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Article

Measuring, Mapping, and Evaluating Daytime Traffic Noise Levels at Urban Road Intersections in Doha, Qatar

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Abstract: In this study, equivalent hourly traffic noise levels at different intersections in the city of Doha, Qatar were measured and compared to the local and World Health Organization (WHO) thresholds. As part of the study, equivalent sound pressure levels, ambient temperature, humidity, and wind speed were recorded during the morning, afternoon, and evening hours on weekdays and weekends. The results showed that regardless of the day (weekday or weekend), the mean 16-h daytime traffic noise levels at all sites exceeded the local and the WHO's recommended thresholds. The values of the mean weekday noise levels at the sites ranged between 67.6 dB(A) and 77.5 dB(A), whereas the weekend values ranged between 68.8 dB(A) and 76.9 dB(A). The measured noise levels were also compared with traffic noise levels reported in other countries. Finally, some recommendations to reduce excessive traffic noise levels were suggested. The results of the study could be used as a benchmark of traffic noise levels in the country after the implementation of any countermeasures in the future.

Keywords: noise assessment; noise pollution; noise standards; road noise; noise environment

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1. Introduction

Environmental noise that crosses certain acceptable thresholds, beyond which adverse short-term or long-term physical, physiological, or psychological effects are felt by an individual exposed to it, is known as noise pollution. According to the World Health Organization (WHO) Regional Office for Europe, after air pollution, noise pollution originating from roadways is the second most hazardous issue that directly or indirectly affects the health and well-being of a population. Consequently, it has set the acceptable noise intensity threshold at 53 dB(A) during the daytime [1]. However, children and elderly people are believed to be vulnerable to much lower noise intensities such as 45 dB(A).

The seriousness of the adverse effects of excessive traffic noise pollution on human health is not distinctly quantifiable or noticeable in the short term. However, cumulative exposure to it has been linked to sleep disturbance, reduced cognitive performance, loss of hearing, cardio-vascular diseases, increased stress levels, irritability, and anti-social behavior [2–5]. For instance, Western Europe alone bears a burden of about one million healthy life years lost annually due to environmental noise caused by traffic [6]. Hence, high-intensity noise generated on the roads by automobiles is considered a nuisance by most urban planners, acoustic designers, researchers, and policymakers [7,8].

The urban environment in Doha, the capital of Qatar, is becoming increasingly crowded as Qatar's population and the total number of registered vehicles continue to grow exponentially due to a recent boom in the field of construction. Regular peak hour traffic congestions combined with closely spaced buildings and a lack of adequate urban green spaces in the capital are expected to increase environmental pollution within the city and adversely affect the health and well-being of the population. As a result, the Qatar government has been expanding roadways and introducing mass transit systems such as public buses and the Doha metro to reduce traffic congestion and encourage its residents to choose more sustainable and efficient means of transport [9,10].

Nevertheless, studies to measure if and to what extent the existing automobile system contributes to noise pollution in Qatar have not been done yet. Thus, a noise level study conducted in Qatar would be informative to the government, policymakers, and urban planners in understanding where the level the noise pollution in the city is at and in planning any required countermeasures. Therefore, the main objectives of this study were to determine whether traffic noise levels in Qatar are within the local and the WHO's acceptable thresholds, compare the traffic noise levels in the city of Doha with other regions around the world, and suggest solutions to mitigate urban noise pollution if needed.

2. Background

2.1. Traffic Noise Level Guidelines

As noise pollution originating from various sources continues to increase, more and more people have been reported to complain about it to environmental protection agencies [11–14]. In addition, long-term exposure to traffic noise has also been associated with adverse health effects. Although in some cases, the associations have been reported to be weak, addressing long-term cumulative exposure to noise pollution is important as it affects large populations in any given area. The annoyance and adverse health effects experienced by the current population, and the growing noise pollution, if kept unchecked, will affect the future generations' social, esthetic, and economic welfare.

$L_{Aeq,T}$, the A-weighted equivalent continuous noise level over a certain duration T, is the measure used to quantify the continuous noise generated from road traffic [13,15]. It is commonly used as the descriptor of environmental noise in various noise control guidelines. Accordingly, the WHO provides an environment-specific guideline for community noise based on the expected critical health effects caused by equivalent noise levels. Based on this guideline, a 16-h equivalent noise level of 55 dB(A) at school, the playground, and outdoor living areas may cause annoyance to serious annoyance due to an external noise source. On the other hand, in industrial, commercial, indoor, outdoor, and traffic areas, $L_{Aeq\cdot 24h}$. of 70 dB(A) can cause critical health effects such as hearing impairment. In other words, the guideline values are given for specific indoor or outdoor settings and periods.

