPS receiver interfaced with the real time octave band analyzer allowed simultaneous measurement of noise levels and their GPS data. Measured information with GPS variables were exported to ArcGIS software for generating the noise map. Results showed that noise levels were higher than the permissible limits in most parts of the mine, the maximum and minimum average noise levels being were 102 dB (A) and 54 dB (A), mean equivalent A- weighted sound pressure level (L_{Aeq}) was 73 ± 7.3 and L_{Aeq} were ranging between 81-93 dB (A) of drilling, dozer, loader & silo, 71-80 dB (A) at workshop & shovel working locations, 61-70 dB(A) at various haul roads, siding & dump yard locations, and 50-60 dB(A) at roads respectively. The results suggest that interpolating noise levels with GPS variables can enhance the visualization of the noise map and has the potential to be more effective at informing policy decision-making, and actions to be taken as a result of high noise levels.*

Keywords: *noise pollution, noise mapping, equivalent sound levels, coal mine, ArcGIS, GPS*

1. Introduction

Noise is considered as one of the most potential hazards and an environmental issue associated with the generation of higher noise levels from the workplaces. Noise produced from the industries is the most prevalent noise sources and is considered as a global health issue [1]. Noise levels of the current noise sources are measured to study the impact of noise on the miners at their workplaces [2]. Problems of protection and acoustic pollution of the natural environment is getting more relevance now-a-days.

Research suggests that prolonged exposure to high noise levels leads to sleep deprivation, reduced productivity as well as annoyance and irritation [3]. Exposure to high noise levels at workplace are associated with hearing loss which at first causes temporary hearing problem termed as Temporary Threshold Shift (TTS) whereas continuous exposure to higher noise levels over an extended period of time causes permanent hearing damage termed as Noise Induced Permanent Threshold Shift (NIPTS) [4]. Therefore, there is a need for monitoring of noise sources, particularly where heavy machineries are being used for a long period, producing high noise levels. Noise map is a graphical representation of the sound level distribution existing in a given area, for a defined period and is defined in relation to the Environmental noise directive (END) of the European Parliament and Council (Directive 2002/49/EC of 25 June 2002). Noise mapping is a developing concern, drawing significant consideration, compared to other environmental concerns. Noise map is used to represent a stationary situation computed either with input data correlated with real measured noise levels, or a predicted situation based on assumptions about the evolution in the future and are exceptionally useful in determining detailed assessment of noise impact influences and describe spatial distributions of noise levels [5].

Noise mapping has been made mandatory in the Indian mines in the Recommendations of the Tenth Conference on Safety in Mines [6-7]. The essence of standardized noise mapping tools, and concern for the improvement of these tools, such as accuracy of noise measurement; analyzing complex acoustic phenomena due to surrounding structures, were described to optimize quality and efficiency of noise effect studies [7-9].

Challenges have to be met in terms of data management, data reduction, calculation methods, validation techniques and presentation of results, so that the maps can be used as powerful tools for noise planning and design [10]. Additionally, one must consider large amount of datasets describing the characteristics of the source, measured L_{Aeq} values and GPS locations at various positions for developing a noise map [11]. The accuracy of any noise map will be directly constrained by the accuracy and amount of the input data.

Cho et al. produced noise maps using measured noise levels and GPS variables to evaluate the current noise situation and to identify existing noise problems [12-

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14]. Similar methodology is applied in the present study by using a real time octave band analyzer, a GPS receiver, a program to manage the measured data and to develop the noise map of the area. Computer modelling techniques simulate the acoustic emission and propagation, enables the visualization of noise maps judiciously fast. The results are presented in the form of color-coded noise maps, each color corresponding to a given interval of noise levels, typically in steps of 5 dB (A). The primary objective for generating a noise map is to get useful information which will enable one to correctly evaluate a noisy situation, and study what best solutions are to comply with given noise limits in and around the mine. Further processing on the data in ArcGIS can also produce Digital Terrain Model (DTM) files.

