Computational Modelling of Noise Pollution and Its Health Hazard Using Probability Distribution Models: A Systematic Review

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ABSTRACT

Noise pollution is one of the man-made environmental hazards after air, water and land pollution that is given the least attention by the World Health Organization (WHO). Noise pollution is an excessive sound produce intentionally or accidently that can have deleterious effects on human and animal’s health and even environmental quality. The major Sources of this sound are industries, highways, railways, and aircraft traffic and entertainment cafes. This research work was to conduct systematic review regarding the application of probability distribution models and other computing techniques in modelling the effects of extensive sound in human health and also the critical level of sound to human exposure as compare to WHO standard.

1. Background

Noise pollution (NP) is considered as the third most hazardous type of environmental pollution. High noise pollution in residential areas is recognized in the world as a major threat to health and affecting liveability Min & Min (2017); Foraster et al., (2018); Alnuman & Ghnimat (2019); Lim & Thurston, (2019); Oguntunde et al., (2019); Weihofen et al., (2019); Jensen & Ekholm, (2019); Basner, Witte & McGuire, (2019); 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 Babish (2014); Halonen et al., (2015); Foraster et al., (2018); Basner, Witte, & McGuire, (2019); Brown, Lam, & Kamp, (2015). Individual and community activities Ali, (2011); Xingsong et al., (2020). In fact, it is noticed that about 70% of environmental noise generated by moving vehicle caused due to engine and exhaust systems Clara et al., (2018). It is also believed that noise pollution can be pose health hazard on human beings such as sleep disturbance, stress, mental disorder, cardiovascular disorder and loss of hearing, etc.

Le et al., (2017); Basner, Witte & McGuire, (2019); Rudolph et al., (2019); Li et al., (2019). Quite a number of studies on noise pollution has been carried out for example, 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. Gollamandla et al., (2017), used Microsoft excel and developed a model that recognizes the dependences of the intensity noise. Ify and Ofem (2014), utilized linear, quadratic and cubic curves fitting and predicted there is high of correlation between traffic volume and noise pollution, also calculated that noise level on express way in about 113dB (A). Akirnay et al., (2007) suggested that sound propagation can be influenced by metrological or weather parameters such as wind and temperature gradient. Okoro et al., (2016) in their study stated sound level increase in commercial areas especially in timber industry. According to Priyanka et al. (2015) noise pollution can cause health hazard more than just hearing disorder and that NP is liable to cause other health problems like blood pressure, tiredness and increase blood pressure cholesterol.
However, in Nigeria most commercial areas such as market area constructed right in the heart of the cities, milling and timber industries some are built zero meter from residential areas, this research is carried out to estimate the noise pollution level in residential areas. Whereas the following challenges shall be address to model and estimate the amount of noise level of different activities in residential area to determine the probability of exceeding critical point of specific health hazards, and compare the noise level estimated with the world health organization (WHO).

**Table 1.** Depicts some environmental noise exposure and correspond health hazards

| Health Hazards       | Noise (dB) | Exposure Time (Hours) |
|----------------------|------------|-----------------------|
| Hearing impairment   | 70-75      | 1-4                   |
| Hypertension         | 70         | 8 daily               |
| Ischemic heart disease | 70        | 8 daily               |
| Annoyance            | 42         | 16 daily              |
| Performance          | 70         | 8 daily               |
| Sleep disturbance pattern | <60     | Any time              |
| Mode next day        | <60        | 10 daily              |

Source: Paschier, Vermeer and Passcheir (2000)

Moreover, WHO, (1999) they further summarize the maximum exact values that can cause these disease like; hearing impairment is 70dB, speech intelligibility is affected by a maximum of 35-50dB, sleep disturbance is causes by a maximum of 30-45dB, psychological function is disturbed by a maximum industrial noise of 5-30dB, mental illness in this exposure of high level of occupational noise can cause neurosis, annoyance can cause by a maximum of 50dB,

