Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 12, December, 2022

Effect of Vehicular Stream Characteristics on Traffic Noise

Amjed J. Abed [1*], Amjad H. Albayati [1], Yu Wang [2]

[1] Department of Civil Engineering, University of Baghdad, Baghdad, Iraq.

[2] School of Science, Engineering and Environment, The University of Salford, Manchester, United Kingdom.

Received 30 September 2022; Revised 16 November 2022; Accepted 23 November 2022; Published 01 December 2022

Abstract

Human health can be negatively impacted by exposure to loud noise, which can harm the auditory system. Traffic noise is the leading cause of noise pollution. This paper studies the problem of noise pollution on the roads in Baghdad, Iraq. Due to the increase in vehicle numbers and road network modifications in Baghdad, noise levels became a serious topic to be studied. The aim of the paper was thus to study traffic noise levels and the effect of the traffic stream on noise levels and to formulate a prediction model that identified the guidelines used for designing or developing future roads in the city. Then, the noise levels were measured based on five variables: the functional classification of roads, traffic flow, vehicle speed, distance from the carriageway, and skid number. An analysis of traffic noise prediction was conducted using a simple linear regression model to accurately predict the equivalent sound levels. Finally, the findings have shown that the formulated prediction model gives acceptable prediction noise levels since the R2 is 88.83%. The results showed that the noise levels measured were 23.1% and 48.8% higher than the allowable noise levels limited by Iraqi standards during the daytime and nighttime, respectively. Further, studying the alternatives used to improve the performance of the environment on the existing roads in Baghdad can be considered as a future research direction.

Keywords: Traffic Noise; Skid Resistance; Stream Characteristics; Vehicle Noise; Pollution.

1. Introduction

Noise not only irritates our senses but is also detrimental to our physical and emotional health [1]. Exposure to high noise levels (i.e., greater than 85 dBA) for at least eight hours may be hazardous [2]. Noise has significant effects on human health in general [3]. Consequently, determining the level of traffic noise in residential areas will aid in comprehending the actual state of noise pollution in that environment. The results will then indicate whether precautions or specific actions are sufficient to address the issue of traffic noise in the affected areas [4]. Table 1 shows the recommended noise level standards for several countries and the World Health Organization (WHO) [5]. Seeing as there had been no previous evaluations of traffic noise levels in Baghdad, it was essential to conduct this investigation.

Traffic noise levels vary based on a variety of variables, such as traffic speed, traffic volume, traffic composition, driver behavior, and vehicle type [6, 7]. It is known that fluctuations in the number of moving motor vehicles will affect the amount of noise produced, and that noise will decrease with distance from the source of the sound. It is necessary to investigate the extent to which the correlation of traffic flow measured in passenger car units (*pcu*) per hour is a source of noise at certain distances from the roadside in relation to the number of vehicles moving on the highway in units of passenger cars per unit of time (source of sound) [8].

Aspects of this problem include the evaluation of current noise levels using various measurement techniques and equipment, as well as the prediction of future traffic noise levels in order to take appropriate preventative measures. In

* Corresponding author: amjed.abed2001m@coeng.uobaghdad.edu.iq

http://dx.doi.org/10.28991/CEJ-2022-08-12-016

order to reduce road noise pollution caused by transportation, it is necessary to predict traffic noise [9]. Numerous models were developed to predict global road traffic noise. Due to a variety of factors, such as the types of vehicles and weather conditions in each region, these models cannot be used in every country. Studies on a large scale have demonstrated that combining proven prediction models with field measurements is preferable to relying solely on field measurements due to their high resource requirements [10].

Table 1. Recommended noise level standards [5]

Noise level standard	Noise level (dBA)	
	Day Time	Night Time
WHO	55	45
Australia	45	35
Germany	45	35
Korea	50	45
Japan	45	35
India	55	45
Philippines	50	45

2. Previous Studies

Since road traffic noise is considered serious environmental pollution, many models for noise descriptors, such as vehicle flow, vehicle speed, traffic volume, and the emission levels of sound, have been developed by using regression analysis for data collected from site experiments [11].

Kumar (2011) developed a model for predicting road traffic noise suitable for the Indian region's conditions using regression analysis based on the Calixto model [12]. Barrigón Morillas (2002) studied the traffic noise in Caceres, Spain. By analyzing his measured data, the results showed that noise levels were very high, since 90% of the values exceeded 65 dBA [13]. Li et al. (2002) studied the road traffic noise on three roads in Beijing, China. After the analysis of their data, they found that the noise levels were higher by 5 dBA than the limits of environmental standards due to the traffic stream during the daytime [14]. Sommerhoff et al. (2004) computed and evaluated the noise levels at numerous periods of the year in Valdivia, Chile, using the day-evening-night level to depict the annoyance in the long term. The study concluded that high noise levels were prevalent in the tested locations due to a lack of commitment to the guidelines in the design and construction processes [15].

Ali et al. (2017) used ArcGIS to generate a land zoning map based on the traffic noise levels in Kirkuk city. They selected six locations that were considered major roads in the city. The study investigated traffic noise levels at peak hours on weekdays. The results concluded from their study show higher traffic noise levels than allowable noise levels according to the Central Pollution Control Board [16]. Al-Mosawe (2018) studied the road noise pollution issue on the University of Baghdad campus. The study included finding the main sources causing the noise and its existing levels and generating a prediction model to evaluate the future noise levels and be a guideline for future design and development on the campus. The study takes into consideration three parameters: the speed of vehicles, the surface roughness, and the distance between the classrooms and the source of the noise. The conclusion from the study on the seven locations was that five locations were within the acceptable range of traffic noise and would not cause any annoyance, while two locations detected high noise levels that caused serious annoyance [17].

Kassem (2018), studied the assessment of road traffic noise in the State of Qatar. The study aimed to evaluate wayside noise monitoring and data analysis of pavements in the State of Qatar generated due to various vehicle types [18]. Azodo et al. (2019), studied the traffic noise levels in Nigeria. They measured the noise levels in shops at nine locations on a section of the Ibadan-Abeokuta Road. During the sound level measurement, shops dealing with any sound source were excluded, such as radio player shops, television shops, and electric generator locations. The results of their study showed that the equivalent noise levels (Leq) in the daytime were 91.3 dBA, while the average noise level was 92.27 dBA. The measured noise levels are higher than the allowable traffic noise levels [19]. Ali & Albayati (2022) studied traffic noise prediction in Kirkuk, Iraq. The data for traffic volume, vehicle speed, and traffic noise were measured at 25 locations in the city. The locations were classified according to their function. A traffic noise prediction model was generated using the measured data as input by using the MiniTab20 software program. The linear regression model showed high accuracy depending on the R^2 value, which was 93.93%. The equivalent noise levels measured in locations were found to be above the World Health Organization's permissible noise standard [5].

Singh et al. (2021) studied the traffic noise prediction models in Patiala, India. The study was dependent on several traffic parameters: traffic volume, heavy vehicle percentage, and average vehicle speed. The measured data were analyzed to generate a prediction model using the adaptive neuro-fuzzy inference system (ANFIS). The data were also analyzed with four other software programs to generate prediction models. The software programs were artificial neural networks (ANN), generalized linear models (GLM), random forests (RF), decision trees (DT), and support vector machines (SVM) to make a comparison between the results and show the accuracy of each prediction model for the same measured data. The ANFIS model was found to be the most accurate, with an actual value range of 0.5 dBA [20].

Gilani et al. (2021), studied the modeling of traffic noise under various traffic conditions in India. The aim of the study was to develop a traffic noise prediction model with the use of the graph theory approach, taking into consideration road traffic parameters. The involved parameters were the vehicle's speed, the traffic volume, the heavy vehicle percentage, the road width, and the honking effect. The measured data for the study was collected from five locations for three months at three different times during the day. All the variables were incorporated into a matrix by assigning weights to the selected parameters, represented along the matrix's diagonal, and weights were assigned to the variables' interactions, represented by the off-diagonal elements. Models were developed by performing a simple linear regression between noise parameters and permanent noise index values. The resulting model showed reasonable predicted values depending on the R^2 value [21].

Singh (2022), studied the traffic noise in Patiala, India. The aim of the study was to generate a prediction model for traffic noise depending on three variables: traffic volume, the percentage of heavy vehicles, and vehicle speed. The measured data from 502 samples were increased tenfold using the Monte Carlo simulation method. The data were analyzed using the Neural Network Fitting application in MATLAB R2020a. The results showed that the increment of data generated by the Monte Carlo simulation method generated a more accurate prediction model than the model generated by the original data samples [22].

The results of traffic noise studies can be summed up as follows: all measured noise levels on roads in various cities were found to exceed local or WHO standards. Consequently, it can be considered a global issue and significant action is required. Noise reduction techniques must be improved and considered a design requirement. Numerous prediction models can be generated based on the utilized parameters and statistical software. Prediction model results showed acceptable accuracy in noise level prediction.

3. Review of Some Traffic Noise Models

3.1. FHWA Model

In the United States, the Federal Highway Administration (FHWA) published a traffic noise prediction model, "Highway Traffic Noise Prediction Model" in 1978 [23]. Like many other prediction models, this one makes several modifications to the reference sound level before arriving at the anticipated noise level. The energy-related emission level serves as the reference level in the FHWA model. Next, adjustments are made to the reference energy mean emission level to account for [24]. The algorithm form of the traffic noise prediction is shown in the Equation 1 [25].

$$Leq = L_o + \Delta L_i \tag{1}$$

where Leq is the hourly equivalent noise level, L_o is basic noise level for a traffic stream, and ΔL_i is adjustments to be applied.

3.1.1. Adjustments in the FHWA Model

A number of adjustments should be taken into consideration during the prediction of traffic noise levels as shown below [16]:

- Volume and speed adjustment (Avs).
- Distance adjustment (AD).
- Flow adjustment (AF).
- Barrier adjustment (AB).
- Gradient adjustment (AG).
- Ground cover adjustment (AS).

