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Observation and Prediction of Noise Levels in Residential Areas Surrounding Power Generators in Najaf, Iraq

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ABSTRACT: The key objective of this work is to investigate the impact of noise from generators on a residential area in Najaf, Iraq and to determine the optimal distance between the generator and the residential area. To achieve this objective, predictions were conducted and observations were collected at 3 downwind distances (7 m, 20 m, and 50 m) from the generator on selected dates of winter and summer (Jan 25-28 and Feb 1 and 10 and June 13-14, 2025). The observations showed that when the generators were in operation, noise levels exceeded the Iraqi standard and WHO guidelines. However, when the generators were not in use but the national grid was in operation, noise levels were below the Iraqi standards, except for maximum levels. In the absence of noise from the generators and national grids, the noise levels were below the standards. The noise generally decreased by 8 dBA when moving from 7m to 20m from the generator, and by 3 dBA when moving from 20 to 50 m. There was a negative relationship between wind speed and temperature on one hand, and noise level on the other hand, with a correlation coefficient of 0.45 to 0.65 with wind speed and 0.65 to 0.7 with air temperature. In contrast, the correlation with the relative humidity was positive (0.68). Also, a simple model was applied to analyze noise dispersion over a domain of 400m. The optimal distance estimated by both modeling and linear regression to meet the Iraq daytime standard of 60 dBA is 75 m and to meet the Iraqi nighttime standard of 50dBA is 120m. The results showed the predicted LA_{eq} were overpredicted by 2% at 7m but underpredicted by 3% and 5% at 20m and 50m, respectively.

KEYWORDS: Noise pollution; Power generators, Urban noise modeling, Urban environment.

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1. INTRODUCTION

Noise is derived from the Latin word "nausea" and is often referred to as an unwanted or harmful outdoor sound created by human activity (Menkiti & Ekott, 2014 Singh & Davar, 2004). The World Health Organization (WHO) declared that noise pollution can be considered one of the most serious environmental issues in the world, following air and water pollution. WHO also reported that the acceptable noise level for daily exposure in residential areas is 55dB and can be set as a safety noise level for outside (Jarosińska *et al.,* 2018; Van Kempen *et al.,* 2018). WHO, (2011) recommended noise levels to be less than 30 dBA in bedrooms and less than 35 dBA in classrooms. Further, researchers have shown that exposure to a continuous noise level of greater than 55 dBA causes serious annoyance, while exposure to greater than 50 dBA causes moderate annoyance in residential areas (WHO, 2009). According to ASHA (2017), exposure to noise levels of 70dBA or higher for 8 hours or more is known to be hazardous for human hearing.

Noise pollution from industrial and commercial activities in urban areas represents a significant environmental hazard to public health (Sonibare et al., 2003; Vlachokostas et al., 2012). High noise level was discovered to cause sleep disturbances, high blood pressure, annoyance, stress, reduced productivity, cardiovascular and metabolic issues, and a decreased ability to concentrate (Abulude *et al.,* 2018; Sobotova et al., 2010; Mead, 2007; Dursun et al., 2006). Further, noise pollution adversely affects plant growth and development. The photosynthetic process can be disrupted by high noise levels, leading to reduced plant production (Abulude et al., 2018). Continuous exposure to high noise levels can also cause gradual damage to the eardrums, resulting in significant pain for the individual (Evandt *et al.,* 2017; Gori *et al.,* 2014; Oguntunde *et al*., 2019). When sleep disruption becomes chronic, the results are mood changes, decreased performance, and other long-term effects on health and well-being. On the other hand, acute noise exposure can cause nervous and hormonal responses, resulting in temporary increases in blood pressure, heart rate, and vasoconstriction (Goines & Hagler, 2007).

Environmental noise can arise from different sources, including traffic, power generators, and construction activities. However, electric power generators can be considered as a main noise source in residential areas, besides being sources of air pollution in the residential areas of Iraqi large cities. Operators of generators, workers, or residents who are staying very close to power generators are expected to expose to the noise levels of more than 90-115dB, causing psychological and organic influences with temporary or permanent hearing loss (Jadaan et al., 2016; Vladimir & Madalina, 2019). A previous study discussed in detail the impact of generators on the air quality surrounding the residential area. The present study aimed to study. 1) the impact of generator noise emissions on surrounding residential areas, 2) the optimal distance between a power generator and residential area, 3) the correlation between certain metrological parameters and noise level and 4) evaluate dispersion modeling results by comparing them with actual measurements of noise at one residential site.

2. MATERIAL AND METHODS

2.1 Sampling Site Description

The sampling was conducted at AlGadeer Residential Village (see table 1) in Najaf City, capital of Najaf Governorate, which is located about 160 km (99 mi) south of Baghdad. Najaf is at 32°1'33.38"N, 44°20'46.5"E and with an altitude **of 60 m above Mean Sea Level**. Najaf Governorate is a flat region extending from the Euphrates River in the northeast to the Saudi Arabian border in the southwest and has a total area of 28,824 km^2 and an estimated population of about 1,410,000 people in 2024. Najaf has a hot desert climate, with long, very hot summers and mild winters. Measurements of meteorological parameters for Najaf during one year from April 2015 to March 2016 (Hachim et al., 2017) showed that the overall maximum temperature could reach as high as 50.4°C occurred in July month and the minimum temperature as low as 0.9 °C occurred in January. The annual average temperature is 23.6 °C, and the rainfall averages 69 mm (2.71 in). The daily maximum solar radiation (1,071 W/m^2) was recorded in May, whereas the highest daily average solar radiation of 587 W/m^2 was recorded in June. The highest daily maximum wind speed was 16.3 m/s, noted in August, while the monthly average was 4.9 m/s, noted in January. Whereas the minimum wind speed of 0.2 m/s was noted in May, 2016.

The sampling sites were selected at three different distances (7m, 20m and 50m) from power generator and surrounded by residential neighborhoods (AlGadeer Village Residential Area) with no significant industrial sources nearby as shown in Fig.1. The measurements were carried out for about 15 minutes on each sampling point (7m, 20m, and 50m) during daytime, evening and night time in winter (Jan, 2025) and summer months (June, 2025). The coordinate of AlGadeer Village is shown in Table 1.

Table 1: Coordinates of sampling site in Najaf

Site name	Latitude	Longitude	Distances to the generator (in m)	Type
AlGadeer Village	32° 4'46.67"N	44°19'56.13"E	3, 30, and 50	Residential

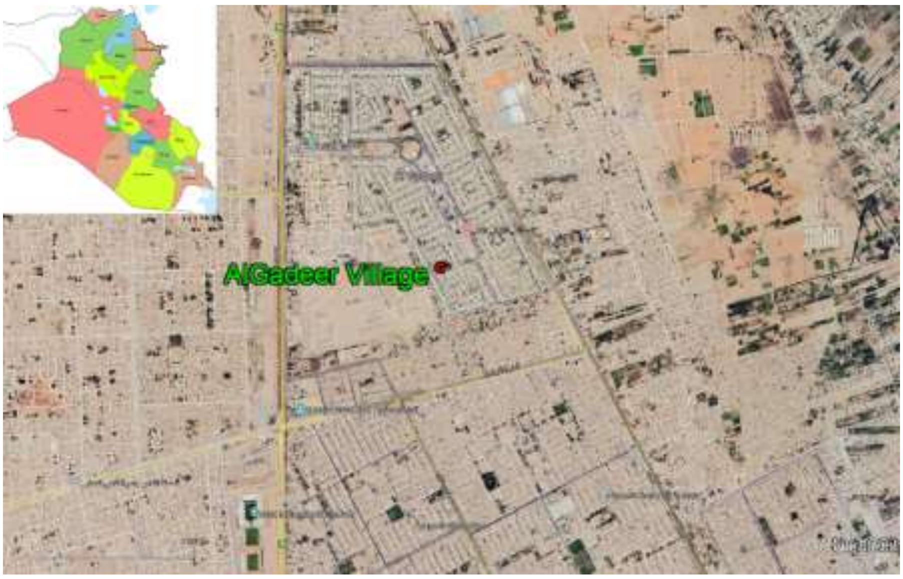

Fig. 1. Aerial image showing the location of Najaf on the Iraq map (top left with blue circle), and another image for the sampling site within Najaf city. Map of study area with location of noise source (red circle). (created in Google Maps, maps.google.com)

Figure 2 shows the four directions of the power generator to indicate the direction from which the measurement was taken, and the sampling points at different distances from the source.

