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RESEARCH

Noise modeling using multiple probability distribution functions

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Many research has been conducted to develop an appropriate statistical model for assessing noise level potential. The key parameter in estimating this potential is the noise from the generator, which is inherently random, making statistical methods essential for accurate estimation. Consequently, noise level probabilities can be analyzed using various probability distributions. Accurately determining the probability distribution of noise level values is crucial for evaluating the noise level potential of the university. However, this paper applies the use of lognormal, Weibull, Nakagami, and gamma distributions to datasets from a specific location in Adamawa State University (ADSU), Mubi. To identify the most suitable distribution, the study employs the Kolmogorov-Smirnov (K-S) test and Anderson-Darling (A-D) test along with graphical representations of the cumulative distribution function (CDF) and probability distribution function (PDF). The (K-S) test was found to be the best model over the (A-D) test. Based on both graphical analysis and computed goodness-of-fit results, the gamma distribution was found as the best-fitting model with a fitness of 0.13805, followed by Nakagami, Weibull, and lognormal with 0.14130, 0.14579, and 0.15709, respectively. Additionally, 62.54% was found to be the probability of exceeding the critical point (PECP).

Keywords: statistical models, goodness of fit, noise level, probability of exceeding critical point, noise modelling

Introduction

There has been an increase in noise pollution day by day as technologies keep increasing, most especially in urban cities. The effects of noise pollution related to health have been of great concern. Many studies reported that noise pollution can cause mental disorders, stress, sleep disturbance, and loss of hearing due to the impact (1, 2). However, the World Health Organization also reported that traffic noise pollution is one of the environmental pollutants that is associated with environmental exposure in urban areas (3). Also, railway traffic, milling machines, and block industries are considered by some authors as sources of noise pollution in the surrounding area that are majorly associated with mental disorder, hypertension, sleep disturbance, spontaneous abortion, infertility, and hearing ability (4–6). Some research shows that noise pollution is an unpleasant sound that brings about discomfort and stress to human beings, physiologically and psychologically (7).

In Nigeria today, the impact of noise hazards generated from standby electric power generators is of great concern to academic, administrative, and social activities in Nigerian schools. Adamawa State University (ADSU), Mubi, is one of the schools also associated with this concern. Thus, some authors are of the opinion that noise pollution has less contamination in an environment (8). In contrast, the effect of noise pollution generates adverse effects and has aesthetic, sociocultural, and economic effects (9).

This great concern among staff and students over the negative impact of noise pollution on their health and academic activities perhaps indicates the need for research. The following challenge shall be addressed: the best-fit probability model for the noise modeling will be selected. To determine the goodness of fit using the K-S test, to determine the probability of exceeding the critical point (PECP) that is capable of causing a health hazard, to compare the estimated noise level with the World Health Organization (WHO), and to draw a conclusion on the health effect of the noise pollution. Many researchers have used probability distribution models in different works for analysis, prediction, wind speed, modeling, air quality, rainfall, environmental modeling, river discharge, and others (10, 11). Commonly used distribution models include lognormal, normal, Nakagami, gamma, and Weibull distribution, to mention but a few (12).

However, the following challenges shall be addressed: To model and calculate the university generator's noise level, to determine the best GoF model, to assess the likelihood of exceeding critical thresholds for specific health hazards, and to compare the estimated noise levels with those set by the WHO so as to draw a conclusion on the health implications for staff and students of the university, most especially those living in hostels that are located in proximity to the generator.

However, **Table 1** presents the environmental noise exposure and corresponding health hazard of some diseases. Additionally, the WHO 1999 outlines the maximum thresholds that may result in several health issues, such as 70 dB for hearing loss, 3,550 dB for speech clarity, 3,045 dB for sleep disruption, 530 dB for industrial noise, and 50 dB for mental annoyance resulting from working in the workplace.