3.1.2. The FHWA Prediction Equation

The FHWA model can be presented as shown Equation 2 [25]:

$$Leq = L_o + A_{VS} + A_D + A_B + A_F + A_G + A_S \tag{2}$$

The adjustment factors can be calculated from the following equations:

$$A_{vs.} = 10 * log_{10}\left[\frac{D_0 * v}{s}\right] - 25 \tag{3}$$

$$A_D = 10 * log_{10}\left[\frac{D_0}{D}\right]^{1+\alpha} \tag{4}$$

$$A_B = 5 + 20 * log\left[\frac{\sqrt{2\,\pi\,N_{0i}\,cos\theta}}{Tan\sqrt{2\,\pi\,N_0\,cos\,\theta}}\right] \tag{5}$$

$$A_F = 10\,log_{10}\left|\left[v\pi D_0\,\frac{v}{s}\right]S.T\right| \tag{6}$$

where v is volume for each vehicle type in *veh/h*, S is vehicle speed in km/h, D_0 is the reference distances, D is distance from the center of the lane to the receiver, α is coefficient of ground cover, N_{oi}: Fresnel number for the particular class, $N_0 = 2\left(\frac{\delta_0}{\lambda}\right)$, δ_o is the path length difference measured along the perpendicular line between the source and receiver, λ is the wavelength of the sound radiated by the source, and T is time period over which the equivalent sound level is computed.

3.2. The CoRTN Model

"Calculations of Road Traffic Noise (CoRTN)" is a model for noise prediction that was developed and released in 1975 and was considered to be the first official prediction model by the Department of Transport, Welsh Office in Britain [26].

3.2.1. The calculations of CoRTN

To calculate the road traffic noise, the following equation should be applied [27]:

$$L_{A10,1h} = 42.2 + 10logq + \Delta f + \Delta g + \Delta p + \Delta d \tag{7}$$

where $L_{A10,1h}$ is the noise level overtaken a percentage of 10% of the time through a period of one hour, q is the vehicles flow, Δf is the traffic stream adjustment, Δg is the gradient adjustment, Δp is the road surface type adjustment, and Δd is the distance adjustment.

3.2.2. The Adjustment Calculations of CoRTN

To apply the adjustments to the $L_{A10,1h}$ in the model, the following equation is to be used [28].

- The traffic flow adjustment Δf is applied to adjust the heavy vehicle percentage and the flow speed.

$$\Delta f = 33\,log\left(V + 40 + \frac{500}{V}\right) + 10\,log\left(1 + \frac{5P}{V}\right) + 68.8 \tag{8}$$

where V is the mean traffic speeds and P is the heavy vehicle percentage.

$$P = \frac{100f}{q} \tag{9}$$

where f is the hourly flows of heavy vehicles and q is total vehicles flow.

- The gradient adjustment Δg can be computed from Equation 10.

$$\Delta g = 0.3G \tag{10}$$

- The adjustment due to pavement surface type Δp should be taken as -1 dBA in the case of the concrete surface layer or impervious asphalt surface layer with traffic speed not exceeding 75 km/h.
- The distance adjustment Δd is applied for the distance from the sound source to the sound meter and can be computed from Equation 11.

$$\Delta d = -10\,log\left(\frac{d'}{13.5}\right) \tag{11}$$

where d` is the minimum incline distance from the source point:

$$d' = \sqrt{d^2 + h^2} \tag{12}$$

d is the minimum horizontal distance between the edge of the inner lane and the sound meter and h is the vertical distance between the sound source and the sound meter.

4. Predicting Road Traffic Noise (Case Study)

4.1. Location Selection (Mapping)

A total of eighteen locations were set up in the study to meet all functional classifications of roads and two types of surface pavement, flexible and rigid. Figure 1 represents the map location done with the Google Earth software.

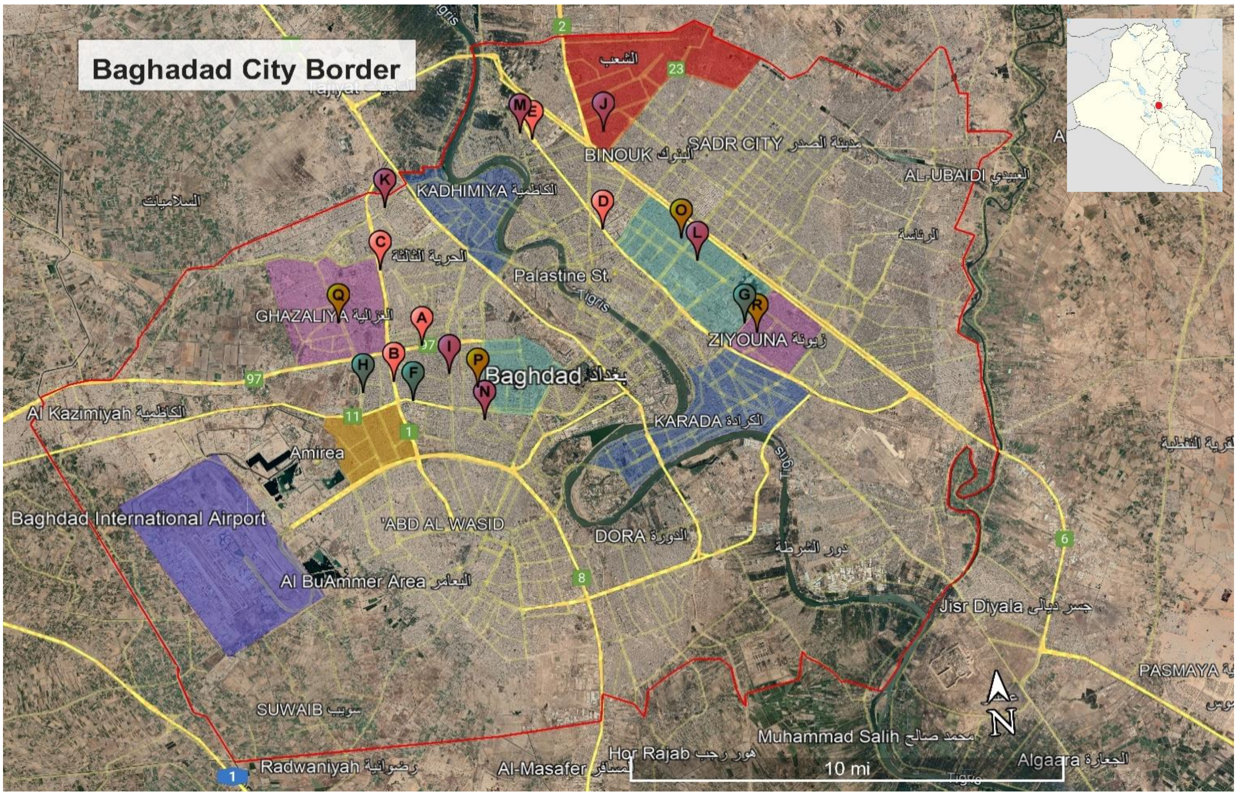

Figure 1. Location Mapping for Studied Locations

The road classification, name, and type of surface layer pavement for the studied locations are shown in Table 2.

Table 2. Locations selected for the study

Location Name	Location Symbol	Functional classification	Surface Type	Coordinates		Skid no.
				N	E	
Abu Ghraib Expressway	A	Major Arterial	Flexible	33°19'45.67"	44°18'51.10"	54
Salah-Aldeen Highway	B	Major Arterial	Rigid	33°19'3.59"	44°18'6.78"	44.2
Salah-Aldeen Highway	C	Major Arterial	Flexible	33°21'24.31"	44°18'0.36"	46.2
Mohamed Al-Qasim Expressway	D	Major Arterial	Flexible	33°21'54.15"	44°23'22.91"	44
Mohamed Al-Qasim Expressway	E	Major Arterial	Rigid	33°23'52.84"	44°21'52.82"	42
AL-Shaik Thari	F	Minor Arterial	Flexible	33°18'37.75"	44°18'32.15"	52.5
Muthanna Bin Haritha Al-Shaibani St.	G	Minor Arterial	Flexible	33°19'43.42"	44°26'34.40"	52.6
Al-Basra St.	H	Minor Arterial	Flexible	33°18'52.30"	44°17'21.58"	44
Al-Rabie St.	I	Collector	Flexible	33°19'7.95"	44°19'26.89"	60.4
Sumer St.	J	Collector	Flexible	33°23'56.46"	44°23'35.69"	51
Chkook St.	K	Collector	Flexible	33°22'41.35"	44°18'14.32"	48
Palestine St.	L	Collector	Flexible	33°21'6.04"	44°25'34.49"	53.4
Othman Bin Affan St.	M	Collector	Flexible	33°24'2.23"	44°21'36.39"	42.2
Four Streets	N	Collector	Flexible	33°18'7.42"	44°20'12.06"	47
Street in Palestine neighborhood	O	Local	Flexible	33°21'35.60"	44°25'14.26"	51.2
Street in Al-Mansour neighborhood	P	Local	Flexible	33°18'48.50"	44°20'5.87"	51
Street in Al-Ghazalia neighborhood	Q	Local	Flexible	33°20'21.95"	44°16'54.65"	45
Street in Zayouna neighborhood	R	Local	Flexible	33°19'29.92"	44°26'50.96"	46

4.2. Devices and Equipment

Several devices were used for the data measurement.

- Sound level meter, using a CEM (DT-8852 Data Logger) model sound level meter to measure the traffic noise levels in different locations.
- . British Pendulum Tester for skid resistance measurements.
- A speed gun detector, using a Bushnell model velocity speed gun for measuring vehicles' speed at locations.

4.3. Measurement Method

In each location, the sound level meter was set at a height of 1.5 meters [29]. The vertical distance between the edge of the inner lane and the sound level meter was variable (1, 3, 6, and 9 meters). The sound level recording duration was 1 hour. Vehicle spot speed was detected by using a speed gun, whereas the speed gun was pointed into the direction of the vehicle and manually recorded at the same time as the sound levels. The speed and its frequency were analyzed, and the 85-percentile speed was computed and used for each hour of study.

Traffic volume was also counted manually during the same duration taking into consideration the vehicle type. The vehicles were classified into two categories: passenger cars and heavy vehicles. In all locations with flat terrain, a passenger car equivalency factor of 1.5 was used to convert the heavy vehicles into equivalent passenger cars. Figure 2 shows the measuring stages and Figure 3 shows the pipeline of the measurement method.

