Realizing Modeling and Mapping tools to Study the Upsurge of Noise Pollution as a Result of Open-Cast Mining and Transportation Activities

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Abstract

Introduction: In open-cast mines, noise pollution has become a serious concern due to the extreme use of heavy earth moving machinery (HEMM). Materials and Methods: This study is focused to measure and assess the effects of the existing noise levels of major operational mines in the Keonjhar, Sundergadh, and Mayurbhanj districts of Odisha, India. The transportation noise levels were also considered in this study, which was predicted using the modified Federal Highway Administration (FHWA) model. Result and Discussion: It was observed that noise induced by HEMM such as rock breakers, jackhammers, dumpers, and excavators, blasting noise in the mining terrain, as well as associated transportation noise became a major source of annoyance to the habitants living in proximity to the mines. The noise produced by mechanized mining operations was observed between 74.3 and 115.2 dB(A), and its impact on residential areas was observed between 49.4 and 58.9 dB(A). In addition, the noise contour maps of sound level dispersion were demonstrated with the utilization of advanced noise prediction software tools for better understanding. Conclusion: Finally, the predicted values at residential zone and traffic noise are correlated with observed values, and the coefficient of determination, R², was calculated to be 0.6891 and 0.5967, respectively.

Keywords: Federal highway administration, ISO 9613-2, noise mapping, noise pollution, noise prediction, open-cast mines, predictor lima

INTRODUCTION

Noise mapping is considered as a significant document in noise impact assessment for urban, rural, and occupational regions among the European nations. In India, so far, noise mapping practices are not given much attention; however, recently the Directorate General of Mines Safety (DGMS), India has made noise mapping compulsory in the mining region. As a result of this, these studies may become significant in the coming years. DGMS has specified that occupational noise level limits for an individual worker should not be more than 85 dB(A), which should be taken care of by the authority in charge of every mine.[1] Above all, open-cast mining involves several operations that produce annoying noise, which is caused due to drilling, rock crushing, blasting, etc. This may cause harm to the ears, sleep disturbance, and other health-related problems depending on the magnitude of the noise.[2] In addition, the intensity of noise generated during impulsive blasting is so high that it puts a negative impact on nearby human dwellings and dedicated establishments.

According to the Directorate of Mines and the Government of Odisha, India, there are more than 26 types of valuable minerals obtainable in the state.[3] In Odisha, mining is the backbone of core industries, contributing to the growth of other crucial industries such as the power plant, steel plant, and other manufacturing plants. As a result, there is a rapid increase in the demand of minerals from such large industries, and mining has become vigorous. To meet this demand, raw minerals are exported in huge quantity via heavy vehicles through a transportation route that passes within and around human dwellings causing noise as well as air pollution.
Conveying transportation involving various types of vehicles is a key factor causing increase in the sound pressure levels, \( L_p \), in the residential zone. Thus, mining as well as the use of heavy vehicles for transportation is the major source of noise and a prime concern for the people residing nearby mining areas.

Figure 1 shows the process of raw mineral extraction in open-cast mining and depicts the equipment used during each stage. Consequently, the use of modern equipment such as rock crusher, drilling, crushers, dumper, and trucks is the root cause of a significant increase of noise levels in and around the mining region. As a matter of fact, though only for a fraction of minutes, blasting produces enormous noise in open-cast mining, and the noise level from it can be reached up to 120 dB(A).\(^4\) For this reason, it is necessary to measure and evaluate the noise impact on the environment as well as on the surrounding.

In recent years, the study on the impact of noise exposure on human dwellings and dedicated establishments due to mining and its related activities is gaining more attention in India. A few significant studies performed earlier are discussed in this section. Gorai and Pal analyzed the noise level impact of iron ore mines over residential, commercial, and sensitive areas, in which it was found that noise levels were much higher than permitted by the national guidelines.\(^{5}\) A similar investigation was performed to measure the sound levels of heavy earth moving machineries used in open-cast mining, and its impact because of noise on sensitive, residential, and commercial zones, in which it was found that the noise levels exceeded the permissible limits.\(^{6}\)

Acoustic modeling can prove as an essential document during the planning stage of a construction project and opens up many possibilities to evaluate alternatives. Jeong et al. has conducted a similar study, in which noise mapping was used to predict the noise level dissemination of construction site and road traffic noise in the city of Korea. In this study, noise maps were developed using SoundPLAN software to demonstrate noise scenarios during the execution of construction work and after the construction work was accomplished. Its results show that noise maps may be used as a noise mitigation document in urban areas.\(^{7}\) In the city of Guwahati, India, a noise distribution map showing the noise levels of commercial, residential, and silence zones was developed, which was compared with the permitted limits of the Central Pollution Control Board (CPCB) and the Bureau of Indian Standard.\(^{8}\) Predictor-LimA (7810) is used to predict the noise levels in the various types of occupational areas. One such study predicted three different working shifts, considering different operating machines in each scenario for open-cast mining.\(^{9,10}\)

The aforementioned studies conducted noise assessments, which were performed by considering few mines, and the noise mapping was done either for large areas of cities or for traffic noise. However, this study is based on the mapping of the clusters of mines and traffic noise induced due to raw material transportation activity. This study involves a comprehensive approach to assess the effects of noise on human dwellings as well as on dedicated establishments. This noise mapping study is a first of its kind, covering an area of approximately 1300 sq. km, which makes it a unique work in the Indian subcontinent.