2. Study area and objectives

This study was conducted in a highly mechanised opencast coal mine situated in Chhattisgarh state of India during June 2015 and December 2015, is shown in Figure 1. It has a vast deposit containing over 707.92 million tonnes reserve, and is a leading front-runner for coal production in India. Current annual production is about 40 million tonnes and is under expansion. Approximately 600 workers were involved in the mining related activities in the opencast coal mine. There were 3 shifts, where each shift runs for about 8 hours, and the workers spend 6-8 hours a day in the noisy work place.

The primary objective of the research was to interpolate noise levels figured on GPS variables and produce noise map of the coal mine. This was done in order to improve the accuracy of noise maps particularly in terms of data interpolation, as well as offering enhanced visualisation opportunities and a centralised data management facility which is capable of integrating various types of spatial data into noise mapping studies.

Figure 1. *Mine location of highly mechanised coal mine situated in Chhattisgarh, India*

3. Methodology

Noise impact studies comprise of the following phases:

- Measurement of noise levels and
- Association of measured noise levels with the GPS data to produce noise map and determine impact of noise

Noise levels were calculated in decibels in A-weighted scale as recommended by DGMS Technical circular 5 of 1990, ISO 9613-2:1996, (Acoustics − description, measurement and assessment of environmental noise), ISO 6395:2008 (Earth Moving Machinery − Determination of sound power level − Dynamic test conditions) and other related standards [6-7, 15-19]. Selection of microphone positions and number of measurements to be taken for assessment of sound power level of any source are amply described in the standards. Emphasis was placed on interpolating noise levels with GPS variables in order to enhance visualization and efficiency of noise mapping studies. The study was carried out at heavy noise level zones of the mine. The noise levels were measured using Extech, Type 1 real time octave band analyser having accuracy of ±1 dB (model: 407790) at various frequencies between 25 Hz and 10 kHz in A-weighted scale as recommended by the acoustic standard [20-21]. All the noise levels were measured in L_{eq} as specified by the 1996-2:2007, which has recognised L_{eq} as an international standard for measuring environmental noise in 1978 [17].

The noise levels of different areas of the mine were measured for two period interims: 08:00 a.m.–12:00 N and 14:00 p.m.–16:00 p.m. during June 2015 and December 2015. Measurement of noise exposure was done using sampling method, in which measurements were carried over a period of 20 minutes at each location. Garmin GPSmap 60CSx with an accuracy of ±2 degrees was used to collect GPS variables at each location of the sampling points. SPL were collected at 1.5 m height above the ground level using real time octave band analyser according to ISO 9613-2:1996 standards. The equivalent A- weighted SPL L_{Aeq} has been calculated using the following Eqn. (1).

$$L_{Aeq,T_{meas}} = 10\ \log\left[\frac{1}{n}\sum_{i=1}^{n}\left(10^{0.1\ L_{pAi}}\right)\right] \qquad (1)$$

Where, L_{pAi} is the A-weighted SPL, in decibels for sample i, n is the total number of samples collected within T_{meas}, the duration of the time intervals. At the end of study, data were downloaded to a computer and were processed using the utility software. GPS variables collected at various locations in the mine were imported from the receiver via its RS232C serial interface.

Noise mapping in Indian mines has not been standardized, a study following DGMS Technical circular 5 of 1990 and ISO 9613-2:1996 Standards was carried out to develop noise map and to assess the impact of noise at various locations in the coal mine. Noise measurement and SPL at a particular point with the necessary attenuation factors have been authenticated with ISO 9613-2:1996, using Eqn. (2) [7,15-16,28].

$$L_{fT}(\mathrm{DW}) = L_w + D_c - A \qquad (2)$$

Where, L_{fT} is the equivalent continuous downwind octave band SPL at any receiver point, L_w is the octave-band SWL, D_c is the directivity correction in decibels and A is the octave-band attenuation. The attenuation term A in the Equation 2 is given by the Equation 3:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad (3)$$

Where A_{div} attenuation due to geometrical divergence, A_{atm} attenuation due to atmospheric divergence, A_{gr} attenuation due to ground effect, A_{bar} attenuation due to a barrier and A_{misc} attenuation due to miscellaneous other effects.