Similarly, based on the expected community reaction to noise exposure and its consequent harmful health effects, noise rating scales [16] and risk zone criteria [17] have been developed to measure and compare community noise levels (see Table 1). Rating scales or risk zone criteria help assess area-specific noise exposure and identify noise hotspots. A noise level above 76 dB(A) has been categorized as very severe noise exposure with moderate to extremely high risk of harmful health effects.

Table 1. Noise level scale for categorizing noise exposure and noise risk zones.

Noise Rating Scale [16]		**Noise Risk Zone Criteria [17]**	
Day–Night Level dB(A)	Noise Exposure	Noise Level dB(A)	Risk Zone
≤55	Minimal		
56–60	Moderate		
61–65	Significant	<66	Safe
66–70	Severe	66–71	Tolerable
71–76	Moderately Severe	71–76	Low Risk
≥76	Very Severe	76–81	Moderate Risk
		81–86	High Risk
		>86	Extremely High Risk

Moreover, according to the WHO, noise pollution caused mainly due to traffic on densely crowded roads can be as high as 75–80 dB(A), particularly in the urban areas of developing nations. As a result, governments around the world have developed ambient noise standards to deal with the increasing problem of noise pollution in various sectors such as residential, commercial, industrial, and silent areas. For example, in 1989, the Central Pollution Control Board (CPCB) in India established ambient air quality standards for different areas [18]. Similarly, the Columbian Ministry of Environment, Housing, and Territorial Development also set the maximum permissible noise levels for Columbia in 2006 [19]. Likewise, the Qatar State Environment Protection Law of 2002 defined the maximum allowable ambient noise limits for Qatar [20].

Accordingly, Table 2 summarizes the specified limits set by the three governments. In general, daytime is considered between 6:00 and 21:00, whereas nighttime is considered between 21:00 and 6:00. In the case of mixed land use, when at least 50% of the use of that area falls within one of the specified land uses in Table 2, it is considered to belong to that category [20]. However, in some cases, the category of mixed land use is declared by an appropriate authority [16,17]. In Qatar, the silence zone is combined with the residential area, and the daytime noise limit is 55 dB(A). On the other hand, commercial and industrial areas are combined in Columbia with the daytime noise limit set at 75 dB(A). Columbia also has a higher daytime noise limit for the residential area (65 dB(A)) unlike India and Qatar—both of which have a lower daytime noise limit of 55 dB(A). Columbia also has a higher silence zone daytime noise limit of 55 dB(A) when compared to India (50 dB(A)).

Table 2. Land use or area-specific noise level threshold guidelines as per Columbia, India, and Qatar.

Columbia [19]			**India [18]**			**Qatar [20]**		
Land Use	Day	Night	Land Use	Day	Night	Land Use	Day	Night
Hospitals, libraries, public health buildings, etc.	55	50	Silence zone (areas 100 m around hospitals, educational institutions, and public service buildings)	50	40			
Residential, hotels, educational institutions, research facilities, parks, etc.	65	55	Residential	55	45	Residential and public corporations (schools, hospitals, and mosques)	55	45
			Commercial	65	55	Commercial (department stores, business offices, garages, and places of work)	65	55
Commercial and industrial	75	75	Industrial	75	70	Industrial facilities	75	75

According to the National Academy of Engineering (NAE), similar to most developed nations in the world, road, rail, air traffic, and industrial activities are the main sources of noise in the U.S. [21]. Therefore, in residential areas, the U.S. Environmental Protection Agency (U.S. EPA) recommends a day–night 24-h average noise level (L_{DN}) exposure limit of 55 dB(A) to keep the public safe from all adverse health effects [22]. In this case, a 10 dB(A) penalty is applied to the nighttime noise levels recorded between 22:00 and 7:00 to account for disruption to sleep, whereas no penalty is applied to the measured daytime noise levels. Likewise, 55 dB(A) is the European Union's (EU's) threshold for daily noise exposure [13].

Moreover, based on population density and land use, the Italian legislation (1997) recommends a maximum noise level of 55 dB(A) and 60 dB(A) for residential and mixed land use, respectively [23]. Along new roads, the New South Wales Australian Environmental Protection Authority specifies a maximum L_{Aeq}. of 60 dB(A) for the daytime. On the other hand, in Thailand, noise pollution guidelines (1996) allow a maximum of 70 dB(A) $L_{Aeq \cdot 24h}$ in residential areas [13,24].