**Study area**

The inspection of equivalent sound level (L\(_{\text{Aeq}, \ T}\)) was conducted within and around different types of mines.
located in the Sundergadh, Keonjhar, and Mayurbhanj districts of Odisha, India [Figure 2].

The study area consisted of 16 mines and three major highways. The mines located in these three districts were S1 to S3 of Sundergadh, M1 to M3 of Mayurbhanj, and K1 to K10 of Keonjhar; the highways were SH10B, NH215, and NH49, as illustrated in Figure 3.

MATERIALS AND METHODS

Data collection is a most crucial part of the noise assessment study; hence, the methodology followed is in accordance with the acoustics guidelines (ISO 9613-2).[11] On the basis of the standard guidelines, data collection for sound pressure levels was performed within and surrounding the 16 operating open-cast mines for point sources such as drilling machine, excavators, and crushers and moving sources such as dumpers and heavy vehicles at the mines along with its geographic positions. Similarly, noise levels for line sources such as road traffic along the three highways were also measured. Finally, according to the geographic position of each source, a study area map was generated and imported into the predictor Lima software for noise prediction and developing a noise map of the entire study area. The instrument used for precise noise level measurements was Cirrus Optimus (SLM-172B), which has a measuring range of 20 Hz to 20 kHz (20–140 dB(A)) with one-third octave band filter. To check the favorable conditions for noise monitoring, the wind speed, temperature, and humidity were measured using a digital anemometer.

The $L_{dn}$ was computed over 24 h with a penalty weight of 10 dB(A) for a designated nighttime period. The $L_d$ was assigned for the daytime period from 6:00 AM to 10:00 PM, and the $L_n$ was assigned for the nighttime period from 10:00 PM to 6:00 AM[12]. The following expressions were used for calculating $L_d$, $L_n$, $L_{dn}$, and $L_w$:

$$L_d = 10 \log_{10} \left( \frac{1}{16} \sum_{i=1}^{n} t \times 10^{0.1 \times (L_{eqi})} \right),$$

(1)

$$L_n = 10 \log_{10} \left( \frac{1}{8} \sum_{i=1}^{n} t \times 10^{0.1 \times (L_{eqi})} \right),$$

(2)

$$L_{dn} \text{ [dB(A)]} = 10 \times \log_{10} \left[ \frac{16}{24} \left( 10^{L_d/10} \right) + \frac{8}{24} \left( 10^{L_n/10} \right) \right],$$

(3)

where $L_{dn}$ is the equivalent noise level of day and night, $L_d$ is the equivalent noise level of daytime, $L_n$ is the equivalent noise level of nighttime, $L_{eqi}$ is the level of equivalent noise, $n$ is the total number of sample data, and $t$ is the sampling time coefficient.[13]

To get quick results with accuracy, the Predictor-LimA (Type 7810) software was utilized for mapping the mines.
noise as well as the transportation noise. This software has a predefined program to calculate and predict output noise levels using ISO 9613 calculation methods. It takes input in the form of sound power level ($L_{w}$); therefore, $L_p$ of each source was converted to $L_{w}$ using expression (4).

$$L_w = L_p - 10\log \left( \frac{Q}{4\pi r^2} \right),$$  \hspace{1cm} (4)

where $L_w$ is the required power level, $L_p$ is the pressure level, $Q$ is the directivity factor, and $r$ is the distance between source and receiver in meters.

Furthermore, the prediction of transportation noise levels was obtained using the Federal Highway Administration model as per Indian environments. In this particular model, the vehicles were categorized into six classes, and the $L_{eqi}$ was calculated using expression (5).

$$L_{eqi} = L_O + A_{VS} + A_D + A_S,$$ \hspace{1cm} (5)

where $L_{eqi}$ is the hourly equivalent noise level for each type of vehicle, $L_O$ is the reference energy mean emission level, $A_D$ is the distance correction, $A_{VS}$ is the volume and speed correction, and $A_S$ is the ground covers correction.

Thus, for major highways, the distance of the sound level meter to the centerline of the road was 17.5 m, and the instrument was kept about 4 m away from the building and reflective surfaces. The number of vehicles were counted manually, and the dimensions for each highway were taken in terms of road width, carriageway width, the number of lanes, etc., which were required for distance correction.