Study area

Nigeria's northeastern geopolitical zone is home to ADSU, Mubi. The university is situated between latitudes 10° 16′ 46″ N and 10° 17′ wha12″ N of the equator and longitudes 13° 16′ 27″ E and 13° 17′ 12″ E of the prime meridian (13). The university has a total land area of about 1.04 km. ADSU, being located within the Mubi region, falls within the tropical wet and dry climate region of the Koppen's climatic zone. It is characterized by warm and hot temperature conditions with mean annual values greater than 22°C (14–16). It is marked by a distinct wet season from May to October and a dry season which starts from November to April.

TABLE 1 | Environmental noise exposure and corresponding health hazards (3).

Diseases/health hazards	Noise (dB)	Exposure time (hour)
Hearing problem	70–75	1–4
Hypertension	70	8 daily
Heart disease	70	8 daily
Annoyance	42	16 daily
Performance	70	8 daily
Sleep disturbance	<60	Any time
Next day mode	<60	10 daily

Source: Ali Danladi et al. (17)

Materials and methods of data collection

The measurement was carried out at the 5,000 kVA university standby generator. A noise level monitoring application installed on mobile equipment was used to measure using a tape measure at intervals of 5 m from the generator's base. The meter was held at 1.5 m above the ground. As the meter responds to the noise, the pressure level is recorded. The measurements were taken from the generator's base to a distance of 50 m at intervals of 5 m for the period of 1 month, at exactly 6:45 pm when there is NO load on the generator, and at 8:00 pm when it is on peak load. By determining the PECP, students who reside close to the generator will have knowledge about the safety distance, and so will staff residing in the university quarters. However, verbal ethical approval was obtained from the Works Department, ADSU, Mubi.

Method of data modeling

The method of modeling involves five different types of probability distribution functions (PDFs), which are applied to model the noise level measured from the study area. These include gamma, Weibull distributions, lognormal, and Nakagami.

Gamma distribution model

Let the noise level be denoted by a variable (Y) and have a mean of $(\overline{Y})$. Therefore, the Gamma distribution model (GDM) parameters can be estimated using Equation 1.

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

where the scale and shape parameters are denoted by α and β, respectively. However, Equations 2 and 3 can be used to determine the maximum likelihood parameters, respectively.

$$\log\overline{Y} - \varphi\,(\overline{\alpha}) = \left[\frac{\overline{y}}{(\prod_{i-1}^{n} x_i)^{\frac{1}{n}}}\right] \quad (2)$$

$$\overline{\beta} = \frac{\overline{Y}}{\overline{\alpha}} \quad (3)$$

Weibull distribution model

Equation 4 can be used to determine the Weibull distribution model with two parameters, σ and β.

$$f\,(X, \sigma, \beta) = \frac{\sigma}{\beta}\left(\frac{X}{\beta}\right)^{\sigma-1} \exp-\left(\frac{X}{\beta}\right)^{\sigma}; (\sigma > O, \beta > O) \quad (4)$$

where σ and β are the shape and scale parameters, respectively.

Lognormal distribution

If "X" is - lognormal distribution function, then the distributed function model has two parameters μ and σ. The PDF is usually given using expression (5).

$$f\,(x;\ \mu,\ \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left(\frac{\ln\,(x-\mu)^2}{2\sigma^2}\right);$$

$$(-\infty\ \leq \mu \leq +\infty)\,;\,(0.125\ \leq \sigma \leq 10) \qquad (5)$$

where "x," "μ," and "σ" are the noise level measured, the location, and the scale parameters, respectively.

Nakagami distribution

Equation 6 can be used to determine the parameters "m" and "Ω" of the "PDF" when "L" is Nakagami distributed.

$$f = (L, M, \Omega) = \frac{2M^m}{\Gamma\,(M)\,\Omega^m} X^{2m-1} \exp\left(-\frac{M}{\Omega}L^2\right);$$

$$(0.5 \leq M \leq 5)\,,\,(1 \leq \Omega \leq 3)\,. \qquad (6)$$

where the location and scale parameters are denoted by M and Ω, respectively.