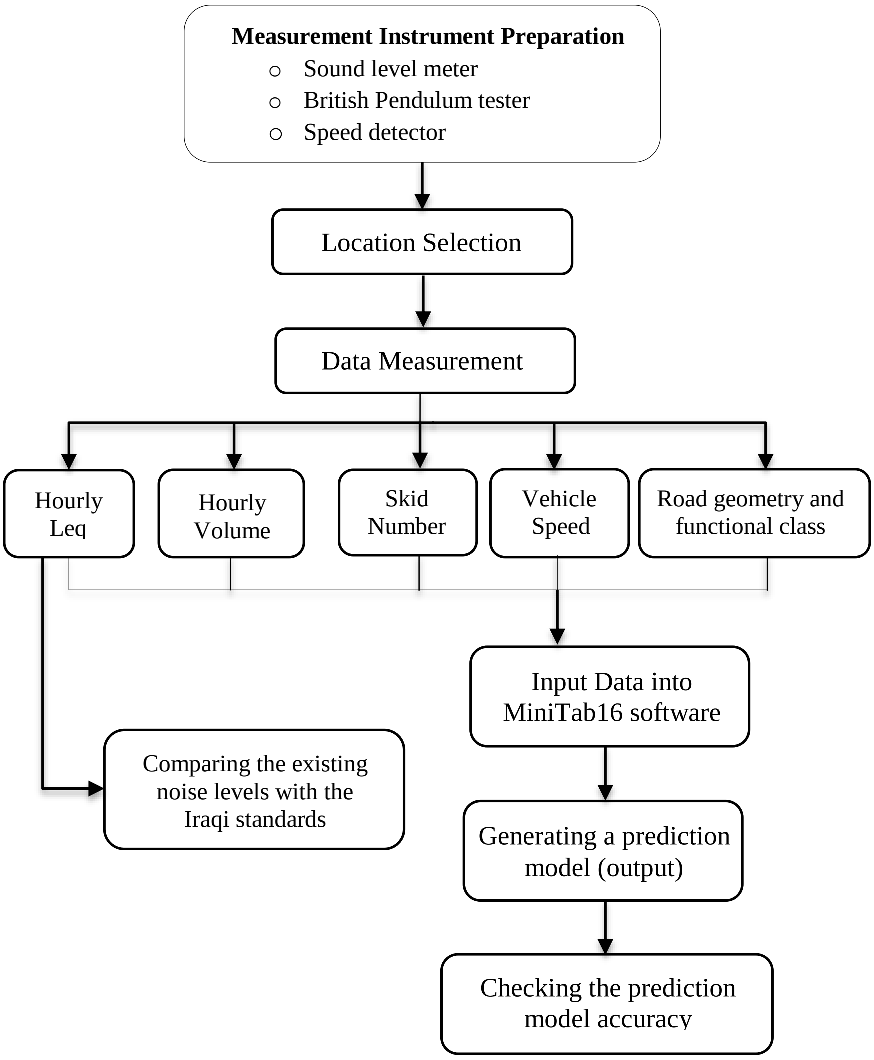

Figure 2. Pipeline of the proposed model

Every location was tested in the three-time interval (5-6 AM, 7-8 AM, and 9-10 PM) during weekdays only. The weather conditions during the data collection were clear, with low wind speeds. In each location, the selected section for collecting data avoided any traffic stream obstructions such as intersections, interchanges, bumps, pedestrian crossings, surface distortions, and with no acceleration or deceleration lane.

Figure 3. Measuring stages

4.4. Results and Discussion

The data resulting from the field survey for the locations are shown in Tables 3 to 6. The data were divided into four groups according to the functional classification of the locations.

Table 3. Data measured for major arterial roads

Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)	Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)
A	5-6 AM	1	113	1077	80.66	C	7-8 AM	6	110	2555	81.12
A	5-6 AM	3	113	1107	77.6	C	7-8 AM	9	106	2512	80.35
A	5-6 AM	6	115	1009	75.05	C	9-10 PM	1	108	1854	81.87
A	5-6 AM	9	110	1038	74.16	C	9-10 PM	3	105	1895	79.63
A	7-8 AM	1	109	2974	83.57	C	9-10 PM	6	110	1909	78.44
A	7-8 AM	3	109	3097	80.73	C	9-10 PM	9	111	1956	76.87
A	7-8 AM	6	107	3078	78.66	D	5-6 AM	1	118	1021	81.07
A	7-8 AM	9	109	3139	75.95	D	5-6 AM	3	119	1099	79.37
A	9-10 PM	1	108	3303	83.92	D	5-6 AM	6	114	1166	73.59
A	9-10 PM	3	108	3338	79.22	D	5-6 AM	9	116	1124	72.28
A	9-10 PM	6	110	3210	76.47	D	7-8 AM	1	99	4346	85.5
A	9-10 PM	9	107	3297	74.11	D	7-8 AM	3	98	5397	84.02
B	5-6 AM	1	107	1952	76.18	D	7-8 AM	6	102	5105	81.72
B	5-6 AM	3	109	1879	74.73	D	7-8 AM	9	100	4643	80.21
B	5-6 AM	6	111	1889	72.28	D	9-10 PM	1	111	1436	81.68
B	5-6 AM	9	110	1927	69.73	D	9-10 PM	3	114	1409	81.33
B	7-8 AM	1	82	3804	79.27	D	9-10 PM	6	110	1270	77.56
B	7-8 AM	3	82	3802	76.19	D	9-10 PM	9	110	1347	76.81
B	7-8 AM	6	85	3765	74.06	E	5-6 AM	1	118	610	79.06
B	7-8 AM	9	84	3818	71.59	E	5-6 AM	3	118	611	77.13
B	9-10 PM	1	96	2286	78.67	E	5-6 AM	6	114	434	73.76
B	9-10 PM	3	98	2339	77.55	E	5-6 AM	9	114	432	71.97
B	9-10 PM	6	93	2424	74.91	E	7-8 AM	1	98	3951	84.6
B	9-10 PM	9	91	2466	73.34	E	7-8 AM	3	98	4171	83.39
C	5-6 AM	1	113	1206	78.57	E	7-8 AM	6	100	4012	80.75
C	5-6 AM	3	113	1137	77.13	E	7-8 AM	9	100	4074	78.18
C	5-6 AM	6	115	1296	76.64	E	9-10 PM	1	110	1319	81.68
C	5-6 AM	9	116	1314	74.77	E	9-10 PM	3	110	1333	80.33
C	7-8 AM	1	109	2621	84.62	E	9-10 PM	6	110	1300	77.65
C	7-8 AM	3	107	2602	82.62	E	9-10 PM	9	110	1140	76.07

Table 4. Data measured for minor arterial roads

Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)	Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)
F	5-6 AM	1	92	399	73.65	G	7-8 AM	3	72	1401	73.04
F	5-6 AM	3	91	356	70.9	G	9-10 PM	1	74	1208	77.8
F	7-8 AM	1	86	1712	78.48	G	9-10 PM	3	75	1138	74.1
F	7-8 AM	3	85	1548	76.03	H	5-6 AM	1	78	218	69.28
F	9-10 PM	1	87	1831	77.19	H	5-6 AM	3	80	194	67.79
F	9-10 PM	3	85	1822	73.88	H	7-8 AM	1	61	1278	74.77
G	5-6 AM	1	84	342	73.39	H	7-8 AM	3	63	1309	73.06
G	5-6 AM	3	84	357	71.29	H	9-10 PM	1	82	919	70.86
G	7-8 AM	1	74	1365	75.43	H	9-10 PM	3	85	943	68.32

Table 5. Data measured for collector roads

Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)	Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)
I	5-6 AM	1	64	117	73.05	K	9-10 PM	1	70	1151	72.51
I	5-6 AM	3	64	98	70.3	L	5-6 AM	1	87	451	67.99
I	7-8 AM	1	49	1468	77.88	L	7-8 AM	1	69	2052	75.24
I	7-8 AM	3	49	1521	75.43	L	9-10 PM	1	42	1752	72.3
I	9-10 PM	1	51	932	76.59	M	5-6 AM	1	65	142	63.51
I	9-10 PM	3	51	966	73.28	M	7-8 AM	1	63	799	68.38
J	5-6 AM	1	45	64	59.65	M	9-10 PM	1	62	881	67.27
J	7-8 AM	1	54	394	69.82	N	5-6 AM	1	64	104	64.54
J	9-10 PM	1	52	338	67.25	N	7-8 AM	1	54	988	72.22
K	5-6 AM	1	67	261	71.35	N	9-10 PM	1	56	726	69.82
K	7-8 AM	1	59	1434	76.46						

Table 6. Data measured for local streets

Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)	Location	Time	Dis. (m)	Speed (km/hr.)	Vol. (pc/hr.)	Leq measured (dBA)
O	5-6 AM	1	33	45	59.29	Q	5-6 AM	1	35	4	58.45
O	7-8 AM	1	33	96	63.99	Q	7-8 AM	1	29	29	62.28
O	9-10 PM	1	36	72	63.45	Q	9-10 PM	1	30	37	62.35
P	5-6 AM	1	33	3	55.3	R	5-6 AM	1	39	7	59.92
P	7-8 AM	1	38	13	61.08	R	7-8 AM	1	30	30	62.44
P	9-10 PM	1	37	21	57.37	R	9-10 PM	1	31	33	61.08

The hourly traffic volume for eight locations was calculated at a 10-minute interval as the sound level meter was recording the traffic sound levels. The measured data were graphed in order to investigate the relationship between traffic volume and the measured traffic noise. Figures 4 to 11 show that the increase in the traffic volume increases the sound levels in a linear relationship. The results confirm with those of Ali & Albayati (2022) [5]; Kholikov (2022) [30]; and Radam & Heriyatna, (2018) [31].

