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Modeling of Noise Pollution in Residential Area and its Health Hazard using Probability Distribution Models

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ABSTRACT

Noise pollution is an excessive sound produced intentionally or accidently which can have deleterious health effects and can reduce environmental quality. This work proposed the modeling of noise level (NL) in a residential area containing block, milling and timber industries. Gamma distribution model (GDM), Lognormal distribution model (LDM) and Weibull distribution model (WDM) were applied to model the NL measured and estimate their respective maximum likelihoods. Goodness of fit (GoF) was determined to select the best fit model. Probability of exceeding critical point (PECP) of the NL at each industry was obtained and the NL estimated was compared with WHO standards. The means of the NL for the three industries were obtained using GDM, LDM and WDM as 50.037dBA, 51.014dBA and 76.747dBA, 51.014dBA, 59.892dBA and 76.745dBA, 58.582dBA, 71.376dBA and 70.886dBA respectively, their corresponding maximum likelihoods (ML) were also estimated as 0.1593, 0.2103, 0.1589, for GDM, 0.1581, 0.1892, 0.1553 for LDM, and 0.1598, 0.2111, 0.1683 for WDM. The PECP were determined as 0.3146, 0.1158 and 0.5471 for block, milling and timber industries respectively. It was found that 'LDM' is the best fit model because it has the least GoF and workers from the block industry are at risk of developing mild annoyance, while workers from the milling industry may suffer severe annoyance, mild sleep disturbance and poor next day mode, whereas workers from the timber industry are likely to develop mild hypertension and cardiovascular problem, severe annoyance, poor next day mode, sleeping disorders and poor performance.

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1. INTRODUCTION

Noise pollution (NP) is considered as the third most hazardous type of environmental pollution. NP in residential areas is recognized in the world as a major threat to health, and may affect the means livability (Huang *et al.,* 2019; Dreger *et al.*, 2019; Basner *et al.,* 2020; Shin *et al.*, 2020). Major sources of noise can be traced to moving vehicles as stated in (Foraste *et al.*, 2018) and about 70% of environmental noise generated by moving vehicles is caused due to engine and exhaust systems (*Clara* et al., 2018). It has been reported that NP can pose health hazard to human beings such as sleep disturbance, stress, mental disorder, cardiovascular disorder and loss of hearing (Rudolph *et al.*, 2019; Li *et al.*, 2019). In fact, quite numbers of studies have been carried out on NP predictions and its health effects. For instance, Kumar *et al.* (2011) conducted a research on mathematical modeling of road noise using regression analysis and reported that their model can be used for noise prediction. Gollomandla *et al.* (2017), used Microsoft excel and developed a model that recognizes the dependence of the intensity of noise. Mjerenje and Drvnoj (2014) reported that NL generated in sawmill (timber industry) exceeds the tolerable exposure standards. Akirnay *et al.* (2007) suggested that sound propagation can be influenced by meteorological or weather parameters such as wind and temperature gradient and that the level increases in commercial areas especially in timber industry. Olushegun *et al.* (2012) in their study reported that workers in block factories do not use hearing protection gadget at work, so they are venerable to health hazards.

Some authors considered noise as an unwanted or unpleasant sound which disturbs, discomforts, stresses human beings and animals physically, physiologically and psychologically (Tzivian, *et al.,* 2016). Many researchers have evaluated that short-term exposure and long-term exposure to noise could cause health risk (Beelen *et al.*, 2014). In urban settings, road traffic, railway traffic, milling machine and block industry are considered as sources of ambient 'NP' which are extensively associated with the major diseases such as hypertension, mental disorder, cardiovascular disease, social behaviour disorder, sleep disturbance, infertility, spontaneous abortion, congenital malfunctions, and hearing impairment (Zhu *et al.*, 2017; Honda *et al.*, 2017; Basner and Mcguire 2018). Moreover, it is further added that exposure to high 'NP' can distort thinking capability, productivity of the workers, human performance and intellectual functionality (Tzivian *et al.*, 2015).