Noise mapping is the geographic presentation of information associated with noise levels and noise exposure with related information on effect to the influenced population [9]. Interpolation is an effective method used by different researchers for noise mapping. Current study considers kriging to evaluate the acoustic behaviour of the study area, as the root mean square error (RMSE) value using kriging interpolation method is far less compared to Inverse Distance Weighting and spline interpolation techniques. At each point p, $Z_e(p)$ is calculated using a weighted average of the known points using Eqn. (4). Estimated error, called as the difference, between the estimated value and the actual value is calculated using Eqn. (5). The scatter of the estimates about the true value termed as estimation variance is calculated using Eqn. (6). Optimal weights, which produce unbiased estimates and have minimum estimation variance, were obtained using the Eqn. (7), Eqn. (8) and Eqn. (9). If no drift exists and the weights used in the estimation sum to one, then the estimated value is said to be unbiased and is calculated using Eqn. (10). Finally, the data value for each point can be estimated by inputting the weights into the Eqn. (11). Estimated variance σ_z^2 also known as the kriging variance for each point is calculated using the Eqn. (12). Noise map of the coal mine was developed using ArcGIS 9.3.1 software for enhanced visual information of the environment using kriging interpolation technique (Eqn. (11)) considering the distances between the sampling locations and noise levels at each location [5, 7, 9, 10-12, 22-24].

$$Z_e(p) = \sum W_i \, . Z(p_i) \qquad (3)$$

$$\epsilon_p = Z_e(p) - Z_a(p) \qquad (4)$$

$$\sigma_z^2 = \frac{\sum_{i=1}^{n} [Z_e(p_i) - Z_a(p_i)]_i^2}{n} \qquad (5)$$

$$w_1\gamma(h_{11}) + w_2\gamma(h_{12}) + w_3\gamma(h_{13}) = \gamma(h_{1p}) \qquad (6)$$

$$w_1\gamma(h_{21}) + w_2\gamma(h_{22}) + w_3\gamma(h_{23}) = \gamma(h_{2p}) \qquad (7)$$

$$w_1\gamma(h_{31}) + w_2\gamma(h_{32}) + w_3\gamma(h_{33}) = \gamma(h_{3p}) \qquad (8)$$

$$w_1 + w_2 + w_3 = 1 \qquad (9)$$

$$Z_e(p) = w_1 Z_1 + w_2 Z_2 + w_3 Z_3 \qquad (10)$$

$$\sigma_z^2 = w_1\gamma(h_{1p}) + w_2\gamma(h_{21p}) + w_{13}\gamma(h_{3p}) + \lambda \qquad (11)$$

Noise mapping can be used for the following purposes [5, 9]: Know the noise levels produced by major noise sources. Assist the improvement of methodologies for controlling noise. Draft a plan showing the areas where noise levels are desired to be decreased.

Analyse the impact of conservational development strategies. Enhance the usage of upcoming strategies to diminish noise source.

Noise mapping process is shown in Figure 2.