Nevertheless, irrespective of the land use, the WHO specifies an allowable noise level threshold of 53 dB(A) and 45 dB(A) for daytime and nighttime noise levels, respectively, to avoid the adverse health effects caused by environmental traffic noise [1]. In addition, the WHO recommends governments and environment protection authorities shift from varying noise regulations to global noise policies to maximize the health benefits of the entire global population [13].

2.2. Measuring Traffic Noise Levels

Several studies have measured noise levels at intersections (signals, roundabouts, or both) in the areas between or near intersections to compare the noise level results to the local or the WHO's allowable noise level thresholds [11,25,26]. While some specified the intersection and the control type of the sites they studied, some studies did not differentiate between the intersection types and only discussed the overall noise levels observed at these sites [2,27].

For instance, Pandya studied urban noise in four typical cities in India namely Delhi, Jamshedpur, Dehradun, and Nagpur [16]. They measured L_{eq}. continuously during the daytime (6:00 to 21:00) and nighttime (21:00 to 6:00) using a precision integrated sound level meter along with a 94 dB(A) calibrator with an accuracy of ±0.3 dB(A). Additionally, they considered a nighttime penalty of 10 dB(A) in their study. Based on their results, they found that Delhi and Jamshedpur experienced severe noise exposure (>76 dB(A)) compared to the other two cities.

In another similar study done at Nashik city, Maharashtra, India, traffic noise levels at four signalized intersections were measured for two hours during the morning, afternoon, and evening peak hours (8:00 to 10:00, 14:30 to 16:30, and 17:00 to 19:00) [28]. Additionally, the traffic volumes were measured at 1-min intervals. Again, the measured equivalent noise levels at these intersections were found to range between 85.3 dB(A) and 91 dB(A) with a mean value of 79.1 dB(A), all exceeding the permissible noise levels specified by the Central Pollution Control Board of India (CPCB).

Similarly, in a noise study done in the capital Dhaka in Bangladesh, noise level and traffic flow data for a period of 1-month on both working and non-working days were collected at five major and busy signalized intersections [29]. Similar to Pandya (2001), they calibrated the Sound Level Meter (set at A-weighting scale and fast response mode at 1 s intervals) with a 94 dB Sound Level Calibrator before and after taking each noise level datum. The resulting L_{eq}. found at all the five intersections ranged between 77.0 dB(A) and 80.5 dB(A)—above the standard limit set by the Department of Environment, Bangladesh. The causes of high noise levels and their relative contribution to the overall noise level were derived in this study using a combination of video and sound level data. Based on the findings, factors such as pedestrians, motorcycle drivers, manual signaling, congestion, use of horns, on-street parking, etc. mainly contributed to the high traffic noise found at the intersections.

On the other hand, Obaidat developed spatial maps depicting sound level contours for peak traffic periods for the capital city Amman, Jordan with the help of ArcView GIS 3.2 to be used as a land-use planning tool [25]. In this study, noise data were collected during morning, afternoon, and evening peak traffic periods (7:30 to 9:00, 13:30 to 15:00, and 21:00 to 23:00) at 29 locations including signalized intersections, areas in-between the intersections, and the surrounding areas using a portable precision sound level meter. The mean noise levels found during the morning, afternoon, and evening hours were 58.6, 59.2, and 55.6 dB(A), respectively. Hence, the morning and afternoon mean values and the evening mean values were just below the Jordanian noise standards for daytime (60 dB(A)) and nighttime (50 dB(A)) noise levels for residential areas within cities. Additionally, in this study, traffic volume at the intersection was found to be the main factor affecting the equivalent noise levels besides the effects of road geometry, approach slope, traffic speed, percentage of heavy vehicles, road surface texture, and others.

A similar attempt at creating noise maps for a city to facilitate modification of land use and policies and to check if the noise levels in an area were within the prescribed limits set by the government was undertaken by Banerjee et. al. [17]. They collected L_{Aeq}. at residential, silence, commercial, and industrial zones on regular business days using a Sound Level Meter Type-2 (set at A-weighting frequency and fast range) along with a 94 dB(A) multi-function acoustic calibrator. Based on the findings, they developed noise contour maps for the city and classified the study area into different noise risk zones ranging from safe (<66 dB), tolerable, and low risk to extremely high risk with intensities greater than 86 dB. They also suggested a modification of land use based on the noise quality observed in the area.