Fig. 2. Four directions around the power generators at AlGadeer site and sampling points (red circle)

Fig. 3. Photographs of the sampling sites: from left to right, 7m, 20m, and 50m distance from the generators during day and night times.

2.2 Instruments

Noise level data were collected using state of a art instrument - a Cirrus Optimus Green Octave Band Analyzer CR-171b (North Yorkshire, UK) for measuring all sound levels. This model has both A and C weightings and a resolution of 0.1dB with fast/slow response. This instrument can measure in the range of 20 to 140 dBA and has an accuracy of ± 1.5 dBA. The Microphone was fitted with windshields and mounted on a tripod such that the microphone was at 1.5 m above the ground surface. The calibration for the instrument was conducted before and after each measurement, and no signal drift was noted to have occurred during any monitoring session. Calibrations were carried out at 93.7 dB(A) at a frequency of 1 kHz using a Cirrus Optimus acoustic calibrator CR-515 (North Yorkshire, UK) as shown in Figure 4. A summary of the main features of this sound meter is shown in Table 2. Additional meteorological data (ambient temperature, wind speed and direction, relative humidity, etc) was recorded using the ZWIN-WS06 Weather system from China. The weather system specification is shown in Table 3.

The following steps were applied when the noise was conducted:

1. The height of the microphone was about 1.5 m above ground level.
2. The distance between the microphone and the noise source was within 7 m.
3. Duration of noise level measurement was 15 min for each measuring period.
4. All measurements were undertaken well away from any existing building or walls that could provide some form of shielding or attenuation, or reflection of ambient noise.
5. The microphone was covered to protect against the effect of wind.

(a) (b) (c)

Fig. 4. Instruments used for monitoring noise: (a) Sound meter and (b) Sound meter with calibrator (CR-515), and (c) Meteorological parameters

Table 2: Sound Level Meter Specification Summary

Main Specification	**Details**
Applicable Standards	IEC 61672-1:2013 Class 1
Total Measurement Range:	20dB to 140dB RMS Single Range
Measurement Control	Different user-selectable durations of manual, 1 min, 5 min, 10 min, 15 min, 30 mins, 1 hour, Lden
Environmental	Temperature operation range: -10°C to +50°C, Temperature storage range: -20°C to +60°C Humidity operation range: Up to 95% RH Non Condensing
Measurement Functions	Statistical indicators: L_{XY}, L_{XYMax}, L_{XYMin}, L_{Xeq}, L_{CPeak}, L_{ZPeak}, L_{APeak}, L_{Ceq}-L_{Aeq}, L_{XE}, and L_{AIeq}

Table 3. ZWIN-WS06 Weather system specification summary

Monitoring parameters	**Measuring range**	**Accuracy**	**Resolution**
Ambient temperature	-40 to 85°C	±0.3°C@25°C	0.01°C
Air humidity	0-100%RH	±3%RH	0.01%RH
Wind speed	0.0 to 40m/s	0.01m/s	± (0. 5 +0.0 5 V) m/s
Wind direction	0-360°	0.1°	± 5 ° (wind speed＜10m/s)
Atmospheric pressure	500-1100hPa	±0.5hPa	0.1hPa

2.3 Power Generators in Residential areas

This study examines the noise emissions by two generators located at AlGadeer Residential area. Each generator provides service to a specific number of houses. Table 3 provides details specifications for the generator in AlGadeer residential area.

Table 4. Generator specifications used in this study

Residential area name	**Generator Manufacturing Co.**	**Generating Capacity (KVA)**	**Fuel consumed (lit/hr), at 75% load**
AlGadeer village	Perkins	550	65

Fig. 5. Power Generators considered in this study of Perkins/Cummins generator with Power Rating of 550 KVA

2.4 Noise Dispersion Model

CUSTIC 3.2 Noise Dispersion Model was applied in this study for predicting the noise impact from the power generator on residential areas in Najaf. CUSTIC model, produced by the Spanish company Canarina, offers the advantage of being a simple and low-cost software solution. However, it does not provide the same level of capability and precision as a complex noise dispersion model, since noise dispersion is a complex physical phenomenon involving various processes, such as turbulence, non-linear dynamics, and thermodynamics of irreversible processes. Nevertheless, the present model can be utilized as an indicative tool for basic modeling purposes in small urban areas (Hadzi-Nikolova & Mirakovski, 2012). The basis of this mathematical model is the linear sound propagation equation, which is used to model simple point source emissions from power generators, vehicles, industries, and aircraft (Hadzi-Nikolova & Mirakovski, 2012). The noise modeling is based on numerical algorithms that estimate noise dispersion in a free field, providing an approximate noise level regardless of the source type, whether it is a point, line, or area source. It calculates the noise level at each point in the space, taking into account each noise source and the atmospheric weather conditions (Hadzi-Nikolova & Mirakovski, 2012).

CUSTIC model works with two different models: the ISO-9613 for punctual sources and the classical CUSTIC model.
In our case, the ISO-9613 was selected because the ISO calculation is primarily used for point sources and takes into account humidity, temperature, and the solid angle for the source.
In addition to the above, the following inputs were assumed for running the CUSTIC model:

- Type of noise sources (power generators): considered as point sources, and the sound level from each source was assumed as 103dBA. This assumed value was based on previous studies. For example, Sellappan (2014) indicated that the noise level from a 500 kVA power generator is in the range of 104 dBA at 1.0 m from the generator. Another study by Buluklu et al. (2022) showed that a diesel generator generates a noise level before installing control devices in the range of 100-110 dBA at the source (0 meters).
- Terrain Options: It was assumed to be simple flat terrain.
- Calculations of noise dispersion were conducted at 1.5m above the ground
- Meteorology inputs: temperature was assumed as 25^{o}C and relative humidity as 35%. These values were taken as the average of all values for temperature and the average of relative humidity, as shown in Table 5
- Total distance in X-Axis (Scale): 400m
- Number of points in X-Axis (grid size): 200
- There are no noise barriers between the source and the receptors.
- Coefficient of attenuation of 1.12 Dba/100m;

Based on the above assumptions, the model calculates the noise levels and presents them in the form of isolines, a numerical grid, or color gradients.