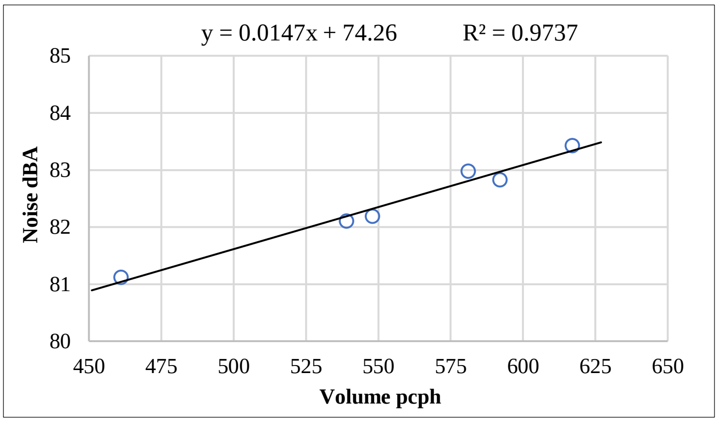

Figure 4. Location A noise - volume relationship

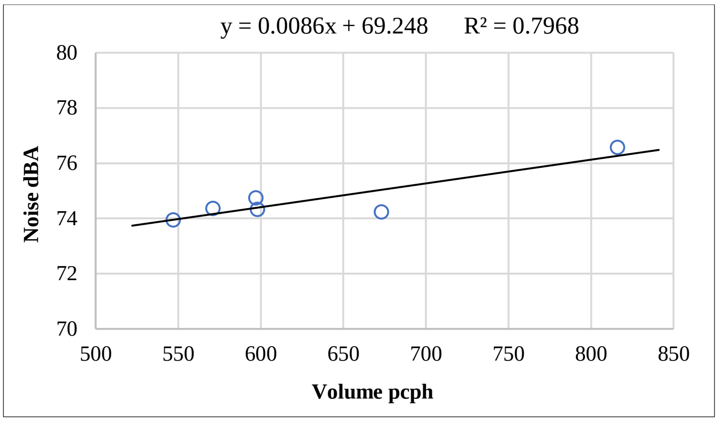

Figure 5. Location B noise - volume relationship

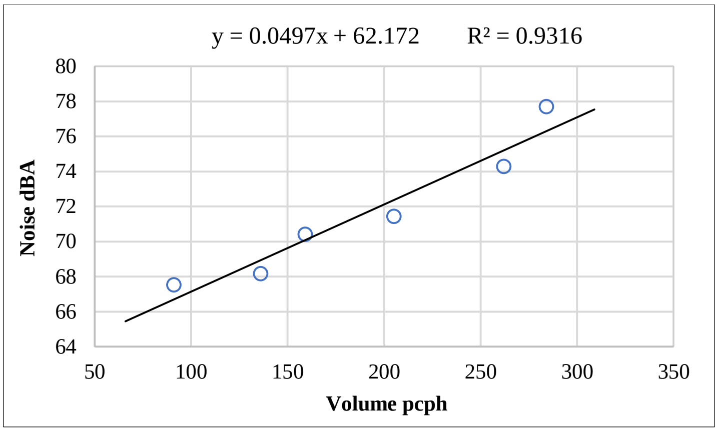

Figure 6. Location C noise - volume relationship

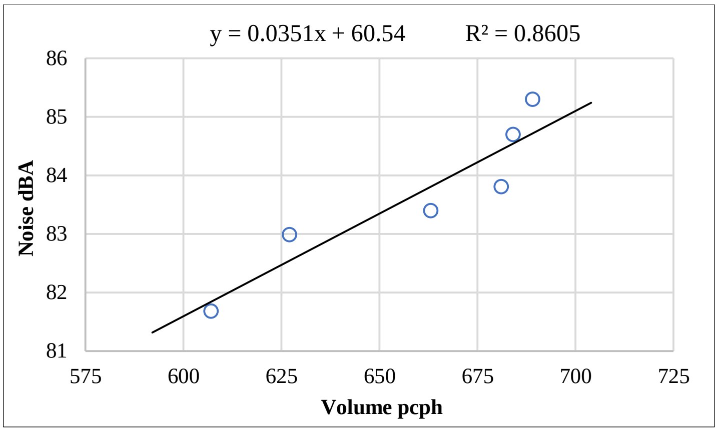

Figure 7. Location E noise - volume relationship

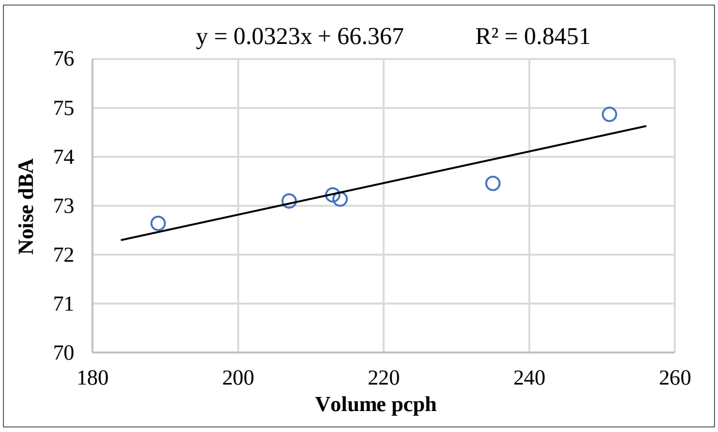

Figure 8. Location F noise - volume relationship

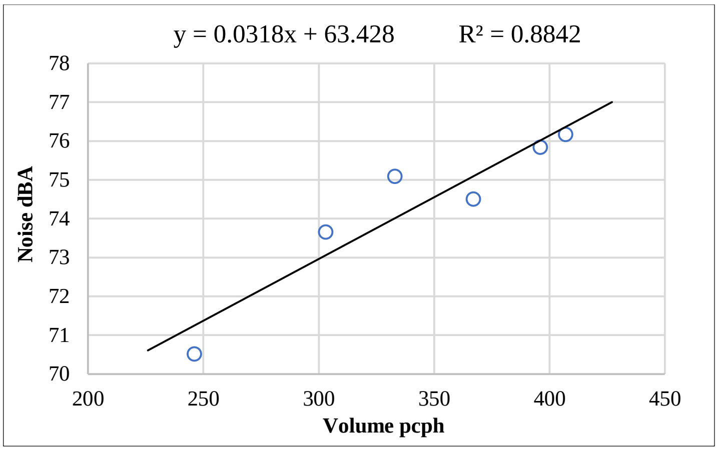

Figure 9. Location G noise - volume relationship

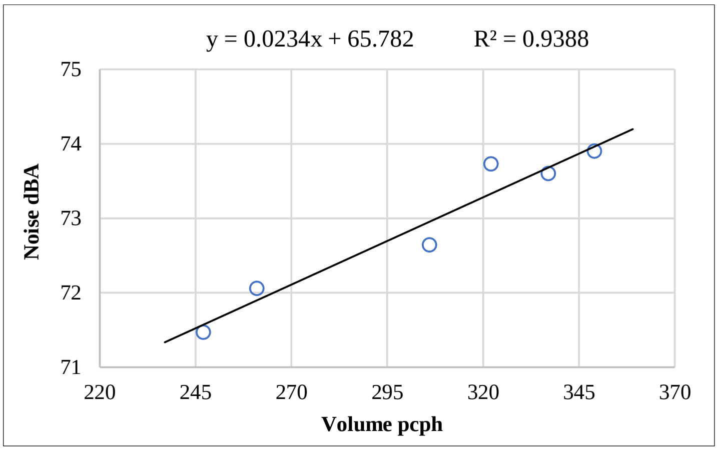

Figure 10. Location H noise - volume relationship

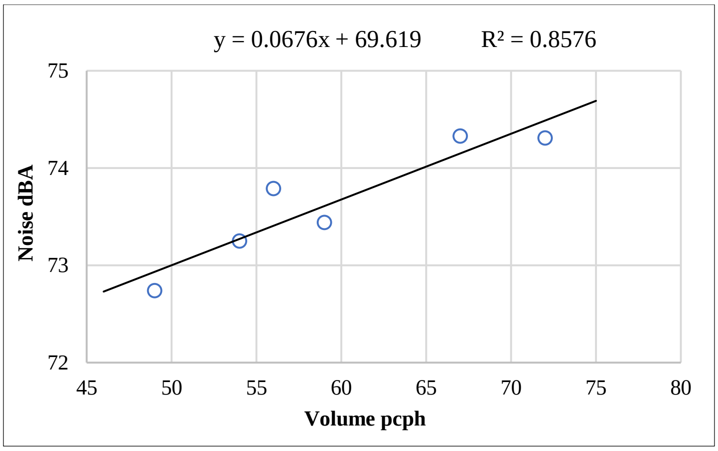

Figure 11. Location L noise - volume relationship

The vehicles' spot speeds were measured at eight locations and the traffic noise generated was measured at the same moment by the sound level meter. The measured data from locations were graphed to show the relationship between vehicle speed and traffic noise. In all tested locations, the behavior of speed produced a linear relationship with the measured noise. This means that increasing the vehicle speed generates higher noise levels. Vehicle speed appears to be a major factor influencing the measured traffic noise.

Figures 12 to 19 describe the speed increment behavior with measured noise from the measured data from locations for different roads. The findings support the findings of Al-Mosawe (2018) [17], Ali & Albayati (2022) [5], and Ohiduzzaman et al. (2016) [32].