Goodness of fit

This is a statistical tool that is used to check the specified validity of a probability distribution model. Basically, there are various testing models, which include, among others, the Anderson-Darling test, Kuiper's test, Shapiro test, Jarque-Bera, and Kolmogorov-Smirnov. In this work, the Kolmogorov–Smirnov and Anderson-Darling tests were adopted to test "GoF" of distributions because of their flexibility and are widely used in analyzing statistical models in an effort to select the best probability model. Equations 7–9 can be used to determine the test statistics of "K-S" given the Nth number of "X."

$$D \equiv \max_{1\leq i\leq n}\left(F\,(X_i) - \frac{i-1}{N},\ \frac{i^{\text{‘}}}{N} - F\,(X_i)\right) \qquad (7)$$

where the Anderson-Darling test statistics are given by

$$\mathrm{A}^2 = -N - S \qquad (8)$$

Were

$$S = \sum_{i=1}^{n} \frac{(2i-1)}{N}\left[\mathrm{In}F\,(X_i) + \mathrm{In}\,(1-F\,(X_{N+1-i}))\right] \qquad (9)$$

$F(\cdot)$ is the cumulative distribution function (CDF) of the continuous distribution that is being tested, and XI is the ordered data.

Probability of exceeding critical point

The PECP from the noise level will be determined from the cumulative frequency distribution $f(x)$ of the best model formed and is evaluated using expression (10).

$$F_n\,(x) = p\,(X \leq x) = \int_{-\infty}^{x} f\,(x)\ dx \qquad (10)$$

Results and discussion

The results of the statistical modeling using the probability distribution models were presented in **Figure 1**, and the results were also presented in **Table 2**. The analysis presents the mean parameters of the maximum likelihood for the ADSU standby generator. In this research, the four statistical distribution models were employed to model the noise level of the study area, which includes the gamma model (GM), lognormal model (LM), Weibull model (WM), and Nakagami model (NM), respectively. The average mean value of the noise level was obtained as 73.1800, 73.1946, 72.8383, and 73.1834 dB, respectively, using the statistical models mentioned above.

Table 2 presents the analysis of mean, scale, and shape parameters of noise level from four statistical models. Probability distribution models were employed to model the noise level of the ADSU generator. These probability models include the GM, LM, WM, and NDM. However, the probability modeling was carried out based on the mean value of N, shapes (β, α, μ, and Ω) and scale parameter (σ). The results of the mean values of N for GM, LM, WM, and NM were obtained as 73.1800, 73.1946, 72.8383, and 73.1834, respectively. LM was found to be the highest, followed by GM and NM, and WM was found to be the least among the models. The maximum likelihood parameters were estimated for GM as = 73.0118 ∝ = 4.95359, LM as μ = 73.1946 σ = 0.0692751, WM as β = 75.644 α = 13.7415, and NM as μ = 55.9597 Ω = 5, 379.79. However, the "CDF" was estimated using the highest likelihood parameter of the best-fit model (18, 19). Thus, not all the probability models were used to model the noise; GoF was employed to ascertain which model best fits (20). However, **Figures 2–5** show the CDF graphical presentation of each of the models used in this research.

TABLE 2 | Analysis of mean, scale, shape, and location parameters for ADSU standby generator.

Distributions models	Mean	Parameters	
Gamma model (GM)	73.1800	β = 73.0118	∝ = 4.95359
Lognormal model (LM)	73.1946	μ = 73.1946	σ = 0.0692751
Weibull model (WM)	72.8383	β = 75.644	α = 13.7415
Nakagami model (NM)	73.1834	μ = 55.9597	Ω = 5, 379.79