2.5 Statistical Indices

The predications from the CUSTIC model were compared to the actual observations to evaluate its performance. Two statistical indices were used: fractional bias (FB) and the fraction of predictions within a factor of two of the observations (Fa2). Each of these measures has been defined by various authors (Kumar et al., 1999 and Gokhale et al, 2008) and is described as follows:

$$\text{Fractional Bias (FB)} = \frac{\overline{Leq}_o - \overline{Leq}_p}{0.5\,(\overline{Leq}_o + \overline{Leq}_p)} \qquad (5.1)$$

Where Leq_p is the prediction values, Leq_o is the actual observation, $\overline{Leq}$ is the average of all values. The value of FB varies between -2 for extreme overprediction and +2 for extreme underprediction, and it is zero for an ideal model prediction.

$$\text{Fa2} = \%\text{ of data that satisfy } 0.5 \le Leq_p / Leq_o \le 2 \qquad (5.2)$$

Fa2 is the percentage of modeling predictions that are within a factor of 2 of the actual observations. The model can be deemed acceptable if Fa2 is greater than or equal to 0.8.

3. RESULTS AND DISCUSSION

3.1 Analysis of the Noise Levels and Weather Condition

The noise levels and the meteorological parameters (ambient temperature, wind speed and direction, relative humidity) were monitored at the sampling site downwind of power generators within AlGadeer residential area in Najaf city (locations of sampling points are shown in Fig. 2) to identify the impact of power generators' noise on the surrounding residential areas. The analysis provided in this study is based on measurements collected during different times, which cover all day and night times (i.e., morning, noon, afternoon, evening, and night hours) on different dates in winter and summer of 2025.

Table 5 summarizes the weather conditions (ambient temperature, wind speed and direction and relative humidity) in the study area during the sampling period. The air temperature and relative humidity varied from approximately 10-18 ºC and 26-70% respectively during winter time and 35.4–47.5ºC and 8.3–21.6%, respectively during summer time. The wind speed varied from 2.0–4.9 m/s with an average of 3.8m/s during winter and 1.8–4.9 m/s with an average of 3.3m/s during summer time. The prevailing wind directions were westerly, northwesterly to northerly during all sampling dates.

Table 5. Hourly measurements for meteorological parameters during the sampling period (January 25, 26, and 28, February 1 and 10, and June 13, 2025)[a]

Season	Date	Date	RH[b] (%)	Temp[c] (C)	WS[d] (m/s)	WD[e]
Winter	25-1-2025	08-00am	70.0	10.0	2.7	310.0
	25-1-2025	10-30pm	67.0	12.0	2.0	340.0
	26-1-2025	11-45pm	45.0	16.0	7.5	325.0
	28-1-2025	12-00pm	40.0	17.0	3.6	305.0
	01-2-2025	03-30pm	26.0	18.0	4.9	300.0
	10-2-2025	05-30pm	43.0	13.0	2.2	345.0
Summer	13-6-2025	08-00am	18.0	37.0	2.5	290.0
	13-6-2025	03-00pm	09.0	46.0	4.9	318.0
	13-6-2025	06-00pm	10.0	43.0	4.0	317.0
	13-6-2025	11-30pm	18.0	35.0	1.8	311.0
Overall Average			34.6	24.7	3.6	316.1
Overall Minimum			9.0	10.0	1.8	290.0
Overall Maximum			70.0	46.0	7.5	345.0

[a] An Hourly measurement was calculated based on one-minute interval data, [b] Relative Humidity (R.H.), [c] Average Temperature (Temp), [d] Wind Speed (WS), and [e] Wind Direction (WD)

The noise levels were measured at varying downwind distances of 7, 20, and 50m from the power generators, covering daytime (07:00-19:00), evening time (19:00-23:00), and night-time (23:00-07:00) periods on selected days during summer and winter of 2025, as shown in Tables 6 and 7. The noise measurements include the following five scenarios:

- Scenario 1: Power generators were in operation during the wintertime
- Scenario 2: Power generators were not in operation, but the national grid provided power during winter times
- Scenario 3: Power generators were in operation during the summer times
- Scenario 4: Power generators were not in operation, but the national grid provided power during the summer times

- Scenario 5: both the power generators and the national grid were not in operation, representing the background level since there are no major noise sources except for natural sounds such as birds and wind in trees, along with intermittent noise from vehicles on the roads and dogs barking.

For all mentioned scenarios, the following noise levels were measured and/or calculated to describe the environmental soundscape in AlGadeer Residential area in Najaf city, as shown in Tables 5 and 6:

- LAeq: represents the equivalent continuous sound level over a period, reflecting the steady sound level that would contain the same acoustic energy as the A - A-weighted fluctuating sound measured over that period
- LAmax: is the maximum A-weighted sound level measured during the sampling period
- LAmin: is the minimum sound level measured during the sampling period, using "A-weighting", which aligns with human hearing sensitivity.
- LAF: indicates the sound level measured with a "Fast" time constant, which responds quickly to changes in sound
- LAF1: is the noise level exceeded for only 1% of the measurement period, indicating very short, high-level noise events.
- LAF10: is the noise level exceeded for 10% of the measurement period.
- LAF50: represents the noise level exceeded for 50% of the measurement period, indicating the middle point of the noise range during the measurement.
- LAF90: is the noise level exceeded for 90% of the measurement period.
- LAF95: represents the noise level exceeded for 95% of the measurement period.
- LAF99: represents the noise level exceeded for 99% of the measurement period, indicating the noise level exceeded for nearly all of the time.

3.2 Statistical Results of noise measurements compared with Iraqi and WHO standards under different scenarios:

Scenario 1: Under this scenario, when the generators are in operation, all noise levels (highlighted in light gray) at all distances and times exceed the Iraqi standard of 60 dBA for daytime and 50 dBA for nighttime (Table 6). Moreover, these levels exceed the WHO guideline limits of 55dBA for daytime and 45dBA for nighttime. The LA_{eq} values at 7m distance from the generator are higher compared to those at other distances, with the highest value (77.2 dBA) recorded in the afternoon, as compared to noon and evening. The LA_{eq} at 20m (69.5 dBA) and 50m (67.5 dBA) from the generator are higher than those recorded at noon and afternoon. The remaining statistical noise indicators (LA_{max}, LA_{min}, LAF_1, etc) are generally higher in the afternoon, although some indicators are higher at 50m during the evening due to dogs barking. The projected 8-hour exposure at different distances from generators and at various times exceeds both the Iraqi standard and the WHO limit. Therefore, the risk to human health from the noise during this scenario is considered to be high unless some control measures are implemented.

Scenario 2: All values under this scenario, when the generators are not in use, are below the Iraqi standards, except for all maximum noise levels (LA_{max}) and some LAF1 values, which exceed both the Iraqi and WHO limits for both daytime and nighttime (Table 6). However, although most indicator values (LA_{eq}, LA_{min}, LAF_5, etc) during morning and afternoon times fall within the Iraqi standards, most noise values still exceed the WHO limit. Further, the projected exposure value for 8 hours at different distances from generators and at different times is below both the Iraqi standard and the WHO limits during daytime, except morning at a 7m distance. However, the values (bold text) exceed the WHO limit during daytime and nighttime. High noise values that are exceeding the Iraqi standards and WHO limits during evening and nighttime times, primarily due to dogs barking. Therefore, if the Iraqi standards are considered, the risk to humans from the noise in this scenario is considered to be low to moderate.