Finally, the observed and predicted noise levels were compared with 55 dB, which is a calculated $L_{dn}$ of CPCB as well as the permissible limit for outdoor $L_{dn}$, as prescribed by the Environmental Protection Agency.\[12,16\]

### RESULT AND DISCUSSION

Combined contour maps of 16 mines and its associated transportation noise levels in three districts were developed to evaluate and assess the noise impact in the study area. Table 1 shows the measured and predicted $L_{dn}$ at various residential zones within the three districts.

Figure 4 shows the regression graph between the measured and predicted values of $L_{dn}$ for the residential zone, which estimates the coefficient of determination $R^2$ as 0.6891. As $R^2$ is close to unity, it indicates that a significant correlation exists between the measured and predicted values.

Figure 5 depicts the noise contour map of mines at Keonjhar and Sundergadh districts. Primarily, the noise levels observed in the mining areas of Keonjhar district varied between 74.3 and 115.2 dB(A). The noise levels observed in the residential areas of Keonjhar varied from 56.5 to 58.9 dB(A), whereas the predicted noise levels were found to be between 57.9 and 62.3 dB(A). The two villages, Bolani and Kiriburu, which are proximal to mines K7, K9, and K10, showed a difference of 2.7 and 0.6 dB(A) between the observed and predicted noise levels. Furthermore, the least affected areas of Keonjhar are Golden Camp and Joda West, where predicted noise expose levels were 57.9 and 58.9 dB(A), respectively; however, these levels exceeded the permissible limits.

Figure 6 illustrates a close-up view of noise contours formed for three mines (S1, S2, and S3) of Sundergadh district. The noise levels within the mines varied between 74.5 and 111.5 dB(A). On the other hand, the noise levels observed in the residential areas of Sundergadh varied from 57.1 to 60.5 dB(A), while it was 58.7–65.2 dB(A) in the predicted range of noise levels. Because the Tensa Township village falls in-between mines S1 and S2, the noise level was 60.5 dB(A), and predicted level was 62.4 dB(A). In Sundergadh district, the number of mines is less, but the noise levels were comparatively higher. This may be due to excessive mining extraction and transportation activity witnessed in

### Table 1: Measured and predicted $L_{dn}$ at residential zone

| District       | Sampling location (residential zone) | Measured sound levels ($L_{dn}$) [dB(A)] | Predicted sound levels ($L_{dn}$) [dB(A)] |
|----------------|---------------------------------------|------------------------------------------|------------------------------------------|
| Keonjhar       | Jaroli                                | 58.9                                     | 60.2                                     |
|                | Limitur                               | 58.4                                     | 60.1                                     |
|                | Balagoda                              | 58.7                                     | 60.7                                     |
|                | Joda West                             | 57.9                                     | 58.9                                     |
|                | Golden Camp                           | 56.5                                     | 57.9                                     |
|                | Kiriburu Village                      | 57.9                                     | 58.5                                     |
|                | Arya Colony, Bolani                   | 58.6                                     | 61.3                                     |
|                | Joda East Town Ship                   | 58.1                                     | 62.3                                     |
| Sundergadh     | Rāikela                               | 58.1                                     | 58.7                                     |
|                | Tensa Township                        | 60.5                                     | 62.4                                     |
|                | Jindal Township                       | 57.1                                     | 65.2                                     |
|                | SAIL Mines Township, Tensa            | 60.5                                     | 62.1                                     |
| Mayurbhanj     | Burudih                              | 56.9                                     | 57.9                                     |
|                | Badampahar                            | 53.2                                     | 55.9                                     |
|                | Gorumahisani                          | 49.4                                     | 50.3                                     |
the area. The Raikela village is situated near S2 mine, where the predicted noise level was 58.7 dB(A), and the measured noise level was 58.1 dB(A). The mine S3 is located far away from residential zone; therefore, the noise exposure level of this mine had very less effect on human dwellings. The difference between the observed and predicted noise levels in Tensa village was 0.3 dB(A), and that of Raikela village was 0.6 dB(A), which showed the suitability of the Predictor-LimA software tool.