In Nigeria, most commercial areas such as markets, milling and block industries are constructed right in the heart of the cities and some are installed in residential areas where human movement and activities are high (Abiola, 2016). This prompted the emergence of this research to estimate the NL in residential areas and the following challenges shall be addressed: to model and estimate the amount of noise level of different activities in residential areas; to select the best fit probability distribution model for noise modeling, to determine the probability of exceeding critical point liable of causing specific health hazards, and compare the noise level estimated with the world health organization (WHO) standards. Probability distribution models have been used in different scenarios, for analysis and prediction processes in time-series modeling, reliability engineering, wind speed, rainfall, environmental modeling, river discharge, air quality, and health among others (Alimohammadi, 2013; Aldahlan *et al.*, 2020). Many commonly used probability distribution models including normal, lognormal, weibull, gamma, generalized extreme value, lognormal, and normal distributions to mention but a few (Jeremie, 2003).

2. MATERIALS AND METHODS

2.1. Study Area

The research was conducted in Mubi North Local Government Area of Adamawa State, Nigeria. Mubi is located at the extreme north eastern part of Nigeria sharing a border with Republic of Cameroon from the north and lies between latitude 10.27^0 North and longitude 13.26^0 East. Mubi is the second largest town in the State next to Yola and considered as the commercial hub of the State.

2.2. Noise Level Measurement

The measurements were taken from three sources; block industry (BI), milling industry (MI) and timber industry (TI). The noise level was measured using noise detector software installed on a Mobile Equipment (ME). The meter responds to pressure change of the noise level; The NL was measured periodically and stored on the ME for length of working hours (8 hours) for 7 days in each location.

2.3. Noise Level Modeling

The NL measured was modeled using the Gamma distribution model (GDM), lognormal distribution model (LDM), and Weibull distribution model, (WDM). Goodness of fit was applied to determine the 'best fit' model. The PECP was then obtained. The NL estimated was compared with the standard values from the WHO.

2.3.1. Gamma distribution model

Let the NL measured be denoted as random variable (x) and its mean be ($\overline{x}$), then the parameters of the GDM can be estimated as expressed Equation (1).

$$f(x,\beta,\alpha)=\frac{1}{\Gamma(\alpha)\beta^{\alpha}}x^{\alpha-1}e^{-\frac{x}{\beta}};\ x\geq 0,\ \alpha\geq 0,\ \ \beta\geq 0 \tag{1}$$

Where β and α are the shape and scale parameters respectively. The parameters of the maximum likelihood may be estimated using Equations (2) and (3).

$$\log\overline{\alpha}-\varphi(\overline{\alpha})=\left[\frac{\overline{x}}{(\Pi_{i-1}^{n}x_i)^{1/n}}\right] \tag{2}$$

$$\overline{\beta}=\frac{\overline{x}}{\overline{\alpha}} \tag{3}$$

Where φ ($\overline{\alpha}$) is a digamma function with an argument defined as:

$$\varphi(\overline{\alpha})=\frac{d}{dx}[\log\Gamma(\alpha)]=\frac{d\Gamma(\alpha)/d\alpha}{\Gamma(\alpha)} \tag{4}$$

2.3.2. Lognormal distribution model

If x is lognormally distributed, then ln(x) is also normally distributed. The probability distribution function (PDF) is obtained using Equation 5:

$$f(x;\mu,\sigma^2)=\frac{1}{x\sqrt{2\pi\sigma^2}}e^{-(\ln x-\mu)^2/2\sigma^2}\quad x,\mu,\sigma>0 \tag{5}$$

Where μ is the location and σ^2 is the scale parameter. The maximum likelihood parameters can be estimated using Equations 6 and 7.

$$\overline{\mu}=\left(\frac{1}{n}\right)\sum_{i=1}^{n}\log x_i \tag{6}$$

$$\overline{\sigma}^2=\frac{1}{n-1}\sum_{i=1}^{n}[\log(x_i-\mu)]^2 \tag{7}$$

2.3.3. Weibull distribution

If 'x' is Weibull distributed, the parameters of the PDF are estimated using Equation (8).