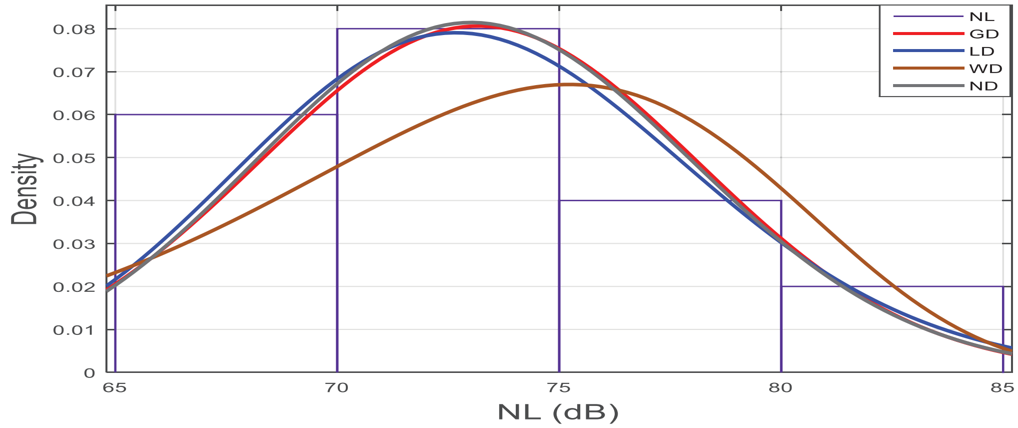

FIGURE 1 | Noise level measured with different probability models.

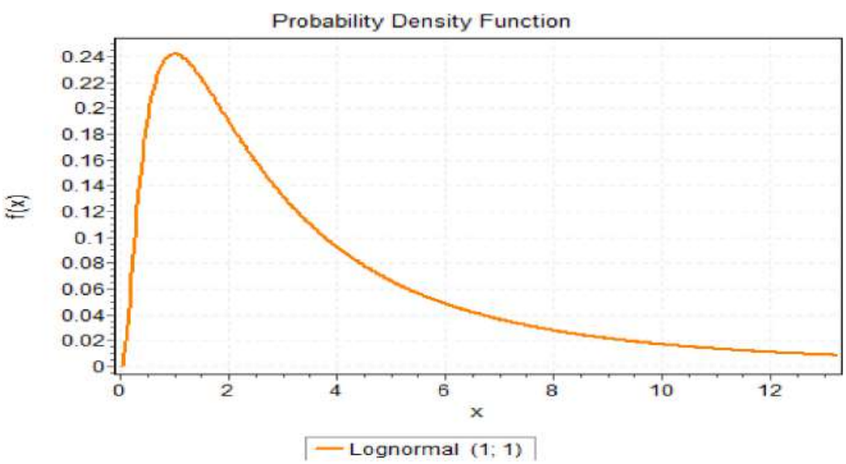

FIGURE 2 | Cumulative distribution function (CDF) of lognormal distribution function.

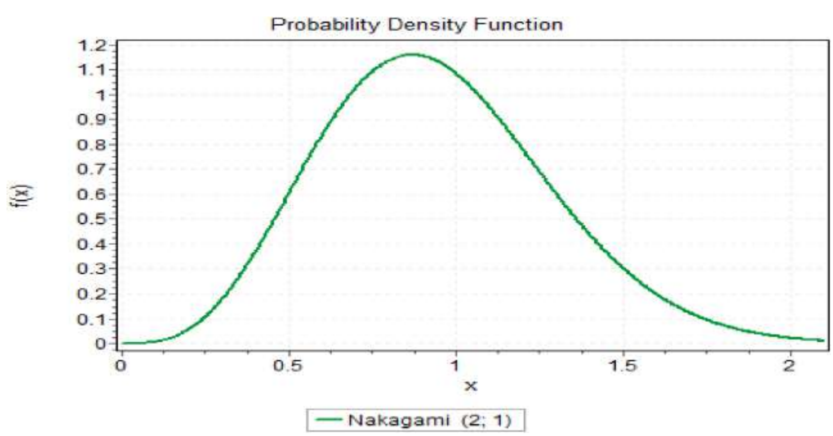

FIGURE 3 | CDF of Nakagami distribution function.

Table 3 presents the GoF statistics for the noise level modelled from the university generator using the K-S test and A-D test, respectively. The result from the K-S test presents the list GoF. The GM was found as the best fit model with the least of GoF statistic of 0.13805. The CDF of the GM was determined using Equation 7. However, modeling experts have reported that GoF explains the degree to which a set of data fits a specific model (19, 21, 22).

Table 4 shows the PECP for the university generator. If a student or staff member is exposed to noise pollution from the generator for more than 8 hours daily, it means that the noise level will increase by 62.54%.