Table 6. Noise results at AlGadeer Village in Najaf during wintertime (January 2025) (All values in gray color exceed the Iraqi standard of 60dBA)

	Scenario 1: With Generators[1]											
	Noon (Jan 28)			**Afternoon (Feb 1)**			**Afternoon (Feb 10)**			**Evening (Jan 25)**		
	7m	**20m**	**50m**	**7m**	**20m**	**50m**	**7m**	**20m**	**50m**	**7m**	**20m**	**50m**
LA_{eq}	74.8	67.6	ND	77.2	69.2	66.0	77.1	68.9	66.6	74.9	69.5	67.5
LA_{max}	78.0	75.5	ND	79.7	74.4	75.4	79.6	72.0	87.5	78.2	79.3	71.1
LA_{min}	71.0	42.3	ND	73.8	64.6	57.3	73.4	64.6	60.1	67.3	66.4	63.2
LAF_1	76.7	72.4	ND	79.0	71.9	70.3	79.1	71.3	74.5	76.8	74.2	70.2
LAF_5	76.3	70.3	ND	78.7	71.5	68.5	78.8	70.9	68.6	76.4	70.7	69.5
LAF_{10}	76.1	69.9	ND	78.6	71.1	68.1	78.7	70.7	67.9	76.1	70.3	69.1
LAF_{50}	74.7	67.1	ND	77.0	68.8	65.7	77.0	68.5	65.2	75.1	69.2	67.4
LAF_{90}	72.9	63.2	ND	75.1	66.4	61.6	74.6	66.4	61.6	72.3	67.9	64.8
LAF_{95}	72.6	**51.7**	ND	74.9	66.0	61.0	74.3	66.1	61.2	70.6	67.6	64.4
LAF_{99}	72.1	45.8	ND	74.5	65.5	**59.5**	74.0	65.6	60.8	69.0	67.3	64.0

Projected Exposure for 8-hour												
8-Hour	74.8	67.6	ND	77.2	69.2	66.0	77.1	68.9	69.8	74.9	69.5	67.5
	Scenario 2: Without Generators (only national grid in operation)											
	Morning (Jan 25, 2025)			**Afternoon (Jan 28)**			**Evening (Feb 1)**			**Night (Jan 25)**		
	7m	**20m**	**50m**	**7m**	**20m**	**50m**	**7m**	**20m**	**50m**	**7m**	**20m**	**50m**
LA_{eq}	**56.0**	**54.3**	**53.0**	44.1	**50.1**	**51.0**	ND	ND	**54.7**	**54.9**	**51.9**	63.0
LAF_{max}	89.0	80.8	60.1	60.4	72.7	72.2	ND	ND	73.1	76.9	64.3	83.6
LAF_{min}	47.9	49.5	48.7	39.0	41.9	42.8	ND	ND	**45.4**	**45.5**	**45.8**	**47.2**
LAF_1	**59.7**	**57.2**	**56.2**	**52.7**	60.1	62.2	ND	ND	64.8	69.1	**59.0**	77.1
LAF_5	**54.7**	**55.5**	**55.1**	47.0	**55.7**	**55.4**	ND	ND	**59.7**	**54.7**	**55.4**	69.7
LAF_{10}	**53.1**	**54.9**	**54.5**	45.2	**52.7**	**51.7**	ND	ND	**57.0**	**51.4**	**53.5**	**58.8**
LAF_{50}	**50.9**	**53.3**	**52.6**	42.4	46.6	46.9	ND	ND	**50.7**	**49.2**	**50.8**	**51.4**
LAF_{90}	49.7	**51.8**	**50.6**	41.0	44.4	45.3	ND	ND	**48.1**	**47.8**	**48.8**	**49.8**
LAF_{95}	49.4	**51.4**	**50.5**	40.6	43.9	44.8	ND	ND	**47.6**	**47.5**	**48.3**	**48.9**
LAF_{99}	48.9	**50.8**	49.9	40.1	43.1	44.0	ND	ND	**46.9**	**46.7**	**47.1**	**48.0**
Projected Exposure for 8-hour												
8-Hour	**56.0**	54.3	53.0	44.1	50.1	51.0	ND	ND	**54.7**	**54.9**	**51.9**	**63.0**
	Scenario 5: Background -Without Generators or National Grid (i.e., There are no noise sources)											
	Morning (Jan 26)											
	20m						50m					
LA_{eq}	45.9						45.9					
LA_{max}	71.8						61.6					
LA_{min}	40.4						41.2					
LAF_1	53.8						**56.8**					
LAF_5	47.6						48.1					
LAF_{10}	46.4						46.3					
LAF_{50}	44.3						43.7					
LAF_{90}	42.5						42.7					
LAF_{95}	42.1						42.4					
LAF_{99}	41.3						41.9					
Projected Exposure for 8-hour												
8-Hour	45.9						45.9					
Maximum Allowable Noise Limits (dBA)												
Iraqi Permissible Noise limit for residential areas within the city, according to Iraqi Law no. 41, 2015: • Day time = 60 dBA • Night time = 50 dBA WHO Recommended Noise Limit for Outdoors: • Day time = 55 dBA • Night time = 45 dBA												

[1] values shaded with light gray are exceeding both Iraqi and WHO limits, while bold values are exceeding only the WHO limit.

Scenario 3: The noise levels in this scenario during summer are similar to those in the winter. However, it is noted that the noise levels are generally higher in the summer compared to the winter for two possible reasons. First, there is a higher electricity demand, meaning the generators operate under higher loads. Second, the higher temperature in summer leads to lower air density, causing the sound to dissipate more quickly. All noise indicators (LA_{eq}, LA_{max}, LA_{min}, LAF_1, LAF_5, et) during all times-during morning, afternoon, evening, and at night, are higher than both Iraqi and WHO limits for both daytime and nighttime. The projected 8-hour exposure for all different distances from generators and at different times is above the Iraqi standard and the WHO limit. The potential harm from noise to human health in this scenario is considered high unless some control measures are implemented.

Scenario 4: All maximum noise values (LA_{max}) and all LAF_1 are above the Iraqi standards and WHO limits for both day and night times. However, the other noise indicators (LA_{eq}, LA_{min}, LAF_5, LAF_{10}, etc.) in the morning and afternoon are within the limits of both the Iraqi standards and the WHO limit. Nevertheless, during the night, the noise indicator values surpass the WHO limit. Furthermore, the projected 8-hour exposure values are below both the Iraqi and WHO limits during daytime. However, some noise levels exceed these limits during the evening and night, mainly due to dogs barking. As a result, the risk to human health from the noise in this scenario is considered to be low to moderate.

Scenario 5: This scenario represents the background noise equivalent levels, which reflect the existing noise environment in the absence of noise from the power generators or national grids. It is characterized by low noise levels, primarily dominated by natural sounds such as insects, birds, and wind in the trees. Moreover, there is intermittent noise from vehicles on roads and some nearby construction works. However, the Leq levels are well below both the Iraqi standards and the WHO Guidelines for avoiding critical human health effects during daytime, except for one value exceeding the Iraqi standard and two values above the WHO limits due to sound from dogs barking. As a result, the risk to human health from the noise during this scenario is considered to be very low.