$$f(x,\alpha,\beta)=\frac{\infty}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}e^{-\left(x/\beta\right)^{\alpha}};\qquad \alpha>0,\beta>0 \tag{8}$$

Where α is the space and β is the scale, parameters respectively. Its maximum likelihoods are given as:

$$\bar{\alpha}=\frac{n}{\left(1/\bar{\beta}\right)\sum_{i=1}^{n}x_i^{\bar{\alpha}}\log x_i-\sum_{i=1}^{n}\log x} \tag{9}$$

$$\bar{\beta}=\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}x_i^{\bar{\alpha}}\right] \tag{10}$$

2.4. Goodness of Fit

Goodness of fit (GoF) can be tested using Anderson Darling test, Kuiper's test, Shapiro test, Jarque – Bera and Kolmogorov – Smirnov among others (Oguntunde *et al.,* 2014). In this work, the Kolmogorov – Smirnov (K - S) test was applied to test the GoF of the distributions in an attempt to select the best fit probability model. Given the N^{th} number of 'x', the test statistics of 'K-S' may be performed using Equation (11).

$$D\equiv\max_{1\le i\le n}\left(F\left(x_i\right)-\frac{i-1}{N},\frac{i`}{N}-F\left(x_i\right)\right) \tag{11}$$

Where N is number of the observations

2.5. Probability of Exceeding Critical Point

The PECP of the NL measured may be obtained from the cumulative frequency distribution of the best fit model and it is integrated to give Equation (12).

$$\Pr(X>x)=1-\Pr(X\le x)=1-\int_{-\infty}^{x}f(x)\,dx \tag{12}$$

Where f(x) dx is the cumulative frequency distribution (CFD)

2.6. Comparison of Estimated NL with Standard Values

The standard values were compared with the NL determined from each industry to help draw conclusion whether the noise generated in the industries is inimical to the health of the workers or harmful to the environment especially to people living close to the industries.

3. RESULTS AND DISCUSSION

The results of the modeling using the PDMs are presented in Tables 1 – 3, and the tables were obtained from Figures 1 to 3, which show the analysis of the mean and parameters of the maximum likelihood for the BI, MI and TI respectively. In this research, three PDMs were applied to model the NL measured, these include the GDM, LDM and WDM for each of the industry as shown in Tables 1 – 3. In Table 1, the mean values of the NL were obtained as 50.037dBA, 51.014dBA and 58.532dBA using the GDM, LDM and WDM respectively. From these values of means, it translates that workers in BI are not likely to be exposured to health hazards accept mild hearing impairment (Alnuman, and Ghnimat, 2019). However, in contrast, Olushegun *et al.* (2012) reported that average NL measured in block factory in their study is higher than what is obtained in this work by above 40dBA. Whereas the maximum likelihood parameters such as shape and location parameters (β and μ) and scale parameters (α and σ) were estimated using GDM as β = 69.031, α = 0.8572, LDM as μ = 4.0662, α = 0.1211, and for WDM were β = 61.914. α = 8.8370 respectively. The values of the parameters of the maximum likelihood would be used to determine the PECP (Oguntunde *et* *al.,* 2014). In Table 2, the mean of the NL obtained at the MI were 59.888dBA, 59.892dBA and 61.800dBA for GDM. LDM and WDM respectively, in this case, workers in MI may be prompted to mild health conditions (Akiryemi *et al.*, 2015), and the parameters of the ML were determined as β = 71.880, α = 0.8572 for 'GDM', μ = 4.0662, α = 0.1211 for 'LDM' and β = 61.800, α = 9.0909 for WDM respectively. In a similar manner, Table 3 shows that the ($\bar{x}$) of TI were estimated as 76.745dBA, 71.376dBA and 70.886dBA respectively, workers are likely to develop mild or severe health conditions (David *et al.,* 2018) and the NL obtained in this work is less than the NL presented by (Mjerenje and Drvnoj, 2014). However, in all the scenarios, the mean obtained from WDM is highest followed by LDM and GDM is the least and these variations may be attributed to the fact that not all the PDMs can be applied to model NL. Furthermore, GoF would be used to obtain the best fit model (Langat et al., 2019).