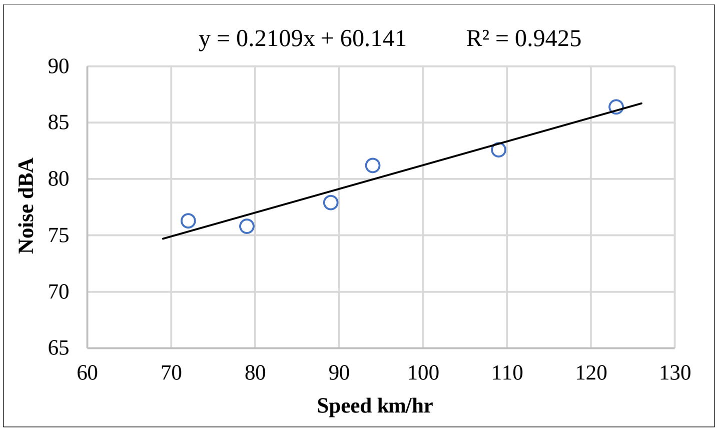

Figure 12. Location A noise – speed relationship

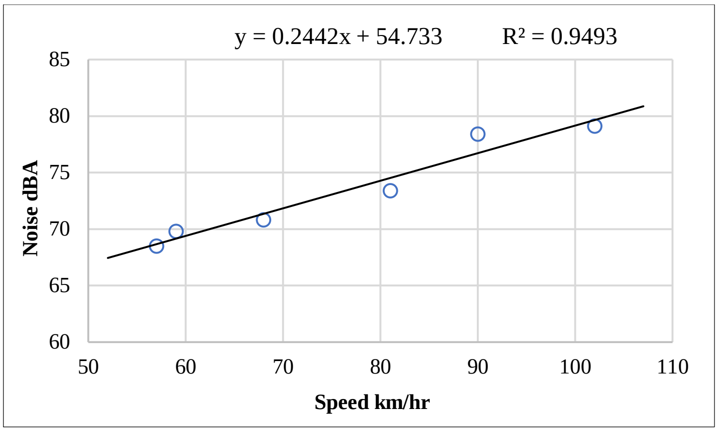

Figure 13. Location B noise - speed relationship

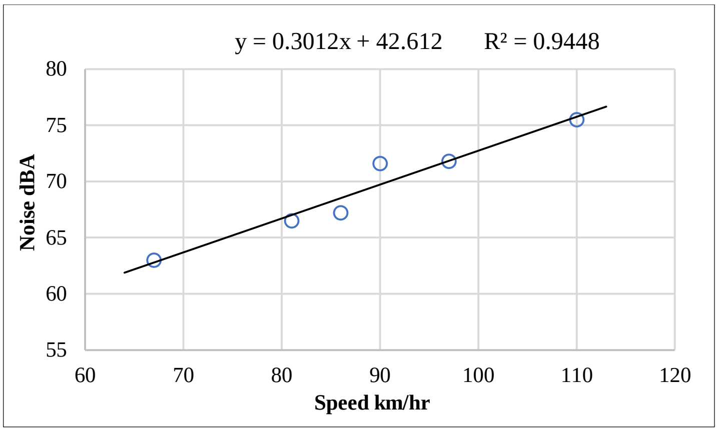

Figure 14. Location C noise – speed relationship

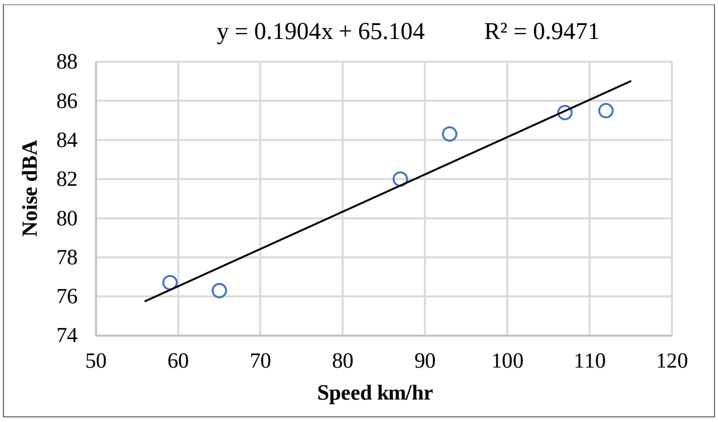

Figure 15. Location E noise - speed relationship

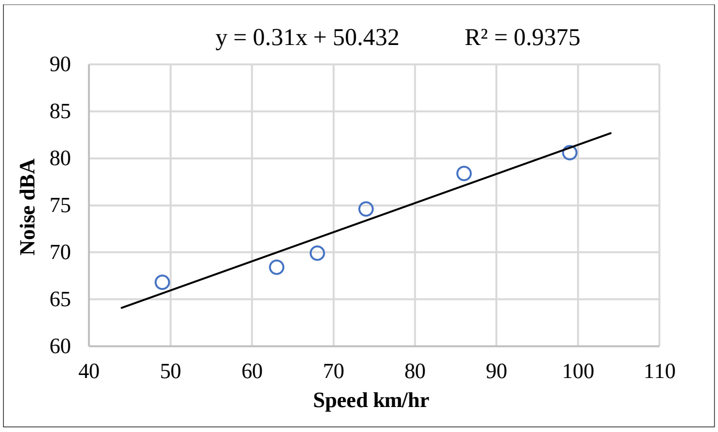

Figure 16. Location F noise – speed relationship

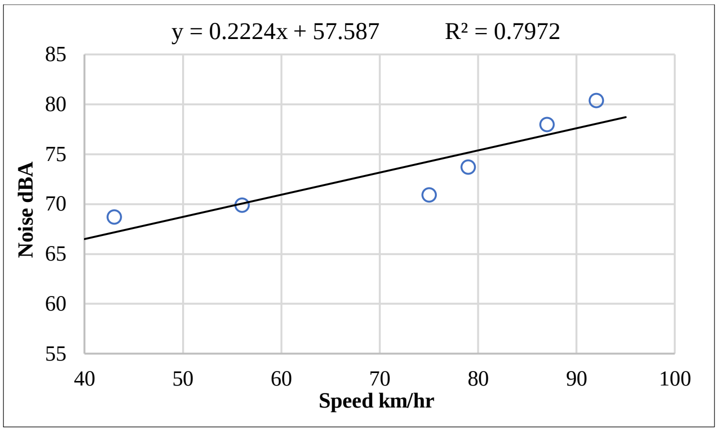

Figure 17. Location G noise - speed relationship

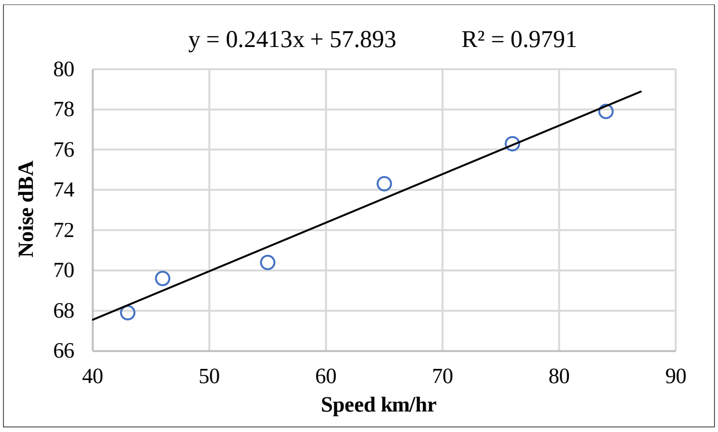

Figure 18. Location H noise – speed relationship

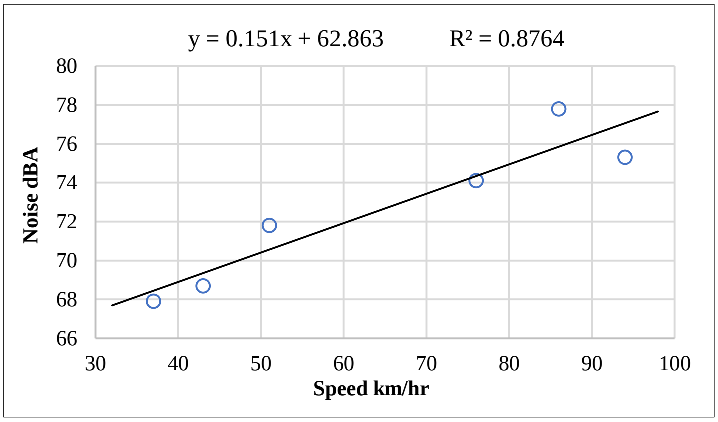

Figure 19. Location L noise - speed relationship

The traffic noise levels were measured at different distances as shown in Table 3. The measured data were graphed as shown in Figures 20 to 24. Graphs from the observed data show that the relationship between noise levels and distance can be considered an exponential relationship. The results in Figures 20 to 24 confirm the results presented by Al-Mosawe et al. (2018) [17], and Ohiduzzaman et al. (2016) [32]. The distance between the noise source and the noise detector was also found to be an independent factor affecting the measured noise levels.