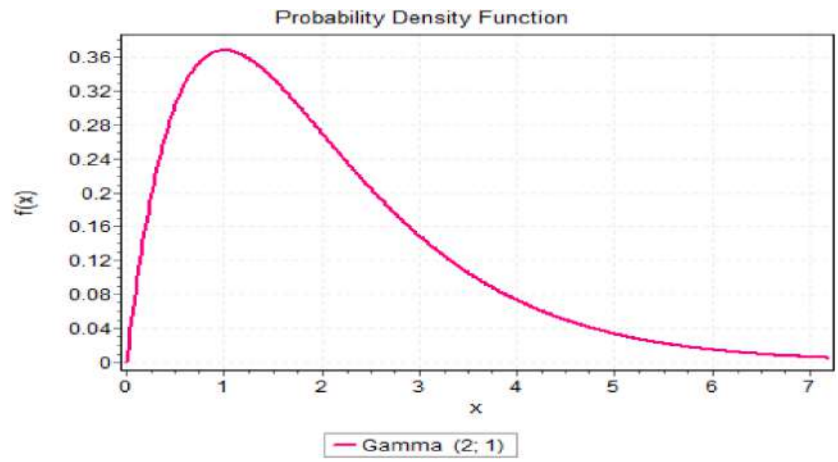

FIGURE 4 | CDF of gamma distribution function.

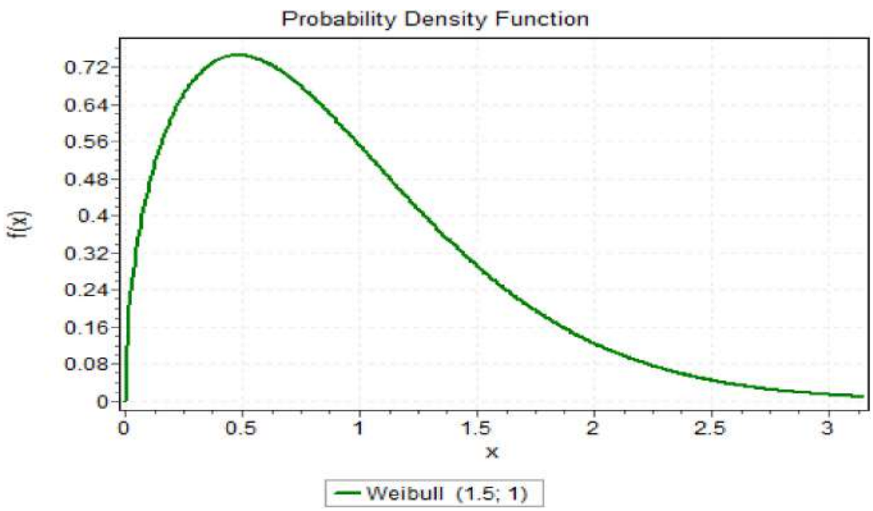

FIGURE 5 | CDF of Weibull distribution function.

TABLE 3 | Fitted distribution type and goodness of fit statistics.

Distributions	Kolmogorov-Smirnov test	Anderson-Darling test
Gamma	0.13805[a]	0.32400[a]
Lognormal	0.15709	0.37520
Weibull	0.14579	0.34620
Nakagami	0.14130	0.39454

[a]Connote the best fit model.

TABLE 4 | Probability of exceeding the critical point (PECP) for the university generator.

Distributions	$F(X)$	$F(X)\%$
ADSU GEN	0.81	81

Table 5 presents the comparison between the WHO standard values of the safety distance recommended and the noise level obtained. A positive sign indicates that exposure to noise from the generator for at least 8 hours may be detrimental to health (23), while a negative sign indicates that exposure to noise for 8 hours also may not cause health damage to both staff and students. Staff and students living within a range of 50 m from the generator will experience a mild hearing problem. However, the difference between two probabilities is often called the probability difference. This idea can be used to compare the probabilities of different events within probability distributions. The probability that a random variable is less than or equal to a particular value is shown by the CDF, such as 0 or 1, and it offers a summary of the variable's probability distribution. The instantaneous failure rate at a specific time is represented by the hazard function. In the meantime, the survival function is connected to the cumulative hazard function and is obtained from the integral of the hazard function over time, which connects the hazard to the survival function by accumulating it over time. Figures 6–10 present the probability difference, Weibull distribution's hazard function, cumulative hazard function, survival function, and CDF.