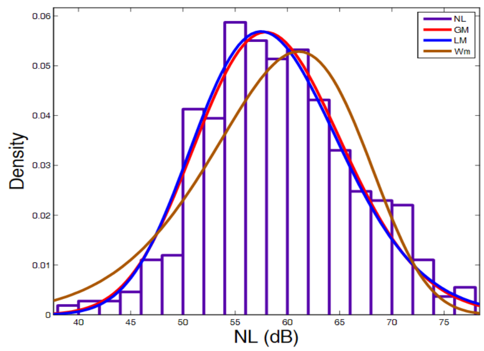

Figure 1: Analysis of mean, scale, shape and location parameters for BI

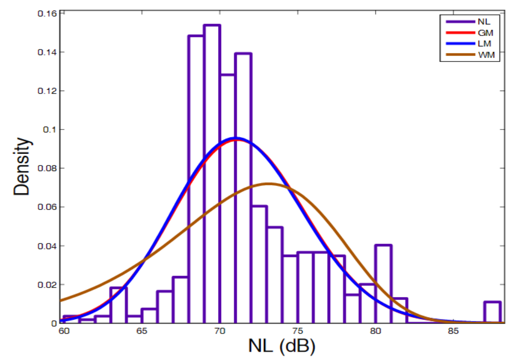

Figure 2: Analysis of mean, scale, shape and location parameters for MI

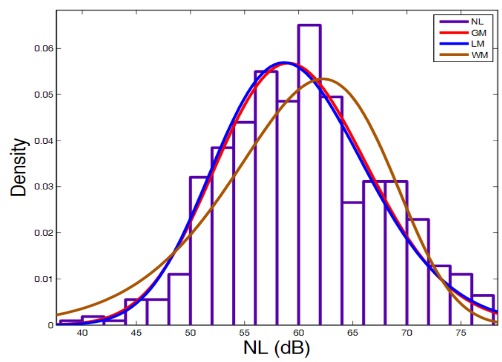

Figure 3: Analysis of mean, scale, shape and location parameters for TI

Table 1: Parameter estimates of the probability distribution model of block industry

Distributions	$\bar{x}$ (dBA)	Parameters	
Gamma distribution	50.037	β = 69.031	α = 0.8512
Lognormal distribution	51.014	μ = 4.0662	σ = 0.1211
Weibull	58.582	β = 61.914	α= 8.8370

Table 2: Parameter estimates of the probability distribution model of milling industry

Distributions	$\bar{x}$ (dBA)	Parameters	
Gamma distribution	59.888	β = 71.880	α = 0.8332
Lognormal distribution	59.892	μ = 4.0855	σ = 0.1187
Weibull	61.800	β = 63.047	α = 9.0909

Table 3: Parameter estimates of the probability distribution model of timber industry

Distributions	$\bar{x}$ (dBA)	Parameters	
Gamma distribution	70.886	β = 287.30	α = 0.2486
Lognormal distribution	71.376	μ = 4.2662	σ = 0.0587
Weibull	76.745	β = 73.510	α= 14.352