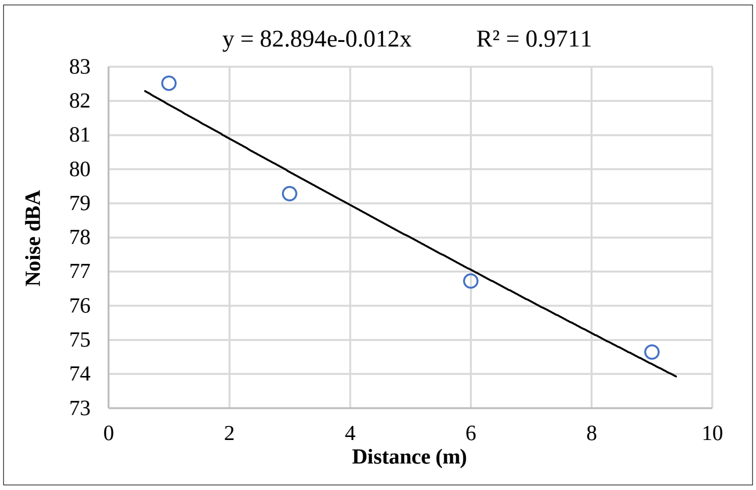

Figure 20. Location A noise – distance relationship

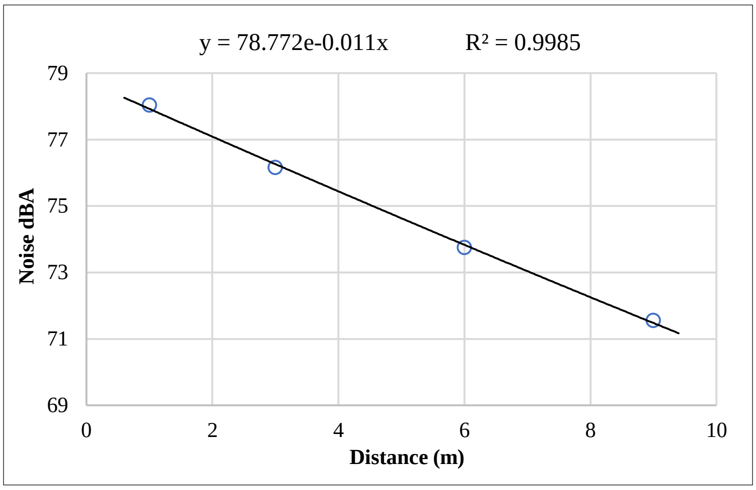

Figure 21. Location B noise - distance relationship

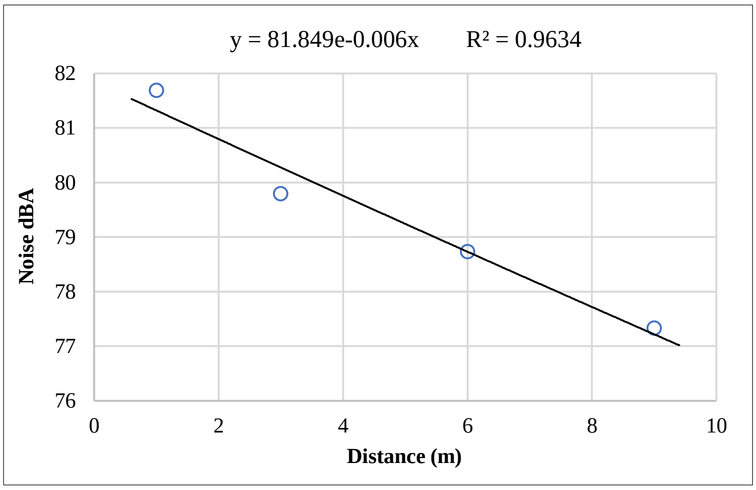

Figure 22. Location C noise – distance relationship

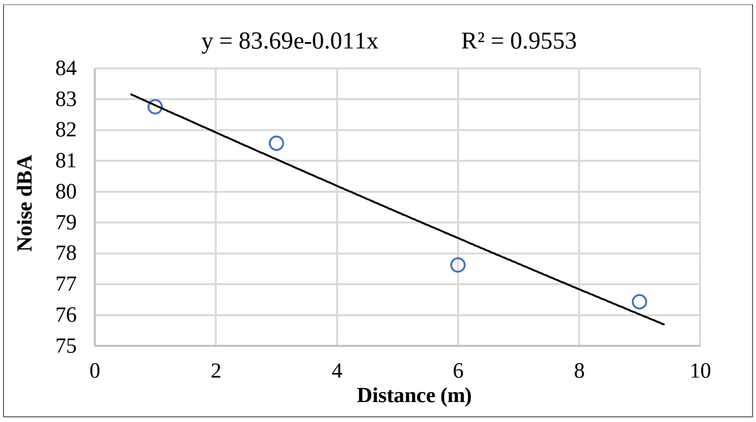

Figure 23. Location D noise - distance relationship

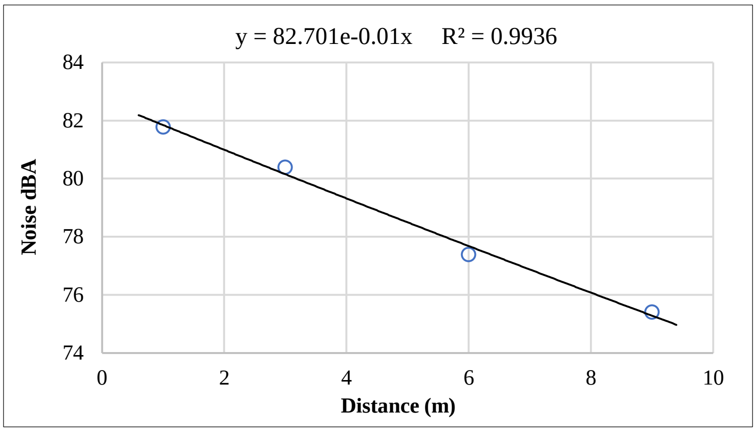

Figure 24. Location E noise – distance relationship

The traffic noise levels ranged from 69.73 to 85.5 dBA on major arterial roads. The minimum noise level was found to be at 5-6 AM, which is considered low traffic conditions, and at the maximum distance between the noise source and noise meter, while the maximum noise level was found to be at 7-8 AM, which is considered rush hour and at the minimum distance between the noise source and noise meter. For minor arterial roads, the minimum and maximum traffic noise levels were 67.79 and 78.48 dBA, while the minimum and maximum traffic noise levels for collectors were 59.65 and 77.78 dBA, respectively. The minimum and maximum traffic noise levels for local streets were 55.3 and 63.99 dBA.

By comparing the noise levels calculated in this study with the acceptable limits fixed by the Iraqi standards shown in Table 7, it shows that only four values were in the acceptable range from 111 values (1 in a collector and 3 on local roads), while all the other noise levels in all locations exceeded the acceptable values. All the acceptable values were recorded at the time (5-6 AM).

Table 7. Iraqi standards of noise levels outside buildings (dBA) [33]

Location	Day Time	Night Time
Hospitals	50	40
Residential areas	60	50
Residential areas (suburbs)	55	45
Hotels	55	50
Schools, kindergartens, universities, and institutes	55	45
Industrial areas, governmental facilities	70	65
Utilities and commercial areas	65	60
Airports, Railway stations, and Harbors	70	60
Cultural and protect urban area	60	50
Recreation areas	60	50
Mixed residential areas and industrial areas (vice-versa)	60	45

Figures 25 to 28 show the difference in sound levels between locations and standard values for the major arterials, minor arterials, collector, and local streets respectively [33].

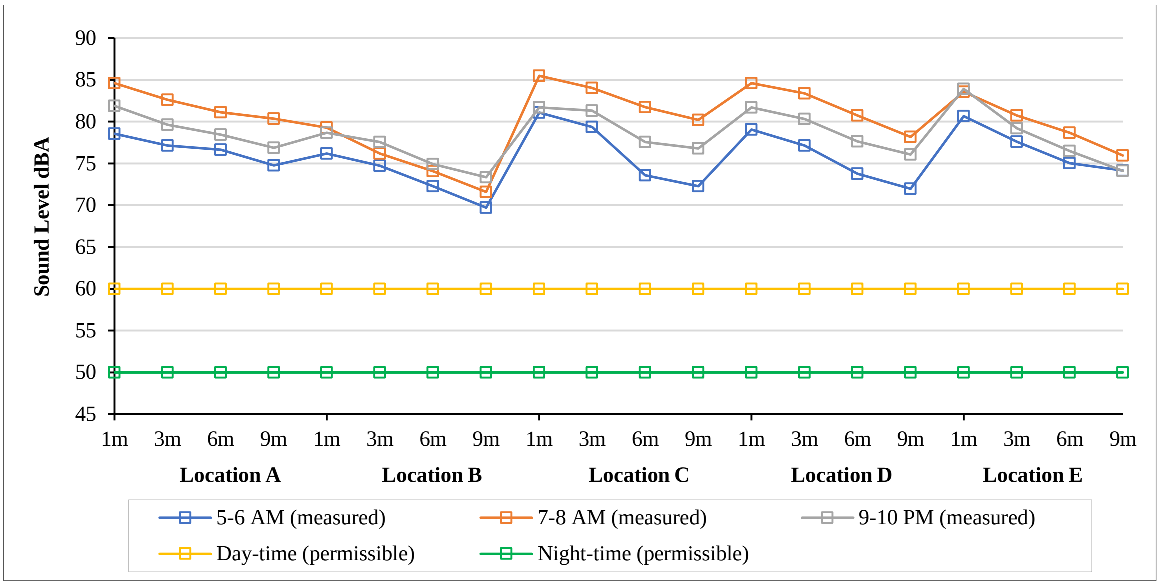

Figure 25. A comparison between measured and permissible limits of sound levels for major arterial roads

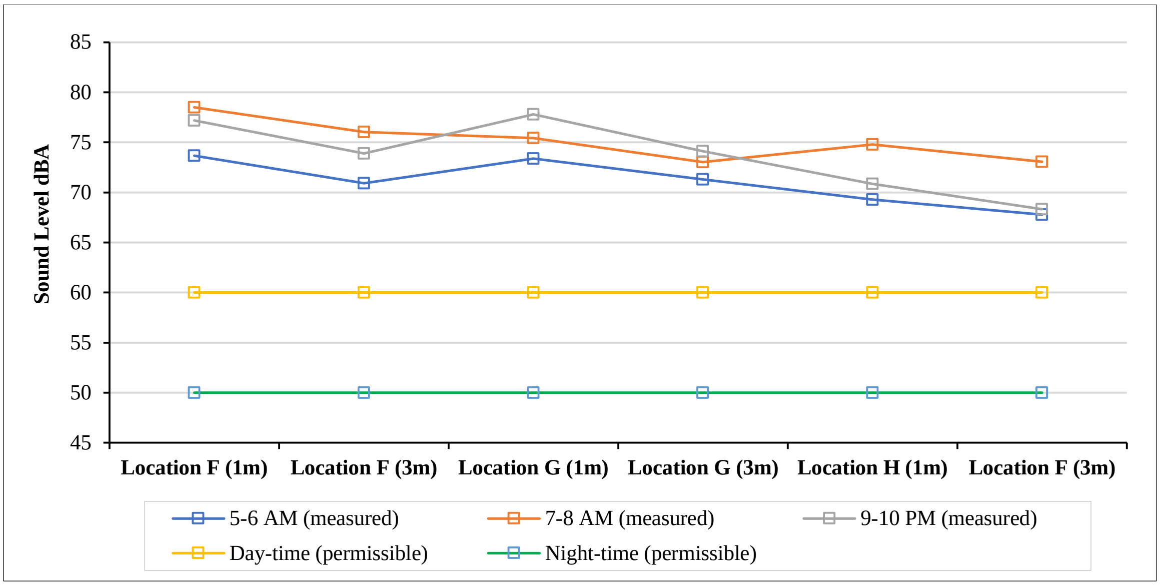

Figure 26. A comparison between measured and permissible limits of sound levels for minor arterial roads

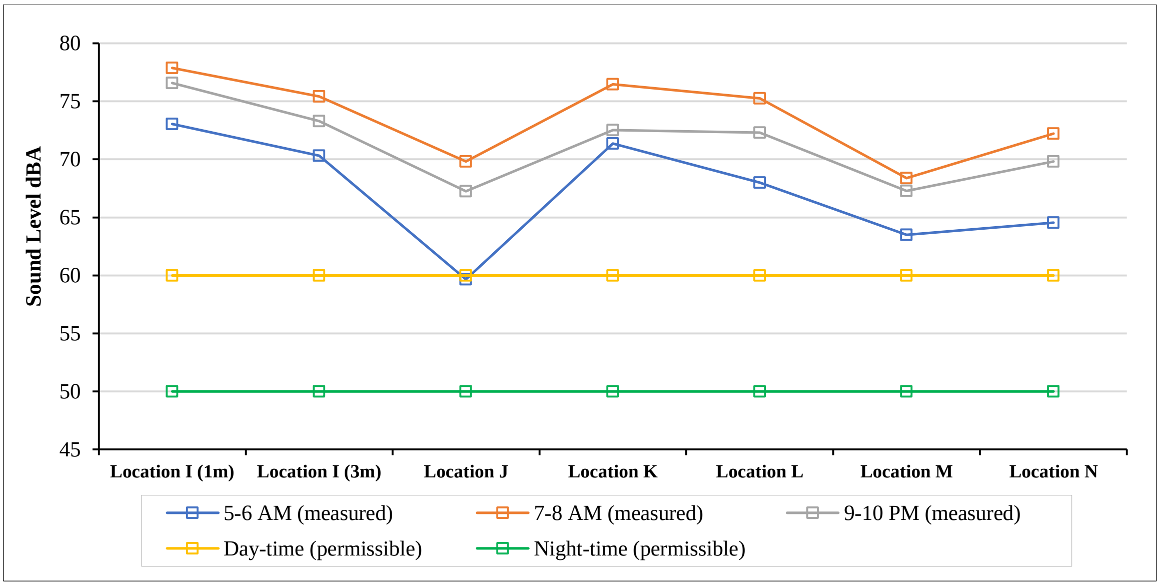

Figure 27. A comparison between measured and permissible limits of sound levels for collector roads