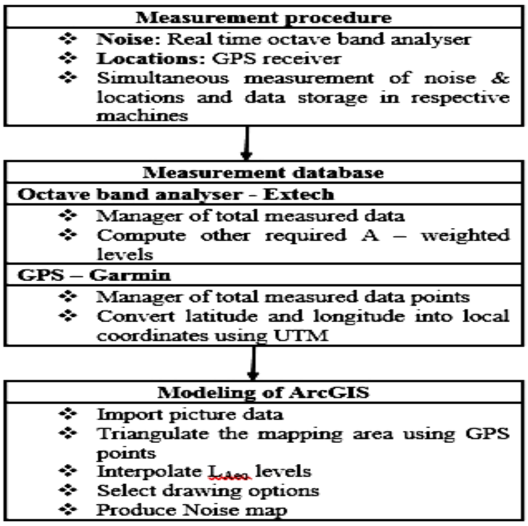

***Figure 2**. Noise mapping techniques using measured noise and GPS data*

GIS is a system which allows one to store, analyse and manipulate different types of spatial data. Interpolating measured noise data with a GIS allows other types of spatial data to be utilised in noise studies [25]. ArcMap is a GIS mapping package within ArcGIS, it offers a centralised data management facility and is compatible with commercial noise software. It is important as the data needed for undertaking measured noise level, noise effect and visualisation studies can be stored in a centralised database. Data can be imported from noise software to ArcGIS via data exchange system.

A table containing x and y coordinate (latitude and longitude) data is added to the map as a layer and is shown in Figure 3. Noise impacts were determined in ArcGIS by interpolating noise levels figured on GPS variables of machineries location with regard to their activities as shown in Figure 4 and Figure 5 [9]. This study utilized GPS to analyse monitoring data collected at 497 locations in the mine, including workplaces of dozer, drill machines, pay loader, shovel, dumpers and etc. Noise level plotting and noise map of the mine were carried to examine its present noise distribution. Noise levels at various workplaces were examined and were compared with respective standards. After predicting the measured values to 8 hours' time weighted values, we can observe that high noise levels above the specified warning limit of 85 dB (A), occurs at the workplaces of dozer, drill machine, pay loader, and crusher point.

Table 1 shows the logarithmic average of statistical machinery noise for different road types and workplaces in the daytime. The equivalent sound level increases with the machinery type and their volume.