2. Literature

Noise is an unwanted sound (Kyoung & Jin-Young, 2017) unpleasant sound (Xingsong et al., 2020) which disturb, discomfort, stress human beings and animals, physically, physiologically and psychologically. Many researches have extensively evaluated the health risk of short-term exposure and long-term exposure to noise (Cathryn et al., 2016; casaroni et al., 2014; Beelen et al., 2014; Foester et al., 2017; Pyko et al., 2017). In urban setting, where road traffic, railway traffic, milling machine and block industry are the important sources of ambient noise pollution which are extensively associated with the major disease in question (Xingsong et al., 2010; Zhu et al., 2017; Levigre et al., 2016; Honda et al., 2017; Hu et al., 2014; Perdersen et al., 2014). The effect of noise includes hypertension mental disorder, cardiovascular disease, social behaviour disorder, sleep disturbance, infertility, spontaneous abortion, congenital malfunctions, and hearing impairment (Kyoung and Jin-Young 2020; Basner et al., 2014; Chamkori et al., 2016; Eisenberg et al., 2015; Wqgam et al., 2016; Collen et al., 2019; Garcia, Smith & Palmer, 2018; Barsner & Mcguire 2018). Moreover, the thinking capability, productivity of the workers, human performance and intellectual functionality are also confirmed to be affected by noise as the studies explored (Barsner et al., 2014; DEFA, 2014; Tzivian et al., 2015).
Sleep disorder is one of the major concerns in human and animal life however, studies suggested that long time exposure to noise may cause postromantic stress disorder, sleep disorder and other related issues as in (Van Kampen et al., 2018; Zare Skhvidi et al., 2018; Pyko et al., 2017; Bersner & Mcguire, 2018; Munzel et al., 2016).

The high severity level in sleep disorder may lead to chronic endocrine and nervous system alteration as the studies shows (Mumzel et al., 2017; Recio et al., 2016).

Table 2. Systematic Review of some specific effects of exposure to excessive environmental noise

| S/N | Author(s) and Year | Effect |
|-----|--------------------|--------|
| 1.  | Correia, et al., 2013 | Cardiovascular risk |
| 2.  | de Kluizenaar, et al., 2013 | Cardiovascular risk |
| 3.  | Guzik & Channon 2017 | Cardiovascular risk |
| 4.  | Hahad et al., 2019 | Cardiovascular effect of noise |
| 5.  | Li et al., 2019 | Cardiovascular and Hearing |
| 6.  | Münzel, et al., 2014 | Cardiovascular risk |
| 7.  | Münzel et al., 2018 | Cardiovascular system |
| 8.  | Münzel et al., 2018 | Cardiovascular risk |
| 9.  | Recio, et al., 2016 | Cardiovascular, respiratory and metabolic health |
| 10. | Stansfeld & Clark 2015 | Psychophysiological effects |
| 11. | Swinburn, Hammer & Neitzel, 2015 | Cardiovascular health hazard |
| 12. | Tabraiz et al., 2015 | Psychophysiological effects |
| 13. | Tobias et al., 2015 | Cardiovascular risk |
| 14. | Basner et al., 2020 | Hypertension and diabetes mellitus |
| 15. | Lim & Thurston, 2019 | Diabetes |
| 16. | Liu et al., 2018 | Diabetes |
| 17. | Shin et al., 2020 | Diabetes mellitus and hypertension |
| 18. | Taban, 2016 | Diabetes |
| 19. | Yang et al., 2018 | Diabetes |
| 20. | Zare Sakhvidi, 2018 | Diabetes |
| 21. | Babisch, et al., 2014 | Hypertension |
| 22. | de Souza, 2015 | Hypertension |
| 23. | de Souza, Périsse & Moura 2015 | Hypertension |
| 24. | Fajar et al., 2019 | Hypertension |
| 25. | Shrestha & Shiqi et al., 2017 | Hypertension |
| 26. | Alnuman & Ghnimat 2019 | Hearing loss |
| 27. | Helzner & Contra, 2016 | Diabetes and hearing impairment |
| 28. | Le et al., 2017 | Hearing loss |
| 29. | Lie et al., 2016 | Hearing loss |
| 30. | Oguntunde et al., 2019 | Hearing loss |
| 31. | Russ et al., 2017 | Hearing loss |
| 32. | Sareen & Singh 2014 | Hearing loss |
| 33. | Lusk et al., 2016 | Stroke |
| 34. | Stokholm 2013 | Stroke |
| 35. | Vivanco-Hidalgo et al., 2018 | Stroke |
| 36. | Vivanco-Hidalgo et al., 2019 | Stroke |
| 37. | Weihsden et al., 2019 | Stroke |
| 38. | Babisch, 2014 | Coronary heart diseases |
| 39. | Banerjee, Das & Foujdar, 2014 | Coronary heart diseases |
| 40. | Foraster et al., 2018 | Adiposity markers and development of obesity |
| 41. | Beutel et al., 2016 | Depression and anxiety |
| 42. | Orban et al., 2016 | Depression |
| 43. | Alimohammadi, et al., 2013 | Mental performance |
| 44. | Clark & Paunovic, 2018 | Mental health |
| 45. | Dzhambov et al., 2018 | Mental health |
| 46. | Helbich, 2018 | Mental health |
| 47. | Lim et al., 2018 | Mental health |
| 48. | Jensen & Ekholm, 2019 | Mental and physical health |
| 49. | Rudolph et al., 2019 | Sleep and mental health |
| 50. | Tzvian et al., 2015 | Cognitive and psychological functions |
| 51. | Basner & Mcguire, 2018 | Sleep disturbance |
| 52. | Basner, Witte & McGuire, 2019 | Effects on sleep |
| 53. | Brown, Lam & Kamp, 2015 | Sleep disturbance |
| 54. | DEFA, 2014 | Sleep disturbance, annoyance, hypertension, productivity and quiet |
| 55. | Delaney, Haren & Lopez, 2015 | Sleep disturbances |
Demian, (2014) has also added how noise disturbance has become threat to health apart from sleep disturbance some research shows that long term exposure to environmental noise lead to daytime sleepless and tiredness, mood changes, cognitive performance and decrease wellbeing (Muzet 2007; Bersner 2008; Babiseh et al., 2009; Elmenhorst et al., 2010; Golnes & Hagler, 2007).