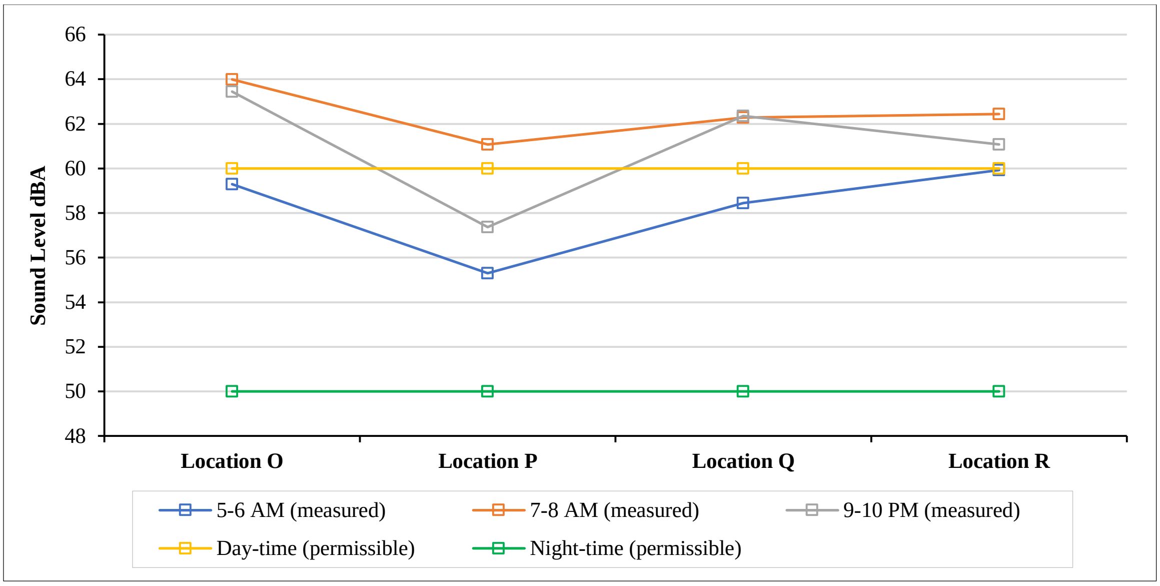

Figure 28. A comparison between measured and permissible limits of sound levels for local roads

4.5. Statistical Model

As mentioned earlier in this research, a statistical model was built to accommodate and link the parameters to traffic noise levels. The observed data in Tables 3 to 6 were analyzed with the aid of the Minitab 16 software program. A simple linear regression was used for this matter. The result was the following model:

$$L_{eq} = 65.9 + 0.0893 \times S + 0.00174 \times V - 0.855 \times D + 0.127 \times SN. -2.99 \times FC \tag{13}$$

where Leq is hourly equivalent traffic noise level (dBA), S is vehicle speed (km/hr.), V is traffic volume (pc/hr.), D is distance between noise source and noise level meter in meter, $SN.$ is skid number, and FC: function classification of roads (Assumed for statistical analysis purpose 1 for major arterials, 2 for minor arterials, 3 for collectors, 4 for local streets).

The Equation 13 represents a general statistical model for the prediction of traffic noise levels for all types of roads. The R^2 values as shown by the (MINITAB 16) software for the analyzed data = 87.4 %. The models show a logical prediction of noise levels as shown in Figure 29. The points are cumulative around the line which indicates a good ability for prediction. The resulting linear line in Figure 29 can be presented in Equation 14 with R^2 = 88.83 %.

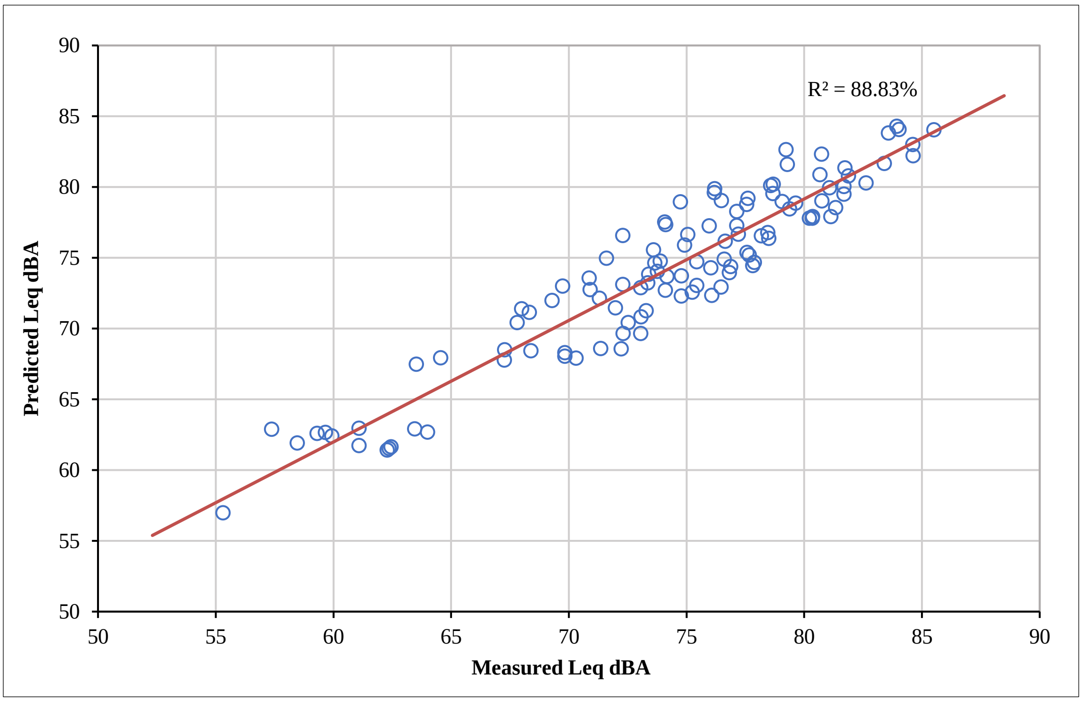

Figure 29. Prediction model results

Other statistical indicators were also plotted such as the normal probability plot and residuals Figure 30.

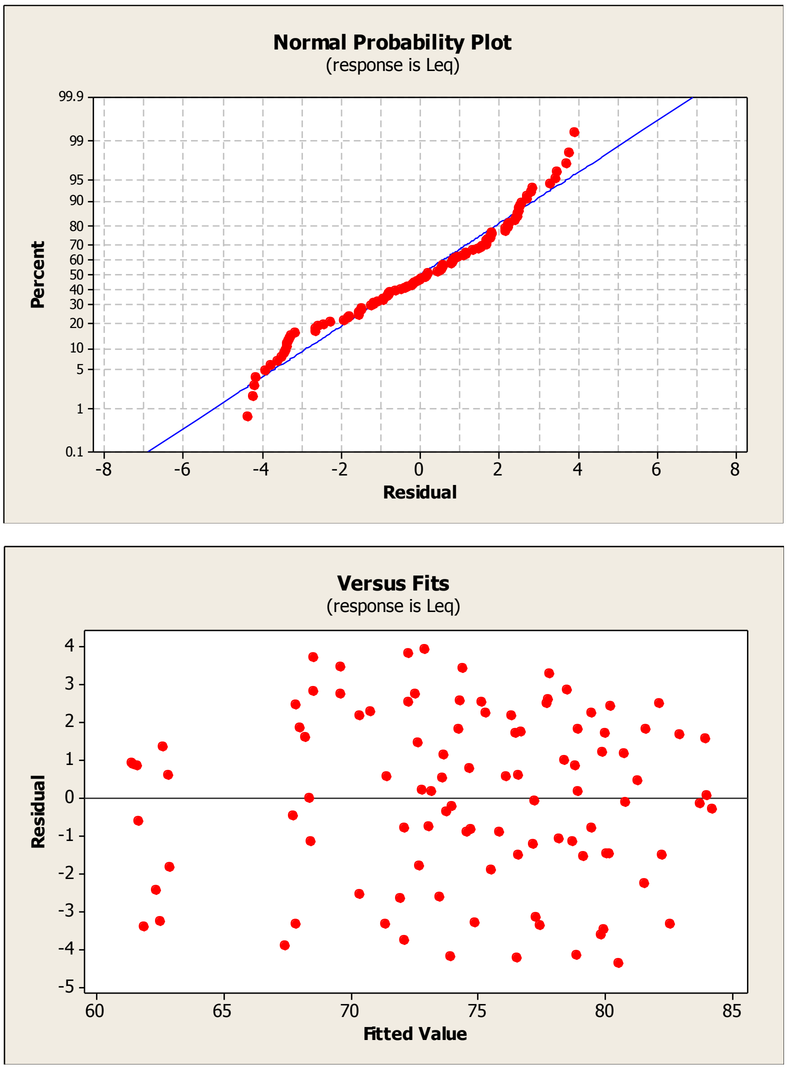

Figure 30. Statistical indicators for the model

4.5.1. Statistical Model Accuracy

Figure 29 depicts the predicted and measured Leq, which indicates the accuracy of the generated prediction model based on the R^2 value. However, data were measured in four locations and were not used in the analysis of generating the prediction model to test the model's accuracy practically by the difference between the measured and predicted Leq. The average difference (ΔLeq) was found to be 1.68 dBA, which is also considered acceptable. Table 8 shows the difference between measured and predicted Leq.

Table 8. Data for prediction accuracy test

Location	Distance (m)	Speed (km/hr.)	Volume (pc/hr.)	SN.	FC	Leq measured (dBA)	Leq predicted (dBA)	Leq Difference
1	3	61	1352	60.4	3	72.41	69.83	2.58
2	6	109	2498	46.2	1	79.17	77.72	1.45
3	1	42	61	51	3	64.37	66.4	2.03
4	1	102	3951	44	1	84.31	83.62	0.69

5. Conclusion

This paper investigated the daytime and nighttime patterns of traffic noise pollution in Baghdad city by investigating the variables: vehicle speed, traffic volume, the skid number for the road surface, the effect of distance between the noise source and the noise level detector, and the functional classification of the road as influential factors that impacted noise levels at eighteen locations. The results showed that all variables have an effect on traffic noise. It was confirmed that these variables are the main factors that influence the increase in noise levels.