TABLE 5 | Comparison of noise level with corresponding environmental health hazards (3).

Diseases/health hazards	Noise (dB)	Noise level difference at university generator (dBA)	Exposure time (hour)
Hearing problem	70–75	+3	1–4
Hypertension	70	−3	8 daily
Heart disease	70	−3	8 daily
Annoyance	42	−31	16 daily
Performance	70	−3	8 daily
Sleep disturbance	<60	−13	Any time
Next day mode	<60	−13	10 daily

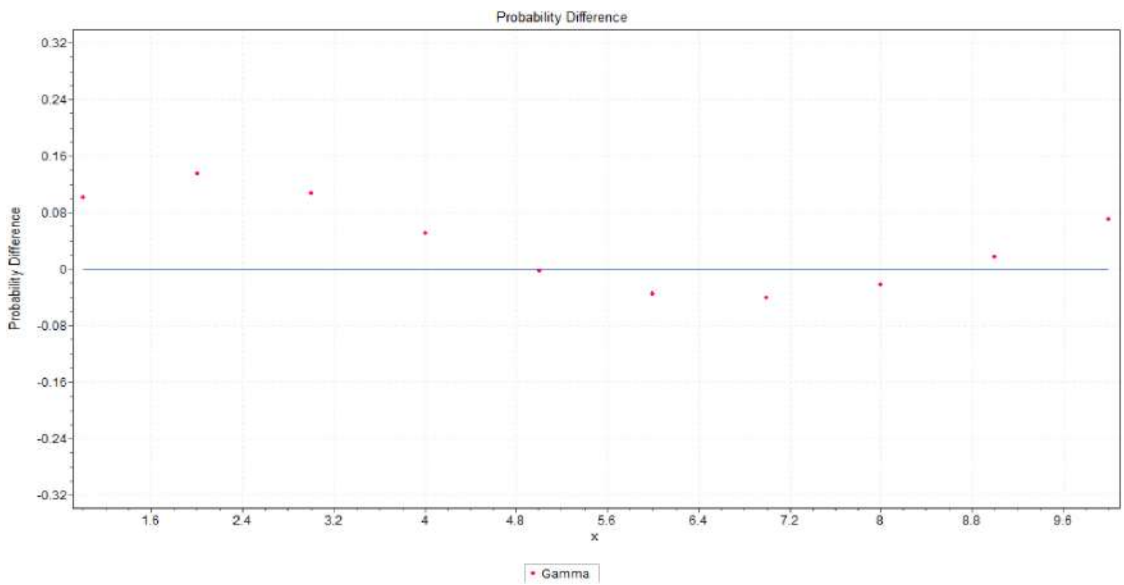

FIGURE 6 | Weibull probability difference.