Table 7. Noise results at AlGadeer Village in Najaf during the Summer time (June 2025)

	Scenario 3: With Generators											
	Morning (June 13)			**Afternoon (June 13)**			**Evening**			**Night (June 14)**		
	7m	20m	50m	7m	20m	50m	7m	20m	50m	7m	20m	50m
LA_{eq}	78.7	70.8	66.4	81.1	72.7	67.3	ND	ND	ND	82.0	74.4	69.0
LA_{max}	81.3	74.2	69.3	82.4	77.7	78.6	ND	ND	ND	88.0	79.5	81.8
LA_{min}	74.7	65.1	62.2	79.9	69.5	63.6	ND	ND	ND	80.4	72.2	66.4
LAF_1	80.5	73.6	68.8	81.8	74.3	71.1	ND	ND	ND	82.6	75.8	72.4
LAF_5	80.3	72.9	68.3	81.6	73.9	69.1	ND	ND	ND	82.4	75.3	69.9
LAF_{10}	80.1	72.7	68.0	81.5	73.7	68.6	ND	ND	ND	82.3	75.2	69.6
LAF_{50}	78.3	70.7	66.3	81.0	72.6	66.9	ND	ND	ND	81.9	74.3	68.7
LAF_{90}	77.1	66.7	64.1	80.5	71.1	65.3	ND	ND	ND	81.5	73.1	67.7
LAF_{95}	76.8	66.3	63.6	80.4	70.8	65.1	ND	ND	ND	81.4	73.0	67.4
LAF_{99}	75.7	65.9	63.1	80.2	70.3	64.6	ND	ND	ND	81.2	72.7	67.0
Projected Exposure for 8-hour												
8-Hour	78.7	70.8	66.4	81.1	72.7	67.3	82.0	74.4	69.0	ND	ND	ND
	Scenario 4: Without Generators (only the national grid in operation)											
	Morning (June 13)			**Afternoon (June 13)**			**Evening**			**Night (June 14)**		
	7m	20m	50m	7m	20m	50m	7m	20m	50m	7m	20m	50m
LA_{eq}	**55.6**	52.9	52.8	**55.5**	53.2	**56.4**	ND	ND	ND	**57.5**	63.5	**57.2**
LAF_{max}	72.1	71.8	74.7	69.1	70.4	85.0	ND	ND	ND	73.8	90.7	77.7
LAF_{min}	53.5	46.8	47.4	54.1	48.5	48.7	ND	ND	ND	**49.2**	**48.6**	**49.1**
LAF_1	63.8	62.5	60.9	**58.5**	62.3	65.8	ND	ND	ND	68.1	77.2	69.7
LAF_5	**56.5**	**56.0**	54.2	**56.3**	**57.5**	60.1	ND	ND	ND	63.0	68.3	62.1
LAF_{10}	**55.6**	**53.9**	**52.8**	**55.9**	**54.8**	**57.8**	ND	ND	ND	**55.6**	62.7	**56.6**
LAF_{50}	54.6	50.6	50.8	**55.3**	**50.8**	52.4	ND	ND	ND	**54.9**	**50.5**	**50.9**
LAF_{90}	54.2	49.1	49.2	54.8	49.6	50.5	ND	ND	ND	**54.5**	**49.6**	**50.2**
LAF_{95}	54.1	48.8	48.8	54.7	49.4	50.2	ND	ND	ND	**54.4**	**49.4**	**50.0**
LAF_{99}	53.9	48.2	48.2	54.5	49.1	49.6	ND	ND	ND	**54.2**	**49.1**	**49.7**
Projected Exposure for 8-hour												
8-Hour	**55.6**	52.9	52.8	**55.5**	53.2	**56.4**	ND	ND	ND	**57.5**	**63.5**	**57.2**
Maximum Allowable Noise Limits (dBA)												
Iraqi Permissible Noise limit for residential areas within the city, according to Iraqi Law no. 41, 2015: • Day time = 60 dBA • Night time = 50 dBA												
WHO Recommended Noise Limit for Outdoors: • Day time = 55 dBA • Night time = 45 dBA												

3.3 Time series of LAeq at 50m distance compared with Iraqi standard and WHO guideline

The equivalent noise levels (Leq) were compared for three different conditions- with generators, without generators (i.e., with national grid), and background (i.e., no generators nor national grid)- at a 50m distance, which is closest to the residential houses. The comparison is made according to the Iraqi standards and WHO guidelines for both day and night times during winter and summer, as shown in Figures 6 and 7. The background values are not shown during the evening and nighttime because they were only recorded during the daytime.

In the wintertime, it is clear from these figures that when the generators are in operation, the noise levels at 50m distances exceed both the Iraqi and WHO limits at all times (i.e., morning, afternoon, and evening). This indicates there will be an impact on the residential area whenever the generators are in use. On the other hand, when there are no generators (i.e., the national grid is in use), most of the LA_{eq} noise values are below the Iraqi standard during daytime, although they exceed the WHO guideline. However, during evening and nighttime in both winter and summer, the noise levels exceed the Iraqi standard due to dogs barking. The background levels are mostly below both the Iraqi and WHO limits because there were no present noise sources under this condition.

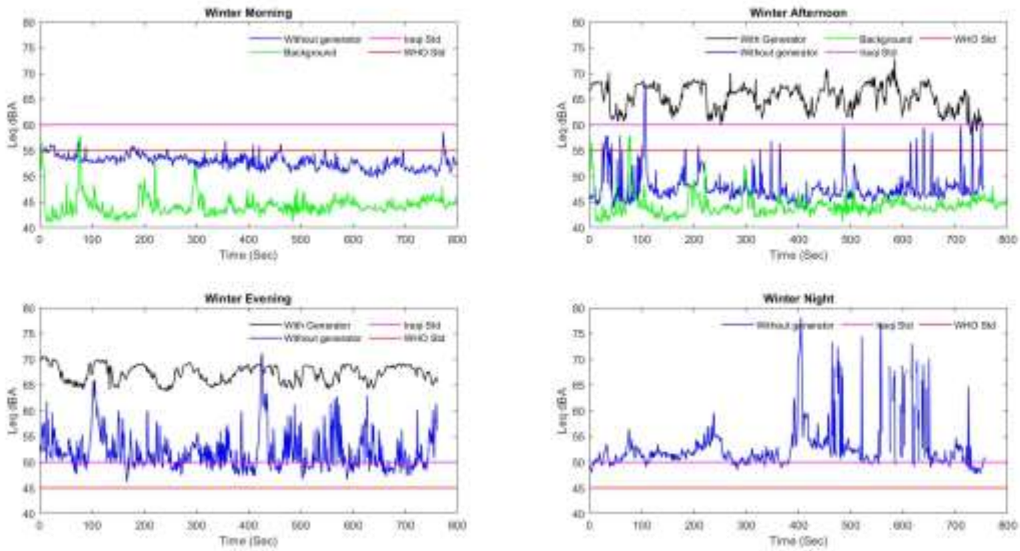

Fig. 6. Comparison of equivalent noise levels (Leq) under different conditions, compared to Iraqi and WHO limits, with and without the generators' operation, as well as background levels during various times in winter 2025.

In the summer, the equivalent noise levels (Leq) at a 50m distance were far above the Iraqi and WHO limits for both day and night when the generators were in use. During the morning, the noise levels without generators were below the Iraqi standard and the WHO guidelines, although there were some exceedances of the latter limit. In the afternoon, there were some exceedances on the Iraqi standard of 60 dBA and many exceedances on the WHO guideline due to construction activities. The noise levels during nighttime were above both the Iraqi and WHO limits due mainly to dogs barking**.** The background values were below the Iraqi and WHO limits, except for two values at all times.