About 40% of people living in the European Union countries have been reported to be exposed to traffic noise levels above 55 dB(A) [6]. Similarly, many urban areas in other countries are also exposed to traffic noise levels that exceed the limitations set by their governments such as the U.S. [30–32], Canada [23,33,34], Colombia [11], Chile [35], Brazil [36], Vietnam [37], Jordan [25,38], India [2,17,28], Pakistan [27], Bangladesh [29], the U.A.E [39,40], and so on.

However, the high noise levels observed in all these studies are not uncommon for roadways located near major urban intersections. According to the WHO, noise pollution caused by traffic on densely crowded roads can be as high as 75–80 dB(A), particularly in the urban areas of developing nations [13]. Nevertheless, such noise levels are perceivably higher than the allowable noise level thresholds and need to be addressed by governments, urban planners, and policymakers alike. However, no comprehensive traffic noise studies have been done in the Gulf region to investigate the presence and extent of noise pollution in the region and suggest any necessary countermeasures. Therefore, a local traffic noise study to evaluate the traffic noise levels against the recommended noise level limits was necessary for Qatar and other neighboring countries in the region. This work is part of a project studying and modeling traffic noise in Qatar [41,42].

3. Methods

3.1. Study Area

The study area of this research was the capital city of Qatar, Doha, which is the largest city in the country. Most of the population lives in the city of Doha. The city suffers from many problems such as traffic congestion, traffic safety, air pollution, noise pollution, and aggressive driving [43–52]. The study was conducted at eight intersections as shown in Figure 1. The intersection types of interest in this study were two 2-lane signalized intersections (locations 3 and 7), two 2-lane roundabouts (locations 4 and 8), two 3-lane signalized intersections (locations 1 and 5), and two 3-lane roundabouts (locations 2 and 6).

Table 3 summarizes the general characteristics of the eight intersections such as the satellite view, street names, speed limits, total number of lanes (sum of through lanes, left-turning lanes, and right-turning/slip lanes at the intersections), and the average road slope. Many site features between the comparable intersections were found to be similar. For instance, the speed limits indicated at the intersections were mostly 50 km/h and 80 km/h. The width of each lane was approximately 3.6 m. At the signalized intersections, the total number of lanes increased by double or more than double due to the inclusion of more left-turning, through, and right-turning lanes. All intersections had almost flat terrains with less than a 2% gradient. Locations 1 and 4 had the maximum negative and positive gradient of 1.6% and 1.1%, respectively, while the rest of the intersections had even lower negative or positive gradients. At all locations, the pavements were asphalt pavements and appeared to have a smooth texture.

Figure 1. Site locations of the study intersections.

Table 3. Characteristics of the study intersections.

Site	Intersection Type	Approach	Street Name	Speed Limit, km/h	Total Lanes	Mean Slope, G%
1	Siganlized Intersection	NB/SB	Al Sidr St	80	28	−1.6
		EB/WB	Snay bu Hasa St			
2	Roundabout	NB/SB	Al Sidr St	80	11	−1.6
		EB/WB	Snay bu Hasa St			
3	Signalized Intersection	NB/SB	Al-Aziziya St	50	12	0.7
		EB/WB	Osama Bint Zaid St.			
4	Roundabout	NB/SB	Umm Al Seneem St	80	8	1.1
		EB/WB	Khaled Bin Ahmed St	50		
5	Signalized Intersection	NB/SB	Jasim Bin Hamad St	80	28	−0.3
		EB/WB	Al Jazira Al Arabiya St			
6	Rounabout	NB/SB	Al Sedaira St	80	10	−0.8
		EB/WB	Al Waab St			
7	Signalized Intersection	NB/SB	Al Zaghwa St	80	16	−0.9
		EB/WB	Zekreet St	60		
8	Roundabout	NB/SB	Wadi Lubara St	50	8	−0.4
		EB/WB	Rawdat Al Thekhriya St.			

NB = Northbound; SB = Southbound; EB = Eastbound; WB = Westbound. Sites 1 and 2 are for the same intersection after being converted from a roundabout to a signalized intersection.