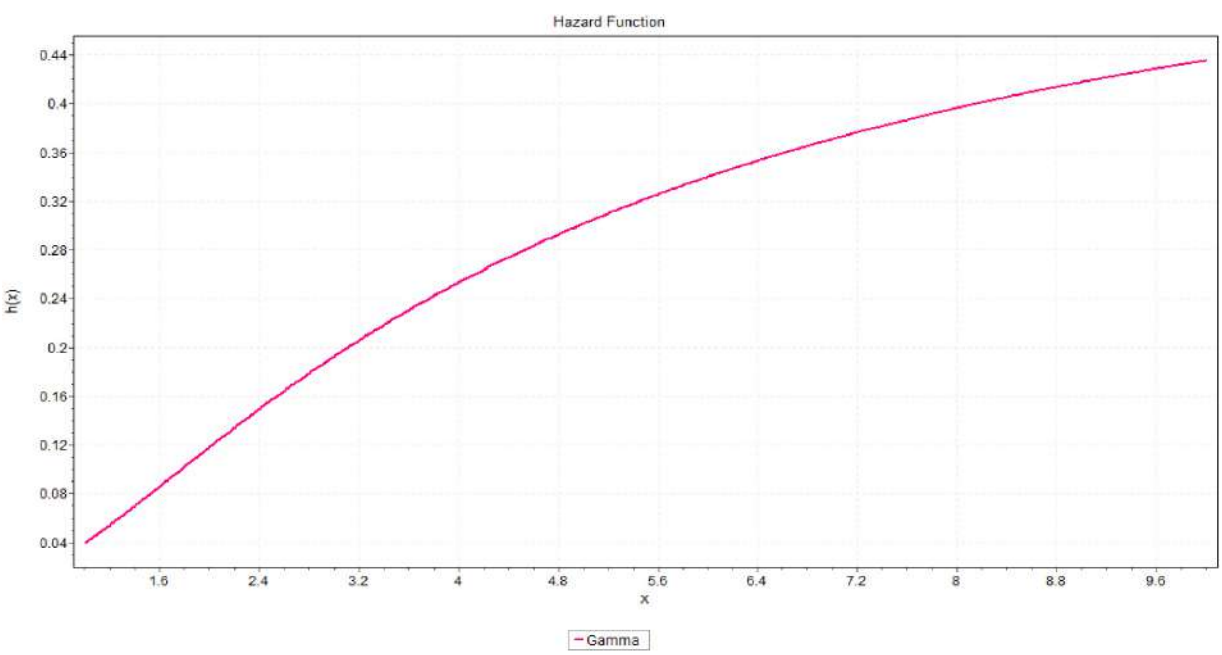

FIGURE 7 | Weibull hazard function.

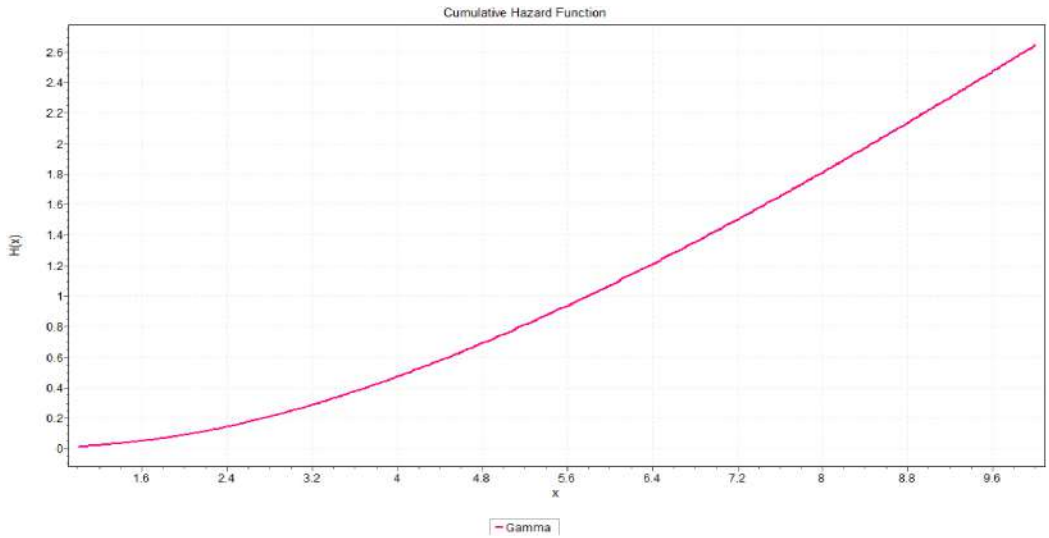

FIGURE 8 | Weibull cumulative hazard function.