The Mayurbhanj district has less mining activities as compared with Keonjhar and Sundergadh districts. It has only three working mines (M1, M2, and M3). The mines were separated from each other by huge distances, as depicted in Figure 7a with their noise contour map. Figure 7b–d shows the noise contour maps of mines. The noise levels of these mines varied between 74.3 and 114.1 dB(A). The noise levels observed in the residential areas of Mayurbhanj varied from 49.4 to 56.9 dB(A), whereas it was 50.3–57.9 dB(A) in the predicted range of noise levels. The Badampahar village is located close to mine M1, where predicted noise level was 55.9 dB(A), which is comparatively less because M1 is surrounded by forest area causing attenuation of noise propagation at a significant level.\textsuperscript{[16]} Gorumahisani village is located far away from M2; therefore, noise generated was only due to transportation activities. The mine M3 is situated

Figure 4: Regression graph of measured and predicted $L_{dn}$ in residential zone

Figure 5: Noise contour map of predicted $L_{dn}$ in Keonjhar and Sundergadh districts
near to the Sulaipat dam reservoir, and near to it is the Burudhi village, where predicted noise level was 57.9 dB(A). Furthermore, heavy vehicles and raw mineral transportation convoys contribute more noise to the residential areas of these
three districts. The gathered noise data regarding transportation from different sampling locations varied between 69.2 and 71.3 dB(A). The Keonjhar district is highly affected due to transportation noise, because the maximum number of mines are located nearby. All the data were taken from six highway and haulage roads, which are NH-215 (two samples – Joda) and SH-10B (two samples – Barbil) at Keonjhar, NH-215 (Koira city) at Sundergadh, and SH-49 (Jashipur) at Mayurbhanj. Table 2 shows the measured and predicted transportation noise from highways with information on the number of vehicles that passed during measurement time.

In addition, some neighboring villages to the haulage road are highly exposed to vehicle noise. For example, transportation from mines S1 and S2 passing through the Tensa village to Koira junction (Koira-Barsuan highway) measured the minimum and maximum noise levels at 69.2 and 67.9 dB (A), respectively. Similarly, the measured and predicted noise levels at Jashipur junction were 71.3 and 69.2 dB(A), respectively. The higher noise levels recorded were because Jashipur junction is close to mines M1, M2, and M3, and all the transportation from these mines gathered at this junction. In Joda and Barbil highways, measured noise levels varied between 70.3 and 71.2 dB(A).

Figure 8 shows the best-fit lines generated between observed and predicted noise levels having a coefficient of determination $R^2$ of 0.5967 for $L_{dn}$, which indicates the adequacy of the model.

Consequently, from Table 1, it can be seen that the 86% reading from observed $L_{dn}$ and 93% reading from predicted $L_{dn}$ surpassed the permissible limits of residential area. In addition, the mean average difference of measured and predicted noise levels was found out to be 1.8 dB(A), which is accepted as significant. The number of mines is more in Keonjhar district as compared to the others. Thus, the sound pressure levels generated from heavy machineries produce excessive noise that is above the permissible limits in most of the mining sites. At the same time, the transportation noise from heavy vehicles is also a prime source of noise in the rural area as well as the urban area, which is the major cause of annoyance and discomfort to the people living in close proximity to the roadways. As an example, the mines K3 and K8 are far away from human dwellings, has and, therefore, it has a low exposure to noise. On the other hand, higher noise levels due to the associated transport activity have been affecting the nearby populations.

**Conclusion**

The current study aimed to measure the noise levels in all working mines along with associated transport noise in the three districts of northern Odisha. In addition, the study developed noise maps to reveal the impact of noise on the residential area.
and dedicated establishments. The noise levels at the source mines ranged between 74.3 and 115.2 dB(A); 74.5 and 111.5 dB (A); and 74.3 and 114.1 dB(A) at Keonjhar, Sundergarh, and Mayurbhanj districts, respectively. The impact of these noise levels on a residential zone was found to be exceeding 86% on the basis of the reading from measured $L_{dn}$ and 93% on the basis of the reading from predicted $L_{dn}$, with respect to the permissible limits of the residential area. From this observation, it was clear that the habitants living near to the mining area and its associated transportation roads were under the influence of high noise levels. Additionally, the mean average difference between measured and predicted noise levels was found out to be 1.8 dB(A), which was accepted as significant. The coefficient of determination, $R^2$, between the measured and predicted values of the residential zone along with transportation was nearer to unity; it can be said that these values were closer to each other, and this was evidence that there existed a relation between them. Measured and predicted values showed that the noise levels in the residential zone of Keonjhar and Sundergarh were high due to associated transportation noise from the mines surrounding them. Herein, noise mitigation was essential, otherwise, in the future, people might face noise-induced hearing loss. Noise arising from the transport used in mines can be regulated by the proper maintenance of vehicles. Another method to reduce noise is to implement a traffic flow relocation plan, according to which, the transportation traffic of heavy and medium vehicles, which pass through the residential zone, must be directly connected to the highway or bypass road. Similarly, the installation of an acoustic absorbent barrier of suitable design between the source and the receiver for the areas where the roadways cross habitat localities is also an effective mitigation strategy for absorbing and blocking unwanted road traffic noise. Noise emission from mines equipment can be controlled by using an acoustic enclosure, silencer, baffles, sound blanket, sound absorbing glasses, etc. Tree plantation is also an effective natural barrier for noise abatement, and it could reduce sound levels up to 6–10 dB(A).

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Conflicts of interest

There are no conflicts of interest.

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