Infertility is a failure to reproduce naturally. According to European society of human reproduction and embryology 2014 believed that infertility affect couples with 20-30% from male and 20-30% due to female infertility. Moreover, 25-40% occurred from the both. Although the causative agent have remained a major concern among researchers some studies indicates that long exposure to noise may cause infertility for both males and females (Kyoung & Jin, 2017) and similarly (Vested et al., 2014; Kenz 2013; Mocarell et al., 2008; Eisenberg et al., 2015; Farzadinia 2016; Julia et al., 2013; Hart 2016).

Recently, several studies has shown that long term exposure to noise mental disorder can cause psychological retardation or disorder (Pun et al., 2017; Zijlema et al., 2016; Orban et al., 2016; Selder et al., 2017; Vert et al., 2017; Kim et al., 2016; Power et al., 2015). Moreover, some epidemiological studies has proved that noise pollution and air pollution can cause mental disorder as in (Markevych et al., 2017; Thiering et al., 2016; Hystad et al., 2014). However, some epidemiological research on psychological effects or mental disorder suggested that there is no consistency on the results because there is differences in terms of exposure of the noise (Ma et al., 2018; Dzhambor et al., 2017).

3. Method of Data Analysis

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 discharges, air quality, and health among others. Anwar and Bibi (2018) had presented that for the analysis of lifetime data, it is important to fit the data by a statistical model. Philip et al., (2019) identified the selection of the most suitable probability distribution model and related parameter estimation process, as a fundamental step in statistical analysis. In the literature, many commonly used probability distribution models including normal, lognormal, Weibull, gamma, generalized extreme value, lognormal, and normal distribution have been explained.

A normal distribution has been described as the commonly used probability distribution for its simplicity of having easily identifiable parameters mean and variance, and for the reason that most large. However, its symmetric nature and excess kurtosis of 0, might not be true for certain natural phenomena (Alam et al., 2018).

Gamma distribution is one of the most used distribution models for special cases in different situations such as exponential and Chi-square (Ramos et al., 2019). The Probability distribution function for a gamma distribution model with two parameters \( \infty \) and \( \beta \) is usually given by

\[
f(x, \beta, \alpha) = \frac{1}{\gamma(\infty) \beta^{\alpha}} x^{\alpha-1} e^{-\frac{x}{\beta}} \quad x, \infty, \beta > 0
\]

(1)

Where \( \beta \) is the scale parameter and \( \infty \) is the shape parameter.
The log-normal distribution function has been described as a highly skewed distribution for the logarithm of the variable. The probability distribution function for a log-normal distribution model with \( \mu \) and \( \sigma \) and \( s \) parameters is usually given by

\[
f(x; \mu, \sigma^2) = \frac{1}{\sqrt{2\pi \sigma^2}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}
\]

(2)

where \( x, \mu, \sigma > 0 \)

Where \( \mu \) is the location parameter and \( \sigma^2 \) is the scale parameter and also the standard deviation of the distribution.

The probability distribution function for the Weibull distribution model with two parameters \( \infty \), and \( \beta \) parameters is generally given by

\[
f(x, \infty, \beta) = \frac{x^{-\beta}}{\beta} e^{-\left(\frac{x}{\beta}\right)^\beta} ; \infty > 0, \beta > 0
\]

(3)

Where \( \infty \), is the shape parameter and \( \beta \) is the scale parameters.