3.2. Traffic Noise Levels

The WHO recommends keeping the A-weighted equivalent continuous road noise level (L_{Aeq}.) during the 16-h daytime hours (6:00–22:00) well below 53 dB(A). According to the WHO's Guidelines for Community Noise, sound pressure levels of noises are integrated over a time interval as they tend to fluctuate over time. The levels are measured on a logarithmic scale, with decibels (dB) as the unit. As a result, all sound pressure measures are referenced to 1000 Hertz (Hz), the human hearing threshold, and simply how much the measured noises are above the hearing threshold [13]. Moreover, A-weighted noise measurements are known to cover the entire human audio range from 20 Hz to 20 kHz and, as a result, approximate the response of the human hearing system at lower sound levels [13,53]. Likewise, to make all sound pressure measurements and their variations over time representative of the integration time of the human hearing system, the fast response time (corresponding to a time constant of 0.125 s) mode is used. The fast response also gives a good correlation between noise from passing vehicles and the integration of its loudness by the human ear [13].

Moreover, arithmetically adding or averaging sound pressure levels are not possible since they are measured on a logarithmic scale. Due to this, unlike arithmetic additions, the summation of two equal sound pressure levels does not double the total noise. Instead, in such a case, the total sound pressure level is only 3 dB greater than the individual sound pressure level [13]. Additionally, when the difference between two noise levels or the residual (positive or negative) is more than or equal to 5 dB(A), the noise level change is readily perceptible to an observer, which otherwise would be barely perceptible to the human ear [54]. Consequently, an increase or decrease of 10 dB(A) in the noise level would be perceived as twice or half as loud. For example, the noise level of 63 dB(A) to an observer would sound twice as loud as the sound at the WHO's allowable threshold of 53 dB(A). Hence, an increase of 20 dB(A) to an observer would be four times as loud [54].

Additionally, the statistical average, $L_{An,T}$, is a commonly used noise pollution index besides the energy average descriptor, $L_{Aeq}\cdot_{T}$, to analyze noise pollution due to road traffic. With $L_{An,T}$, the noise level which exceeds n% of the time T is expressed in decibels, the value of n being anywhere between 0.01% and 99.99%. However, the most commonly used L_{AnT} to quantify road traffic noise levels and background noise levels are $L_{A10,T}$ and $L_{A90,T}$ [15]. By definition, $L_{A10,T}$—the noise level exceeded for 10% of the time T—is used to measure the annoying peaks of the noise level in dB(A). It is a traffic noise descriptor that expresses the disturbance felt by people near busy traffic roads. On the other hand, $L_{A90,T}$—the noise level exceeded 90% of the time T—takes account of the noise levels in the background.

Therefore, the A-weighted equivalent continuous noise levels over 1 h ($L_{Aeq,1h}$.) and 16 h ($L_{Aeq,16h}$.) were the main environmental noise descriptors used in this study to evaluate noise levels at the eight intersections [13,15]. Additionally, the noise pollution indices, $L_{A10,T}$ and $L_{A90,T}$, were statistically calculated from $L_{Aeq}\cdot_{T}$ to quantify annoyance and background noise levels observed at the intersections.

3.3. Field Measurements

Equivalent sound pressure levels and weather data were recorded at the eight intersections at 5-min intervals on eight weekdays and eight weekends from 6:00 until 22:00 (16 h) to capture noise variations over the morning (6:00–11:00), afternoon (11:00–16:00), and evening (16:00–22:00) hours including the green intervals. At the same time, site characteristics such as speed limit, the total number of lanes, mean slope, and pavement surface texture for each approach were also observed at each of the eight intersections. The mean 16-h traffic noise level data were analyzed to evaluate if the traffic noise levels were within the WHO's allowable threshold of 53 dB(A) for daytime (6:00–22:00) noise.

A Type-II Cirrus Optimus Green CR1720 sound level meter (ranging 20 dB(A) to 140 dB(A)), Cirrus sound level calibrator CR514 (94.0 dB $\pm$ 0.4 dB; 1 kHz $\pm$ 1%), and Kestrel weather meter 5500 were the main tools used for data collection. Hence, the sound pressure levels were recorded at 5-min intervals including the green interval using the Sound Level Meter (SLM) set at 1.2 m above the ground level and within 4 m from the edge of the road at each of the 8 intersections. The time history data rate of the SLM device was set at 1 s, that is, it measured noise level every 1 s within the 5-min intervals. In addition, the SLM was set to record equivalent (energy-average) measurements at the A-weighting scale and fast response mode. Furthermore, the 94 dB Sound Level Calibrator was used to calibrate the SLM before and after each measurement. Corresponding to the recorded noise level measurements, the mean ambient temperature, relative humidity, and wind speed at all the sites were recorded using the professional weather meter, Kestrel 5500.