Table 4 provides the GoF statistics of NL modeled for the three industries. It can be seen, that LDM best fits the NL measured. This is because it has the lowest values of 'GoF' of 0.1581, 0.1892 and 0.1553 for BI, MI and TI respectively. It is worthy to say that LDM is a suitable model for modeling NL. This information allows us to determine the PECP (Oguntunde *et at.,* 2014). Furthermore, it is also reported by some modeling experts that 'GoF' is usually applied as tool to describe how close data fits a particular model (Oguntunde *et al.,* 2014; Mamoon and Rahman, 2017; Minho *et al.,* 2018). Table 5 shows the PECPs for each industry. The PECPs of BI, MI and TI were obtained as 0.1158, 0.4146 and 0.5471 using Equation (12). This implies that, if workers in the industries are exposed to noise pollution for more than 8 hour daily the mean of the NL may increase by 11.58%, 31.46% and 54.71% for BI, MI and TI respectively. For example, the mean of the NL estimated by LDM may increase to 55.831dBA, 78.734dBA and 118.74AdB. Consequently, workers from MI and TI are at the high risk of health hazards (Dzhanboo, 2015).

Table 4: Goodness of fit statistics

Distributions	Gamma	Lognormal	Weibull
Block	0.1593	0.1581*	0.1598
Milling	0.2103	0.1892*	0.2111
Timber	0.1589	0.1553*	0.1683

Table 5: Probability of exceeding critical point for the industries

Industry	F (x)	F(x)%
Block	0.1158	11.58
Milling	0.3146	31.46
Timber	0.5471	54.71

Table 6 depicts comparison between the standard values of the safety level recommended by the world health organization (WHO) and the NL obtained. A positive sign signifies that exposure to noise in any of the industries for at least 8 hours may be inimical to health (Basner *et al*., 2019) and negative sign indicates exposure to noise may not cause health hazard. Workers from BI may experience mild annoyance (Freis*et et al.,* 2014). Workers from MI are likely to suffer severe annoyance, mild sleep disturbance and poor next day mode (Delaney *et al*., 2015; McGuire *et al.,* 2016 and Delaney *et al*, 2018). Workers at TI may develop mild hypertension, heart disease, poor performance, severe annoyance, sleep disturbance, poor next mode (Banerjee *et al.,* 2014; Chamkori *et al.,* 2016).

Table 7 presents the variations of the NL of the three industries. In this case, a positive sign means (greater than) and a negative sign stands for (less than). NL measured at the TI is greater than that of MI and BI by 16.856 dBA and 26.711dBA respectively while MI is greater than BI by 9.8558 dBA. This may be attributed to the intensity of the NL varies in different industries.

Table 6: Environmental noise exposure and corresponding health hazards (WHO,1999)

Diseases/health hazards	NL (dB) Standard Values	NL difference at BI (dBA)	NL difference at MI (dBA)	NL difference at TI (dBA)
Hearing Problem	75	-22	-19	-2
Hypertension	70	-17	-9	+3
Heart Disease	70	-17	-9	+3
Annoyance	50	+3	+11	+23
Performance	70	-17	-9	+3
Sleep disturbance	60	-7	+1	+13
Next day mode	60	-7	+1	+13

Table 7: Variations of the noise levels

Industry	NL obtained using LDM (dB)	NL difference at BI (dB)	NL difference at MI (dB)	NL difference at TI (dB)
Block	50.037	0	-9.855	-26.711
Milling	59.892	+9.855	0	-16.856
Timber	76.748	+26.711	+16.856	0

4. CONCLUSION

Noise Level has been measured and modeled using multi probability distribution models such as Gamma, Lognormal and Weibull distributions for block, milling and timber industries in Mubi North, Adamawa State Nigeria. The mean of the NL and parameters of maximum likelihoods were estimated. It was found that the timber industry generates the highest noise with an average of 73dBA. Lognormal distribution model was selected to be the best fit model and found that the probability of exceeding critical point of the noise level at timber industry was the highest followed by milling industry and block industry. It was found that workers at 'BI' may suffer mild annoyance, while workers from MI are likely to experience severe annoyance, mild sleep disturbance and poor next mode and workers at TI may develop mild hypertension, heart disease, performance and severe annoyance, sleep disturbance, poor next mode when they are exposed to noise 8 hours daily. It recommended for further studies that NL should be measured based on seasons to ascertain whether weather conditions can influence NL

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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