According to Aldahlan et al., (2020) the Weibull distribution can prove adequate fits for most of the lifetime data, except those having experimental hazard rates with non-monotone forms. This limitation has motivated more flexible alternatives in terms of modelling, such extended, and beta the modified, the exponentiated, among others, and the more recently, a very flexible extension of the Weibull distribution called the exponentiated power generalized Weibull (EPGW) distribution.

The cumulative distribution function (cdf) of the EPGW distribution with parameters \( \alpha, \beta, \lambda, \) and \( \mu \) is given by

\[
G_{EPGW}(x; \alpha, \beta, \lambda, \mu) = \left[ 1 - e^{-(1+\lambda x^\alpha)} \right]^\beta , x > 0, \quad (4)
\]

Where \( \lambda > 0 \) is a scale parameter, and \( \mu, \alpha, \beta \) are shape parameters

Prior research by Ramos et al., (2019) revealed that Generalized Gamma (GG) distribution models have been effectively applied in diverse areas, such as data processing, reliability, and meteorology, to mention but a few. Accordingly, GG distribution comprises of various sub-models such as the Weibull, log-normal, gamma, and half-normal, Maxwell-Boltzmann, Nakagami-m, Rayleigh, and Chi distributions. Quite a lot of classical methods have been employed for estimating the unknown parameters of probability distributions functions in the literature.

Several types of research viewed the selection of suitable distribution model functions and its parameter estimation procedure as an active and challenging research area currently. Philip et al., (2019) had explained that the identification of Probability Distribution Models depends on the characteristics of available discharge data, followed by event sample variable election, then the estimation and the identification of the best distribution model
suited for the estimation. Philip et al., (2019) considered maximum likelihood (ML) estimation, goodness-of-fit (GoF) tests-based analysis, and information criteria-based selection approach as the most suitable distribution functions models that are best suited for the estimation of maximum, minimum, and mean Parameters.

The maximum likelihood (ML) estimation method has been described as the commonly used estimators that give a minimum variance estimate of parameters, asymptotically normal, and asymptotically efficient.

For gamma distribution the maximum likelihood estimators $\bar{\alpha}$ and $\bar{\beta}$ are given by simultaneous equations,

$$\log \bar{\alpha} - \varphi(\bar{\alpha}) = \log \left[ \frac{x}{\left( \sum_{i=1}^{n} x_i \right)^{\frac{1}{n}}} \right]$$

$$\bar{\beta} = \frac{x}{\bar{\alpha}}$$

Where $\varphi(\bar{\alpha}) = \frac{d}{dx} \log(\bar{\alpha}) = \frac{d\gamma(\bar{\alpha})d\alpha}{\gamma(\alpha)}$

Which is the gamma function with an argument $\bar{\alpha}$

Log normal distribution has the maximum likelihood parameter estimates for $\bar{\mu}$ and $\bar{\sigma}^2$ given by:

$$\bar{\mu} = \frac{1}{n} \sum_{i=1}^{n} \log x_i$$

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

Weibull distribution has the maximum likelihood estimators $\bar{\alpha}$ and $\bar{\beta}$ of the shape and scale parameters determined by:

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

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

Goodness-of-fit tests-based statistical analysis and procedures are used for checking the validity of a specified probability distribution model.

It involves checking the normality by graphical methods, numerical methods, and proper normality tests (Alam et al., 2018). This approach first matches the raw dataset to more than one probability distributions model of interests.
then, the goodness-of-fit tests conducted to determine the distribution that best fits the data. To enable the user to describe the behaviour of the dataset, the best-fitted distribution is essential. Philip et al., 2019 identified the theory of GoF test statistics that are generally accepted for checking the adequacy of probability distributions models, given by

\[ X^2 = \sum_{j=1}^{N} \frac{(O_j(Q) - E_j(Q))^2}{E_j(Q)} \] (12)

Where \( O_j(Q) \) is the frequency of the observed value of the jth class, \( N \) is the number of frequency classes, and \( E_j(Q) \) signifies the expected frequency value of the jth class.

The method of moments (MM) is one of the widely and commonly used estimators for estimating parameters in statistical distribution models. It is normally used mainly for its simplicity (Ramos et al., 2019). Alam et al., 2018 had explained that to calculate the parameters by using MM, the sample mean to say \( \bar{X} \), standard deviation \( s \) and coefficient of skewness are;

\[ \bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \] (13)

\[ \sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2} \] (14)

\[ \gamma = \frac{n \sum_{i=1}^{n} (X_i - \bar{X})^3}{(n-1)(n-2)S^3} \] (15)

Where \( n \) is the number of observations in the dataset, \( i \) is the number of observations, and \( X_i \) is the observed data.