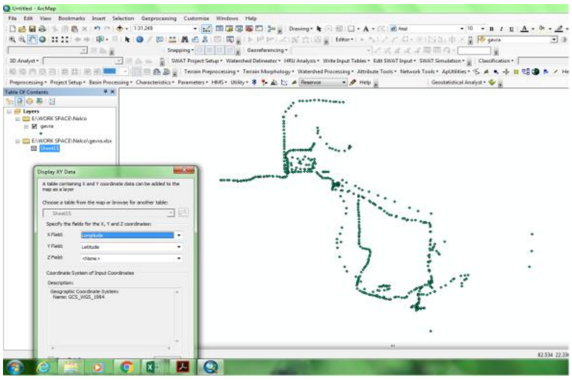

Figure 3. *Importing of GPS and L_{Aeq} data*

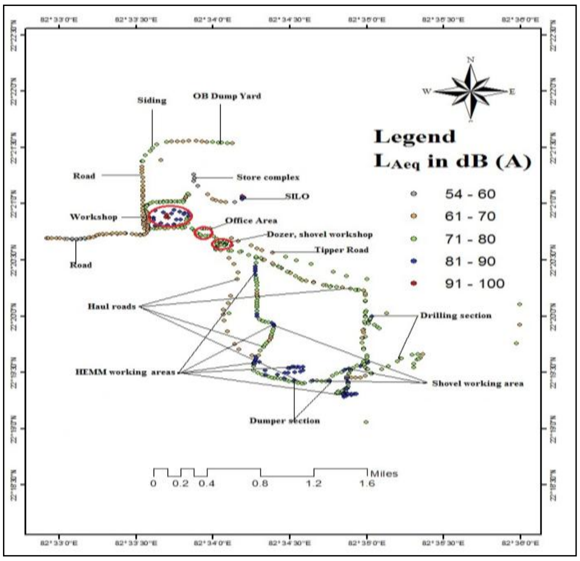

Figure 4. *Noise level plotting produced using GPS data and measured noise*

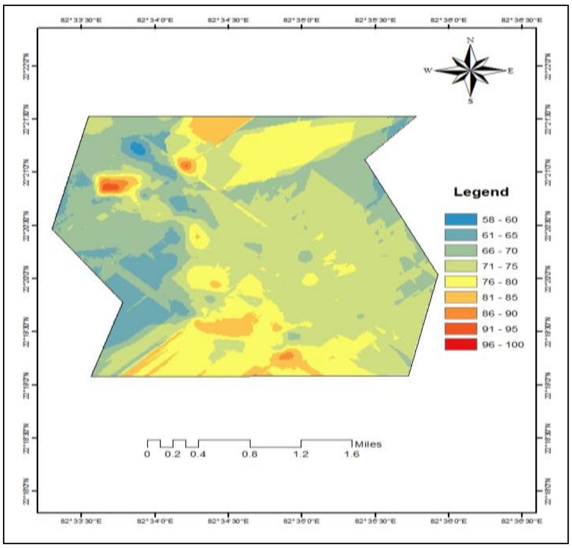

Figure 5. *Noise map produced using GPS data and measured noise*

4. Noise mapping

Noise measurement program was exercised in the mine to comply with the DGMS Technical Circular No. 18 of 1975 and No.5 of 1990 [6]. The fundamental objective was to create quick and modest noise maps that combine both long-term and short-term noise levels. Measurements were usually taken at various locations in the mine over short time periods. These measurements were used to decide source strengths and were interpolated with L_{Aeq} values and GPS variables to develop the noise map. The maps developed depend on L_{Aeq} values decided from measured information while it was noticed that the quality of the map was dependent on the number and precision of the measured data. Results of measured noise levels are represented in Figure 4.

Noise levels of the mine were figured in the program by interpolating noise levels on GPS variables. An exact depiction of the noise status in the surroundings of a noise source has been produced by noise map is shown in Figure 5. The numbers of measured points are satisfactorily high and the required concentration of calculation points also rests on the preferred level of depth of the study that is managed by the motivation behind the study.

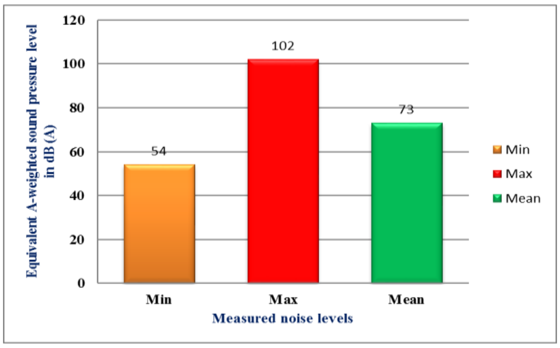

Figure 6. *Indicative results of the measured noise data*

5. Results

Noise impacts in the mine were evaluated with the measured noise levels and information on the activities sensitive to noise.

5.1. Noise maps in the mine

The noise map of the coal mine presents the day noise levels as per Noise Pollution Rules 2000, Central Pollution Control Board (CPCB) and European Noise Directive (END) standards during June 2015 and December 2015 [26-27]. The features were analysed amid the following periods:

5.1.1. 08:00 a.m.–12:00 N

Areas with high noise levels were observed in the workshop, silo, and drilling section. Noise levels usually remained over 85 dB (A). The maximum, average and minimum noise levels monitored in the coal mine were 102 dB (A), 83 dB (A) and 56 dB (A), respectively.

5.1.2. 14:00 p.m.–16:00 p.m.

Areas with high noise levels were observed in the shovel workplace, dumper section and dozer section. Noise levels usually remained over 85 dB (A). The maximum, average and minimum noise levels monitored in the coal mine were 101 dB (A), 85 dB (A) and 55 dB (A), respectively.