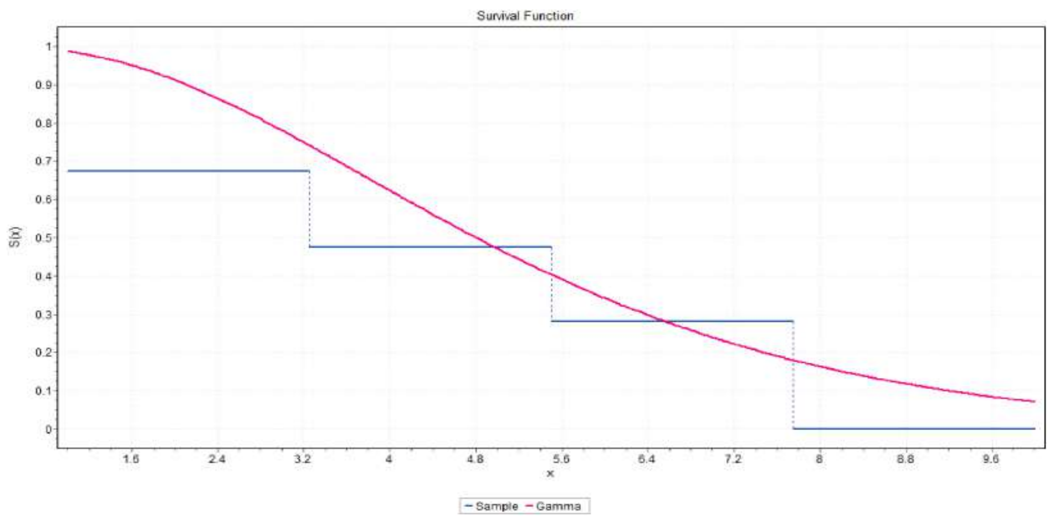

FIGURE 9 | Weibull survival function.

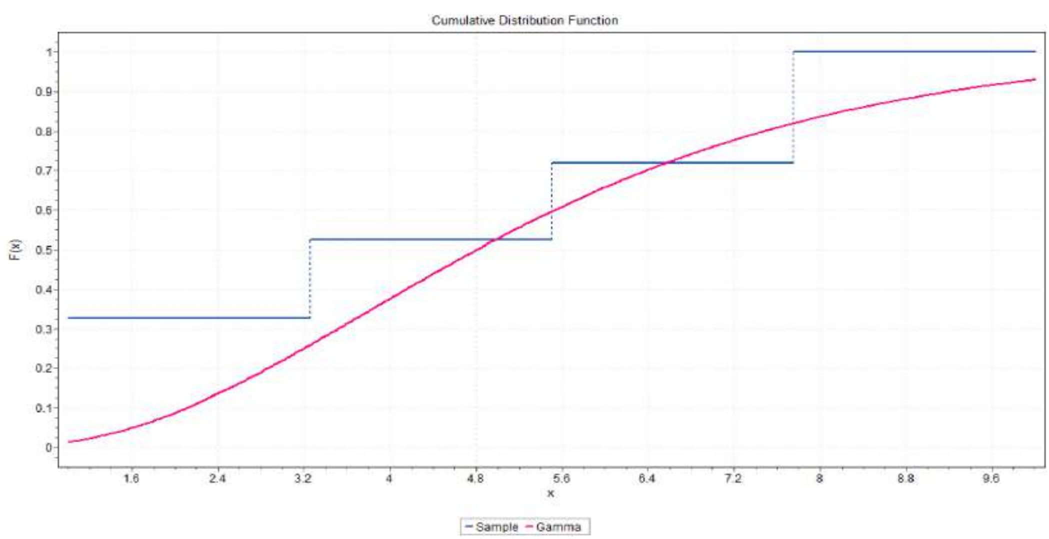

FIGURE 10 | Weibull CDF.

Conclusion

The noise level of the university's 500 kVA has been computed and modelled using multiple probability distribution models like the gamma, Nakagami, Weibull, and lognormal distribution functions. The mean of the noise level and the maximum likelihood parameters were calculated. The gamma distribution function was selected as the best-fit model. The PECPs were also determined as 81%. It was also found that staff and students living within a range of 50 m from the generator will experience a mild hearing problem when exposed to noise for 8 hours daily. Further studies are recommended to monitor the noise level in seasons so as to determine if the atmospheric weather conditions could have an impact on the noise level.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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