In addition to Alam et al., (2018) showed that log-normal distribution can be estimated using MM estimators, with two parameters expressed as follows:

\[ \sigma_\gamma = \sqrt{\ln(1 + \frac{\sigma^2 X}{\mu^2 X})} \] (16)

\[ \mu_\gamma = \ln(\mu X) - \frac{1}{2} \sigma^2 \gamma \] (17)

Where, \( \sigma_\gamma \) is the standard deviation and \( \mu_\gamma \) is the mean for the log-normal distribution. Weibull distribution parameters can be estimated by using the MM estimators given by

\[ \mu = \alpha \Gamma(1 + \frac{1}{k}) \] (18)
\[ \sigma^2 = \alpha^2 \left\{ \Gamma\left(1 + \frac{2}{k}\right) - \left[ \Gamma\left(1 + \frac{1}{k}\right) \right]^2 \right\} \]  

(19)

Where \( \mu \) is the scale parameter and \( \sigma^2 \) is the shape parameter for the Weibull distribution.

Three probability density functions shall be employed to analyse the noise level measured after which the best fit model was applied to determine the probability of the exceeding critical point.

a. Gamma distribution, b. Lognormal distribution, c. Weibull distribution

Different probability distribution models shall be employed to model the noise and best model shall be selected to determine the probability of the exceeding critical point.

(a) Gamma distribution

Let the RFF measured (X) denotes the random variable, the parameters of the probability function can be obtained using expression (1)

\[ f(x, \beta, \alpha) = \frac{1}{\gamma^{(a)}} \beta^{\alpha} x^{\alpha-1} e^{-\frac{x}{\beta}}; x, \beta > 0 \]  

(20)

Where \( \beta \) is the scale parameter and \( \infty \) is the shape parameter, and its parameters of the maximum likelihood may be estimated using equation (21) and (22) as,

\[
\log \infty - \varphi(\infty) = \log \left[ \frac{x}{(\varphi_{-1}^n x)} \right] 
\]

(21)

\[
\overline{\beta} = \frac{x}{\infty}
\]

(22)

Where \( \varphi(\infty) = \varphi(\infty) = \frac{d}{dx} \log \gamma(\infty) = \frac{d_{f}(\infty) d_{n}}{\gamma^{(a)}} \)  

(23)

Which is the Gamma function with an argument \( \infty \)

(b) Lognormal distribution

If \( x \) is lognormally distributed then \( \ln(x) \) is normally distributed. Therefore, the PDF is obtained using (23) as

\[ f(x; \mu, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}} \]  

(24)

Where \( \mu \) is the location and \( \sigma^2 \) is the scale parameters respectively then the maximum likelihood parameter \( \mu \) and \( \sigma \) can be estimated using equation (23) and (24)
\[ \mu = \frac{1}{n} \sum_{i=1}^{n} \log x_i \]  

(25)

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

(26)

(c) Weibull distribution

\[ f(x, \infty, \beta) = \frac{x^{-1}}{\beta} \left( \frac{x}{\beta} \right)^{-1} e^{-\left(\frac{x}{\beta}\right)^\infty}; \infty > 0, \beta > 0 \]  

(27)

Where \( \infty \) is the space and \( \beta \) is the scale parameters respectively. Its maximum likelihood is going to determined using equations (28) and (29)

\[ \dddot{\infty} = \frac{n}{\left(\frac{1}{\beta}\right)^n \sum_{i=1}^{n} x_i^{-1} \log x - \sum_{i=1}^{n} \log x} \]  

(28)

\[ \dddot{\beta} = \left[ \left(\frac{1}{n}\right) \sum_{i=1}^{n} x_i^{-1} \right] \]  

(29)

Probability of exceeding critical point

The probability of exceeding the critical point of the RFF may be obtained from the best fit model and it shall be calculated using equation (29) as,

\[ \Pr(X > x) = 1 - \Pr(X \leq x) = 1 - \int_{-\infty}^{x} f(x)dx \]  

(30)

4. Conclusion

Noise pollution (NP) is considered as the third most hazardous type of environmental pollution. High noise pollution in residential areas is recognized in the world as a major threat to health and affecting liveability. In this research work we have conducted a thorough review on the hazard of noise on human health and explore the level of risk regarding to the level of sound and finally identified the diseases that may be caused if you are exposed to the certain level of noise.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional and personal interests.
Ethical Approval

Ethical approval for this research was given based on institutional guidelines.

Consent to participate

The consent to participate in this research was sought for and approved by the subjects to be used.

Consent for publication

We declare that we consented for the publication of this research work.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

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