According to CPCB guidelines the noise level limits specified for different zones are shown in Table 2. Definitions of span of day and night in CPCB guidelines in India are different from what has been described in the European Noise Directive (END) [7, 26-27]. Since the predicted noise levels of different workplaces were to be compared with CPCB and DGMS guidelines, the authors used overall permissible L_{Aeq} values based on noise levels set by DGMS as described in Table 3 [7, 28-29]. All the computed values are based on a complete 8 h exposure period. Different colour codes indicate different L_{Aeq} noise levels in dB (A) in the noise level plotting map. Noise levels ranging from 54 to 60 dB(A) are indicated by grey, 61–70 dB(A) are indicated by yellow, 71–80 dB(A) by green, 81–90 dB(A) by blue, and 91–100 dB(A) by red bands.

To delineate zones disregarding noise standards, existing noise levels monitored in this study were compared with the DGMS standards. In Figure 4, L_{Aeq} exceeding the warning limit of 85 dB (A), are represented in blue and red colours. Noise map as shown in Figure 5 is used to provide valuable information for decision makers evaluating noise mitigation measures. The above findings specify that average noise levels at silo, dozer section, excavation workshop and drilling section were higher than the other workplaces and have exceeded the permissible limits of 85 dB (A). The areas surrounding the intersection of dozer section, loader section and drill section, through which haul roader passes, also significantly exceeded noise standards. These logical results can help mine officials in recognising the ‘‘hot spots” immediately requiring noise control strategies and in assessing feasibility and adequacy of the existing delineation of noise control areas [9].

5.3. Future work

Further changes to the exercised noise map might be acquainted with upgrade of the procedure: A thorough measurement would enhance confidence and help to regulate the long-term variation of noise over a whole day. This might include the long-term use of monitoring units.

6. Conclusions

The noise mapping application in this paper is aimed to interpolate noise levels with GPS variables and produce noise levels plotting map of the coal mine. Accuracy was a major issue in plotting, and was committed in enhancing the accuracy of interpolation, noise calculation, and noise effect studies. The methodology presented in this paper can be applied to different consistent spatial phenomena. Results of this study demonstrate that noise levels plotting are effective means of understanding noise level distributions in investigated areas and for communicating results of assessment of environmental noise to the mine officials. Additionally, when compared with the current regulation standards mine officials can identify the areas seriously violating the standards to devise noise correction measures and to study alternative scenarios.

Emphasis was laid on integrating measured noise data and their positioning with a GIS. It can be concluded that GIS based noise studies have the potential to enhance the visualisation of noise maps.

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Table 1: *Noise levels at various locations in the mine*

Sl.No	Workplace / Location	Distance from the source	Number of measurements	L_{Max}	L_{Min}	L_{Aeq}
1	Roads	Midpoint of the road	50	75	51	56
2	Tipper roads	Midpoint of the road	20	75	52	66
3	Haul roads	Midpoint of the road	70	80	52	63
4	Siding	5 m	20	75	51	61
5	OB dump yard	5 m	20	82	58	71
6	Store complex	5 m	10	60	51	57
7	Workshop	5 m	50	95	59	78
8	Silo	5 m	10	95	75	84
9	Office area	5 m	17	75	52	71
10	Dozer, shovel workshop	5 m	30	100	56	77
11	Drilling section	5 m	30	102	74	91
12	Dumper section	5 m	30	98	65	82
13	Shovel working area	5 m	40	86	62	79
14	HEMM working areas	5 m	100	98	73	84

***Table 2:** Definitions of Day, evening and Night Periods in CPCB Guidelines and European Noise Directive [7, 21-22, 25]*

Time period	Central pollution Control Board (CPCB)	Hours	European Noise Directive (END)	Hours
Day	06.00 AM to 10.00 PM	16	07.00 AM to 07.00 PM	12
Evening	-	-	07.00 PM to 11.00 PM	4
Night	10.00 PM to 06.00 AM	8	11.00 PM to 07.00 AM	8

***Table 3:** Permissible noise levels adopted by ISO, OSHA and DGMS [26-29]*

Maximum Exposure Time per Working Day, h	Noise level	
	ISO Code	OSHA / DGMS Code
8	90	90
4	93	95
2	96	100
1	99	105
0.5	102	110
0.25	105	115

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