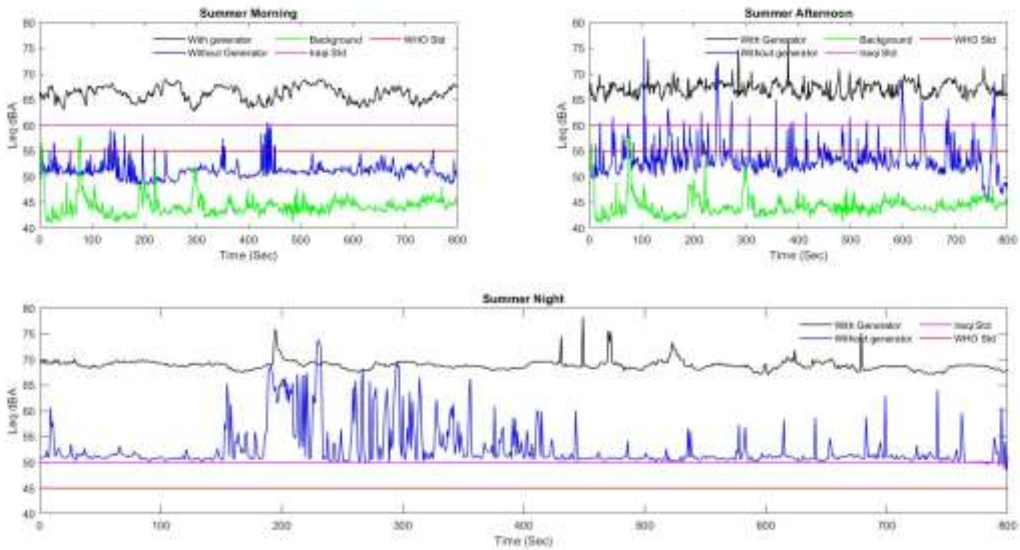

Figure 7: Comparison of noise levels under different conditions, compared to Iraqi and WHO limits, with and without the generators' operation, as well as background levels during various times in summer 2025.

3.4 Trend of Noise levels with downwind distance from the generator

The noise level decreases as the distance from the generators increases due to the natural attenuation of sound over distance (Figure 8). Moreover, the noise levels decrease during different times of the day and time in winter and summer, from 7m to 50m from the generators. This clearly shows a negative correlation between noise intensity and down-distance from the source. It can be concluded from the results that the decrease in noise level during summer is generally greater compared to winter. This suggests that weather conditions, mainly ambient temperature, affect this trend, possibly due to higher demand during the summer time. The noise level generally decreased from about 77 to 68dBA during winter and from 82 to 71dBA when moving from 7m to 20m downwind from the noise source. However, the noise level decreased from 68 dBA to 65 dBA during winter and from about 72 dBA to 66 dBA during summer when moving from 20m to 50m, which is generally less compared to that of 7m to 20m. This indicates that as we move farther from the source, the decrease in noise level becomes smaller.

The findings of this study are consistent with the results concluded by Ekott, E. E. (2018), who investigated the safe distance for installation of a 500 kVA power generator in a residential area. The author noted that the noise level decreased from 80.2 dBA at 5m to 73.8 dBA at 20m, and 63 dBA at 50m from the generator. Additionally, a study by Othman & Sabr (2025) showed that the noise levels ranged from 54 dBA at a 60 m to 92 dBA near the generator site.

The maximum decrease was observed during summer, while the minimum was noted during winter. On average, considering all times, the decrease in noise level is about 8 dBA when moving from 7m to 20m, and 3 dBA when moving from 20 to 50 m.

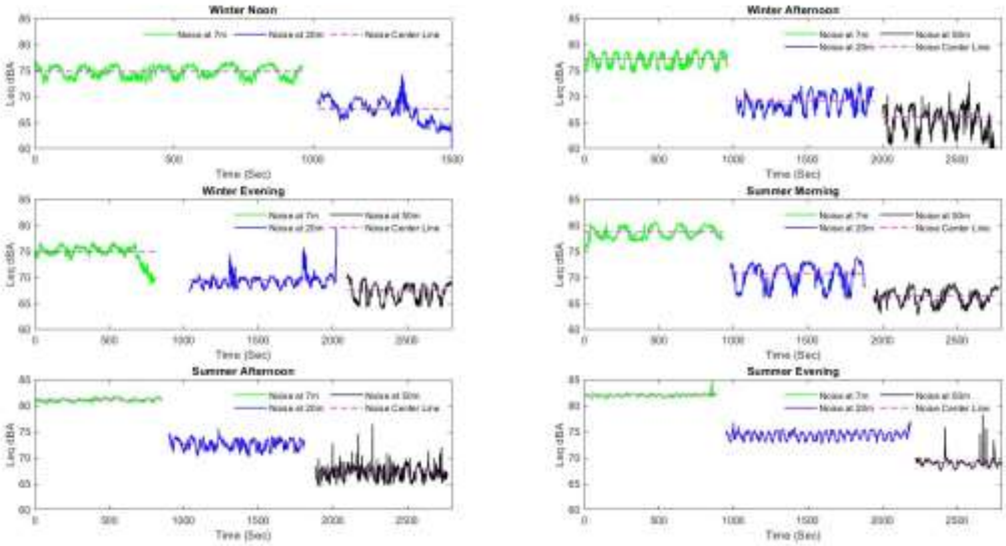

Fig. 8. Effect of distance increase (from left to right) on equivalent noise levels (Leq) from generators during various times of morning, noon, afternoon, and evening in winter and summer time, 2025

Based on the data collected for noise levels with downwind distance from the generator, linear regression was plotted as shown in Figure 9. The linear equation for the relationship between noise level and distance from the generator is also shown in Figure 8. The R^2 value for this relationship is 0.67. Using the linear equation, shown in the figure, it is suggested that the minimum distance for the generator to be located from the nearest residential area, to comply with the Iraqi standard of 60 dBA during the day and 50 dBA at night, is 120 m. However, to comply with only the daytime standard of 60 dBA, the minimum distance is 75m downwind from the source. These findings for daytime are consistent with the study conducted by Ekott et al. (2019), who investigated the safe distance for installing a 500 kVA electric generator in a residential area. The author concluded that such a generator should be installed beyond a distance of 65 m from residential areas.

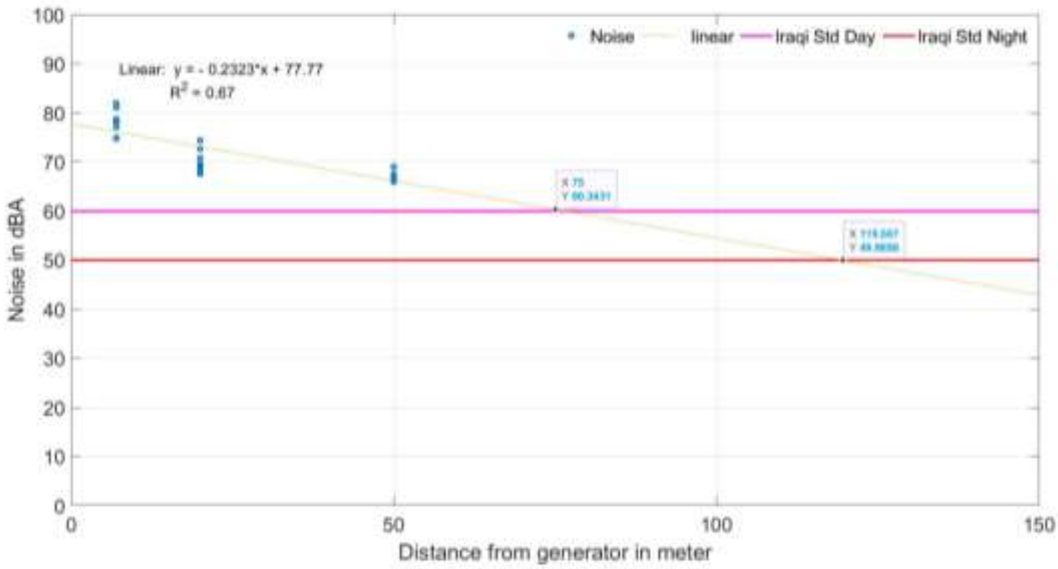

Fig. 9. Linear regression between noise level and downwind distance from the generators