A statistical model was developed in this paper to predict and assess the noise levels at the locations considering the five variables. The model has predicted the level of noise with high accuracy since R^2 was 88.83%, and the accuracy check for data not included in the model generation showed an average difference of 1.68 dBA between predicted and measured equivalent noise levels (ΔLeq). This scenario implies an exact prediction that ranges within the bounds of the actual values.

Also, it has been found that from all eighteen locations (111 hours of data recording), only four hours, representing 3.6% of the data, recorded a traffic noise level lower than the acceptable noise levels limited by the Iraqi standards for noise levels outside buildings. In these four hours, one was recorded in a collector, and three were recorded in local streets between 5 and 6 AM. The results showed that the average noise levels measured were 73.89 dBA during the daytime and 74.42 dBA during the nighttime, which were found to be 23.1% and 48.8% higher than the acceptable noise levels limited by Iraqi standards during the daytime and nighttime, respectively.

6. Declarations

6.1. Author Contributions

Conceptualization, A.H.A. and Y.W.; methodology, A.J.A.; software, A.J.A.; validation, A.J.A., and Y.W.; formal analysis, A.J.A.; investigation, A.J.A.; resources, A.H.A. and Y.W.; data curation, A.J.A.; writing—original draft preparation, A.J.A.; writing—review and editing, A.H.A. and Y.W.; visualization, A.J.A.; supervision, A.H.A. and Y.W.; project administration, A.H.A. and Y.W.; funding acquisition, A.J.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Faisal, A. A., Selen, L. P. J., & Wolpert, D. M. (2008). Noise in the nervous system. Nature Reviews Neuroscience, 9(4), 292–303. doi:10.1038/nrn2258.

[2] World Health Organization (WHO). (2005). United Nations road safety collaboration: a handbook of partner profiles. World Health Organization, Geneva, Switzerland.

[3] Vilniškis, T., Naimušin, A., & Januševičius, T. (2022). Investigation and Modeling of Transport Noise Dependence on Traffic Speed and Impact on Population Annoyance. Journal of Environmental Engineering and Landscape Management, 30(1), 22–29. doi:10.3846/jeelm.2022.16275.

[4] Sulaiman, F. S., Darus, N., Mashros, N., Haron, Z., & Yahya, K. (2018). Traffic Noise Assessment at Residential Areas in Skudai, Johor. E3S Web of Conferences. doi:10.1051/e3sconf/20183402024.

[5] Ali, S. S., & Albayati, A. H. K. (2022). Statistical Modeling for Traffic Noise: The Case of Kirkuk City. Engineering, Technology & Applied Science Research, 12(5), 9108–9112. doi:10.48084/etasr.5173.

[6] Kalansuriya, C. M., Pannila, A. S., & Sonnadara, D. U. J. (2015). Traffic composition and variability of road traffic noise levels in the vicinity of Colombo, Sri Lanka. Journal of the National Science Foundation of Sri Lanka, 43(2), 135–140. doi:10.4038/jnsfsr.v43i2.7941.

[7] Tomić, J., Bogojević, N., Pljakić, M., & Šumarac-Pavlović, D. (2016). Assessment of traffic noise levels in urban areas using different soft computing techniques. The Journal of the Acoustical Society of America, 140(4), EL340–EL345. doi:10.1121/1.4964786.

[8] Xu, L., Ni, H., Zhang, Y., Sun, D., Zheng, Y., & Hu, M. (2022). Porous asphalt mixture use asphalt rubber binders: Preparation and noise reduction evaluation. Journal of Cleaner Production, 376, 134119. doi:10.1016/j.jclepro.2022.134119.

[9] González, D. M., Morillas, J. M. B., & Rey-Gozalo, G. (2023). Effects of noise on pedestrians in urban environments where road traffic is the main source of sound. Science of the total environment, 857, 159406. doi:10.1016/j.scitotenv.2022.159406.

[10] Van Renterghem, T., Attenborough, K., Maennel, M., Defrance, J., Horoshenkov, K., Kang, J., Bashir, I., Taherzadeh, S., Altreuther, B., Khan, A., Smyrnova, Y., & Yang, H. S. (2014). Measured light vehicle noise reduction by hedges. Applied Acoustics, 78, 19–27. doi:10.1016/j.apacoust.2013.10.011.

[11] De Donato, S. R., & Morri, B. (2001). Technical note: A statistical model for predicting road traffic noise based on Poisson type traffic flow. Noise Control Engineering Journal, 49(3), 137–143. doi:10.3397/1.2839649.

[12] Kumar, K., Katiyar, V. K., Parida, M., & Rawat, K. (2011). Mathematical modeling of road traffic noise prediction. International Journal of Applied Mathematics and Mechanics, 7(4), 21–28.

[13] Barrigón Morillas, J. M., Gómez Escobar, V., Méndez Sierra, J. A., Vílchez Gómez, R., & Trujillo Carmona, J. (2002). An environmental noise study in the city of Cáceres, Spain. Applied Acoustics, 63(10), 1061–1070. doi:10.1016/S0003-682X(02)00030-0.

[14] Li, B., Tao, S., Dawson, R. W., Cao, J., & Lam, K. (2002). A GIS based road traffic noise prediction model. Applied Acoustics, 63(6), 679–691. doi:10.1016/S0003-682X(01)00066-4.

[15] Sommerhoff, J., Recuero, M., & Suárez, E. (2004). Community noise survey of the city of Valdivia, Chile. Applied Acoustics, 65(7), 643–656. doi:10.1016/j.apacoust.2004.01.003.

[16] Ali, S. M., Hama, A. R., & Ali, Y. M. (2018). A study of Land Zoning in the base of Traffic Noise Pollution Levels using ArcGIS: Kirkuk City as a Case Study. Al-Khwarizmi Engineering Journal, 13(4), 137–151. doi:10.22153/kej.2017.06.002.

[17] Al-Mosawe, H. M., Alobaydi, D., & Albayati, A. (2018). Development of Traffic Noise Prediction Model in an Educational Urban Area. Civil Engineering Journal, 4(11), 2588. doi:10.28991/cej-03091183.

[18] Ohiduzzaman, Md., Sirin, O., & Kassem, E. (2018). Evaluation of traffic noise in the State of Qatar. Advances in Materials and Pavement Performance Prediction, 249–253, CRC Press, Boca Raton, United States. doi:10.1201/9780429457791-61.

[19] Azodo, A. P., Onwubalili, C., & Mezue, T. C. (2019). Assessment of Observed Building Structure Setback of Shops along an Arterial Road and Noise Intrusion Level. Journal of Engineering, 25(12), 62–71. doi:10.31026/j.eng.2019.12.05.

[20] Singh, D., Upadhyay, R., Pannu, H. S., & Leray, D. (2021). Development of an adaptive neuro fuzzy inference system based vehicular traffic noise prediction model. Journal of Ambient Intelligence and Humanized Computing, 12(2), 2685–2701. doi:10.1007/s12652-020-02431-y.

[21] Gilani, T. A., & Mir, M. S. (2021). Modelling road traffic Noise under heterogeneous traffic conditions using the graph-theoretic approach. Environmental Science and Pollution Research, 28(27), 36651–36668. doi:10.1007/s11356-021-13328-4.

[22] Singh, D., Kaler, P., Lyall, I., Singh, A., & Pannu, H. S. (2022). Traffic noise prediction using machine learning and Monte Carlo data augmentation: a case study on the Patiala city in India. Journal of Physics: Conference Series, 2162(1), 012021. doi:10.1088/1742-6596/2162/1/012021.

[23] Suthanaya, P. A. (2015). Modelling road traffic noise for collector road (case study of Denpasar City). Procedia Engineering, 125, 467–473. doi:10.1016/j.proeng.2015.11.125.

[24] Barry, T. M., & Reagan, J. A. (1978). FHWA highway traffic noise prediction model. Office of Research and development, Federal Highway Administration, Washington, United States.

[25] Shukla, A. K., Jain, S. S., Parida, M., & Srivastava, J. B. (2009). Performance of FHWA model for predicting traffic noise: A case study of metropolitan city, Lucknow (India). Transport, 24(3), 234–240. doi:10.3846/1648-4142.2009.24.234-240.

[26] Steele, C. (2001). Critical review of some traffic noise prediction models. Applied Acoustics, 62(3), 271–287. doi:10.1016/S0003-682X(00)00030-X.

[27] Kundu, S., Mondal, N. K., & Mishra, D. (2021). Prediction of Road Traffic Noise by CRTN Model in a Sub-Urban Town of India. The Global Environmental Engineers, 8, 1–13. doi:10.15377/2410-3624.2021.08.1.

[28] Halim, H., Abdullah, R., Mohd Nor, M. J., Abdul Aziz, H., & Abd Rahman, N. (2017). Comparison between Measured Traffic Noise in Klang Valley, Malaysia and Existing Prediction Models. Engineering Heritage Journal, 1(2), 10–14. doi:10.26480/gwk.02.2017.10.14.

[29] Federal Highway Administration (FHWA). (2018). Noise Measurement Handbook. Final Report, FHWA-HEP-18-065, U.S. Department of Transportation, Federal Highway Administration, Washington, United States.

[30] Kholikov, A. I., & Azizov, K. K. (2022). Traffic Noise Forecasting on Tashkent City Main Streets. Journal of Siberian Federal University. Engineering & Technologies, 15(2), 248-260. doi:10.17516/1999-494X-0388.

[31] Radam, I. F., & Heriyatna, E. (2018). A Correlation Analysis of Noise Level and Traffic Flow: Case of One Way Road in Banjarmasin. Asian Journal of Applied Sciences, 06(02), 60–64.

[32] Ohiduzzaman, M. D., Sirin, O., Kassem, E., & Rochat, J. L. (2016). State-of-the-art review on sustainable design and construction of quieter pavements-Part 1: Traffic noise measurement and abatement techniques. Sustainability (Switzerland), 8(8). doi:10.3390/su8080742.

[33] Presidency of Iraqi Government. (2015). Law of Noise Pollution Control. Presidency of Iraqi Government, Baghdad, Iraq. Available online: https://www.moj.gov.iq/uploaded/4390.pdf (accessed on August 2022). (In Arabic).