3.5 Correlation between noise level (LAeq) and meteorological parameters

Continuous measurements of noise and meteorological parameters (wind speed, temperature, and relative humidity) were taken at one-minute intervals over 24 hours during both summer (June 13, 2025) and winter (Feb 10, 2025) to investigate the correlation between noise levels and these meteorological parameters. The noise measurements were taken at a location relatively far from any power generator to avoid interference from abnormal noise sources, with the main continuous noise sources being traffic, birds, and the sound of trees. The correlation between LA_{eq} and the meteorological parameters is shown in Figure 10 for winter and Figure 11 for summer. From these figures, we can observe that there is an inverse/negative correlation between wind speed and noise level (LAeq) during both winter and summer, as shown in Figures 10 and 11. The linear relationship between LA_{eq} and wind speed is statistically significant ($p < 0.001$), with negative correlation coefficients of -0.45 in winter and -0.6 in summer. This indicates that as the wind speed increases, the noise level (LA_{eq}) decreases.

As for the temperature, the results show an inverse, or negative, relationship between LA_{eq} and ambient temperature, with a correlation coefficient of -0.7 in winter and -0.65 in summer. This indicates that higher temperatures are associated with a decrease in LA_{eq}. This effect is likely due to the influence of temperatures on the medium through which sound travels. In contrast, there is a positive correlation between relative humidity and noise level (LA_{eq}) during both winter time and summer time, as is clear in figures 10 and 11. The correlation coefficients between relative humidity and noise level were 0.67 in winter and 0.7 in summer. This means that as the relative humidity increases, the noise level (LA_{eq}) increases.

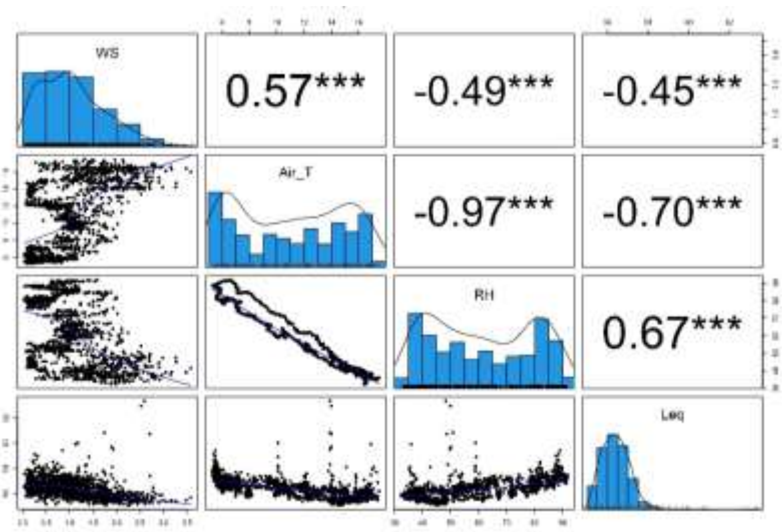

Figure 10. Correlation plot during Feb 10, 2025 sampling date, (n = 1440). The significance level was calculated using Spearman's correlation coefficient (rho). *, **, and * refer to p-values <0.001, <0.01, and <0.05, respectively. Variables include WS (wind speed, m/s), Air_T (air temperature, °C), RH (relative humidity, %), and LA_{eq} (noise level, dBA).**

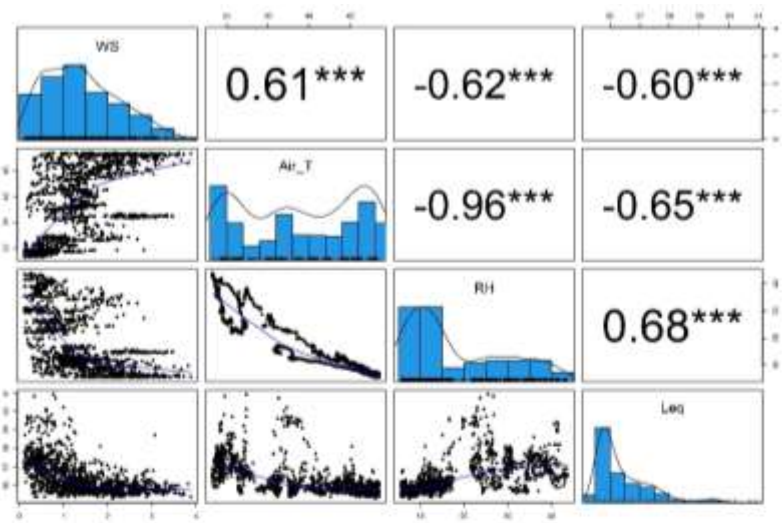

Figure 11. Correlation plot during June 13, 2025 sampling date, (n = 1440). The significance level was calculated using Spearman's correlation coefficient (rho). *, **, and * refer to p-values <0.001, <0.01, and <0.05, respectively. Variables include WS (wind speed, m/s), Air_T (air temperature, °C), RH (relative humidity, %), and LA_{eq} (noise level, dBA).**

3.6 Noise Modelling Results

Prediction of noise

To enhance the understanding of noise levels caused by power generators in the Al-Gadeer residential areas and to assess their contribution to the existing noise levels, the CUSTIC noise model, considered a simple model, was applied to analyze the dispersion of noise over about 400m domain. The methodology used in this model was based on the International Organization for Standardization (ISO) 9613, which addresses Acoustics – Attenuation of sound during outdoor propagation **(ISO, 1996)**. The modeling results were compared with the observations at three selected distances from the power generator (7m, 20m, and 50m). The inputs for the modeling runs considered the following main factors: two power generators as point sources, weather conditions (ambient temperature and relative humidity), ISO 9613 model calculation, noise calculations at a height of 1.5m, and other factors as explained earlier.

The predicted equivalent noise levels (LA_{eq}) over AlGadeer residential village in Najaf, caused solely by the operation of two generators, without including background noise from other sources, and considering the inputs mentioned earlier (Figure 12). The highest predicted noise level, occurring close to the generator, is 91 dBA. The predicted values at sampling points 1, 2, and 3 are 79.7 dBA, 68.7 dBA, and 63.8 dBA, respectively. The distance estimated by both modeling and linear regression to reach the Iraq standard for daytime (60 dBA) is nearly the same, approximately 75 m. However, the distance estimated by modeling to meet the Iraqi standard for nighttime (50dBA) is about 150 m, which is greater than the distance estimated using the linear regression equation, which is about 120m. A study by Ekott & Udokang (2023)) on determining the safe acoustic distance for installing a 635 kVA soundproof power generator in a residential area revealed that the maximum noise level of the generator was 76.9 dBA. The study also found that the generator's adverse effects extended beyond a distance of 70 m, leading to the conclusion that it should be installed at least 80 m away from any residential area. Another study showed that when the generator was turned off, the ambient noise level was below the WHO guideline of 55 dBA for a non-work environment. However, when the generator was turned on, its noise had adverse effects extending beyond a distance of 65 m. This is because at this distance (65 m) from the generator, the generator's sound level was 56.9 dBA, which is greater than the WHO guideline. The authors recommended that this type of generator should be installed at a distance of 70 m from residential areas.

Figure 12. Predicted noise pollution map (isolines) in decibels dBA over AlGadeer Residential village in Najaf, Iraq

By comparing the prediction with observations at three sampling points (Figure 13). The model can predict the equivalent noise levels (LA_{eq}) with high accuracy, as indicated by an R^2 value of 99.9%. This suggests that the contributions from other sources, such as traffic or animals, are minimal when the power generators are in use. It is important to note that the observations reflect contributions from all sources, including generators, whereas the prediction accounts only for the generator's contribution. More details on statistical analysis comparing predictions to observations are shown in Table 6.

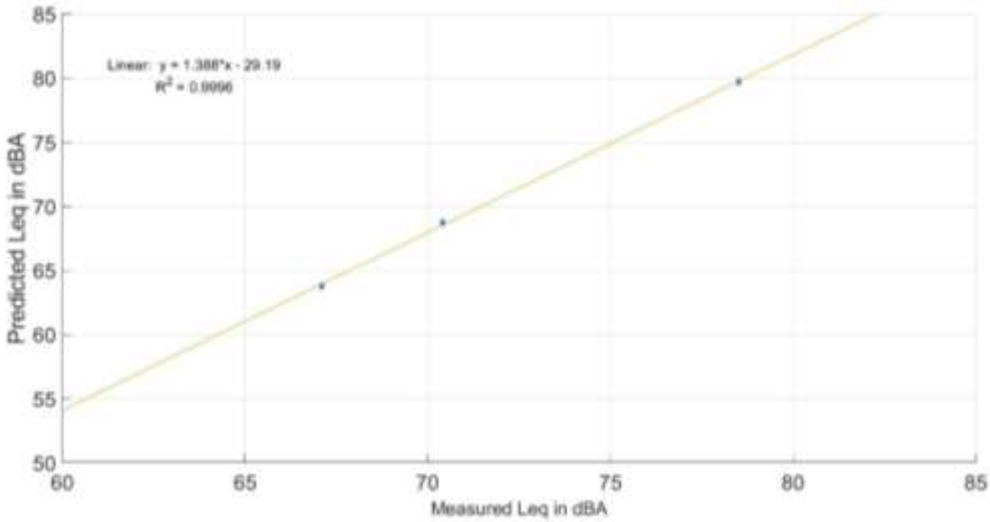

Fig. 13. Prediction vs measurements in dBA (?)

Figure 13. depicts the predicted and measured Leq values, illustrating the accuracy of the generated prediction model based on the R2 values from three sampling points.

Based on the above-mentioned results of this study, it is recommended that the minimum safe distance between a power generator and any residential building should be at least 75m to comply with the Iraqi daytime standard of 60 dBA. For compliance with the Iraqi nighttime standard of 50 dBA, the recommended minimum distance should be at least 120m. The results of this study are consistent with those of a study conducted by Farhan et al. (2021), who investigated the impact of noise from power generators on public health in one of Al-Ramadi's districts, Iraq. The study found that noise levels ranged from 54 to 64 dBA at a distance of 75m from the power generator, while at 100 m, the noise levels ranged from 50 to 54.6 dBA. This indicates that to comply with the Iraqi daytime standard, the minimum distance should be at least 75m, and for the nighttime standard, more than 100m. Another study by Menkiti & Ekott (2014) recommended a minimum distance of 90m to comply with the Iraqi nighttime standard, as noise levels of 55.9dBA were recorded at 85 m. However, Ekott, E. E., et.al. (2019) noted that a distance of 55m from a 500 kVA generator would comply with the Iraqi daytime standard of 60 dBA.

3.7 Statistical Analysis of Noise Model Performance

To evaluate the performance of the CUSTIC model in predicting noise levels, two statistical parameters were computed. The two statistical parameters are fractional bias (FB) and the level of agreement within a factor of two (Fa2). These parameters were based on the observations that accounted for all sources, including the generators, and predictions that considered the contribution of the generator only. As indicated earlier that the measurements were taken at three sampling points. The observed noise levels at each point were averaged over all times of the day (morning, noon, afternoon, and evening) during both summer and winter.

The statistical results in Table 8 show that the fractional bias (FB) value was 0.02, indicating that the model generally provides acceptable results and meets the criteria set by Kumar *et al.* (1999). According to their study, the FB range of $-0.5 \leq FB \leq +0.5$ is considered acceptable and for an ideal model having FB=0. A negative FB indicates over-prediction, while a positive value indicates under-prediction. Based on the predicted noise equivalent levels, it can be concluded that the model slightly underpredicts, as the FB value is 0.02. This suggests that additional sources of noise during these periods were not accounted for in the modeling inputs.

Additionally, the Fa2 results show that the predicted noise equivalent level meets the acceptable criteria, as Fa2 is ≥0.8. The results also indicate that the predicted noise equivalent levels are slightly over-predicted by 2% at the first sampling point (7m), while the predicted levels are under-predicted by 3% and 5% at the remaining two sites (20m and 50m) respectively, suggesting that other noise sources at samples points 2 and 3 during these periods were not accounted for in the modeling inputs. The differences between measurements and predications ranged from 1.2 to 3.3 dBA.

Table 8. Statistical analysis of the model performance evaluation, based on LA_{eq} values from three sampling locations

Location	Observation (dBA)[1]	Prediction (dBA)	LA_{eq} Difference (dBA)	LA_{eqp}/LA_{eqo}	FB
7m	78.5	79.0	0.5	1.01	
20m	70.9	68.7	2.2	0.97	0.02
50m	67.1	63.8	3.3	0.95	

[1] Each value at each location was calculated as an average of all Leq levels for winter and summer

4. CONCLUSION

Noise levels were measured at three downwind distances (7m, 20m, and 50m) from generators within a residential area in Najaf city, covering both day and night times in winter and summer of 2025. The results showed that when the generators are in operation, noise levels (LA_{eq}, LA_{max}, LA_{min}, LAF_1, LAF_{10}, etc.) exceeded both the Iraqi standard of 60 dBA for daytime and 50 dBA for nighttime, as well as the WHO guidelines of 55 dBA for daytime and 45 dBA for nighttime. However, when the generators are not in use, but national grids are in operation, all noise levels are below the Iraqi standards, except LA_{max} and some LAF_1 values, which exceed both the Iraqi and WHO limits. The background noise levels, in the absence of power generators or national grids, are generally well below both the Iraqi standards and the WHO guidelines. The results also showed that the noise levels decreased by about 8 dBA when moving from 7m to 20m, and 3 dBA when moving from 20 to 50 m from the generators. The linear regression equation showed that the optimal distance between the nearest residential area and the generator should be 75m. The correlation between wind speed and temperature on one hand, and noise level on the other hand, was noted as negative, during both winter and summer time, with a correlation coefficient of -0.45 to -0.65 with wind speed and -0.65 to -0.7 with temperature. In contrast, the correlation with the relative humidity was positive of 0.68. The noise modeling results indicated that the predicted LA_{eq} are slightly over-predicted by 2% at the first sampling point (7m), while the predicted levels are under-predicted by 3% and 5% at the remaining two sites, 20m and 50m, respectively.

Based on the findings, the following mitigation measures are recommended to reduce the noise from generators in residential areas: Planting trees around generators can help reduce the noise levels. Alternatively, the owner of the generator should construct an acoustic barrier and insulation using rigid materials such as sheet steel, sand-filled block walls, or solid concrete walls to minimize sound transmission. Additionally, it is recommended that the distance between the power generator and any residential area should be at least 75m.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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