The traffic condition during the data collection days was regular; that is, data were not collected during vacation or public holiday periods. Additionally, in all cases, data were collected only on days with no rainfall to keep the data at all sites consistent and to avoid noise level recording errors related to wet roadways. Based on ISO Standards (1993, 1996), corrections for noise attenuation due to meteorological parameters such as ambient temperature, relative humidity, and wind would be required if the mean temperature and the relative humidity do not fall between 20–40 °C and 60–80%, respectively, and if the wind speed was not less than 4 m/s at the time of noise level data collection period [11,55,56]. Since the mean temperature, relative humidity, and wind speed during the 16-h data collection periods were found to be 29.2 °C, 65.2%, and 0.8 m/s, respectively, (see Table 4), corrections for noise attenuation due to the meteorological parameters were not required.

Table 4. Mean temperature, relative humidity, and wind speed at the sites.

	Weekday Site Avg. (n = 16)			**Weekend Site Avg. (n = 16)**			**Site Avg. (n = 32)**		
Site ID	Temp. (°C)	Rel. Hum. (%)	Wind (m/s)	Temp. (°C)	Rel. Hum. (%)	Wind (m/s)	Temp. (°C)	Rel. Hum. (%)	Wind (m/s)
1	32.2	70.2	0.7	32.0	69.7	0.8	32.1	70.0	0.7
2	39.9	62.3	0.5	37.2	60.5	0.4	38.6	61.4	0.4
3	27.6	61.8	1.7	30.6	73.1	0.5	29.1	67.5	1.1
4	31.1	60.6	0.7	28.3	66.6	1.3	29.7	63.6	1.0
5	30.9	60.7	1.1	31.5	61.8	0.6	31.2	61.3	0.9
6	32.9	64.6	0.7	30.8	67.4	0.8	31.9	66.0	0.8
7	24.5	62.8	1.3	27.4	71.5	0.4	25.9	67.1	0.9
8	25.6	61.3	0.5	26.8	60.7	0.5	26.2	61.0	0.5
Mean	30.6	63.0	0.9	30.6	66.4	0.7	30.6	64.7	0.8

4. Analysis

The noise levels measured at the eight intersections during the morning, afternoon, and evening hours were examined using common descriptive statistics, various noise pollution indices, and color-coded summary tables. Additionally, the 16-h mean weekday and weekend daytime (6:00–22:00) noise levels at the intersections were illustrated as heat maps to visually analyze the findings from a geographical perspective. Finally, the traffic noise level results were compared to the allowable local and WHO's noise level thresholds and compared to traffic noise levels found in other countries.

4.1. Descriptive Statistics of Noise Levels

Descriptive statistics for the hourly weekday and weekend noise level data collected for 16 h at each of the sites are shown separately in Table 5. The minimum weekday mean noise level was found at location 3 and the maximum mean noise level was found at location 4. The maximum range of noise level and the maximum noise level itself were found at location 5. In addition, the maximum and minimum standard error, standard deviation, and variance were found at location 8 and location 6, respectively. Similar to the findings for the weekend data, the weekend minimum and the maximum mean noise level were found at location 3 and location 4. Additionally, the maximum weekend noise level was recorded at location 4. The minimum and the maximum standard deviation, in this case, were found at location 2 and location 3, respectively.

Table 5. Descriptive statistics of noise level measurements (n = 16 h/site).

	$L_{AFeq \cdot 1h}$, dB(A)						**Min.**	**Max.**
Location	1	2	3	4	5	6	7	8
Weekday								
Mean	73.7	71.7	67.5	77.4	76.1	76.2	71.2	72.4
St. Error	0.3	0.3	0.3	0.2	0.3	0.1	0.2	0.4
Median	73.4	72.0	67.5	77.3	75.9	76.2	71.4	72.4
St. Dev.	1.3	1.2	1.1	0.6	1.4	0.4	0.9	1.5
Variance	1.8	1.4	1.3	0.4	1.8	0.2	0.8	2.1
Range	5.5	3.9	3.7	2.6	5.8	1.5	3.3	5.7
Min.	70.9	69.1	65.7	76.1	74.8	75.4	69.1	69.1
Max.	76.4	73.0	69.4	78.7	80.6	76.9	72.4	74.9
Weekend								
Mean	69.8	74.9	67.3	76.7	74.4	74.4	70.8	69.2
St. Error	0.3	0.1	0.7	0.3	0.3	0.4	0.2	0.5
Median	70.0	75.0	66.8	76.7	74.6	75.3	70.6	69.2
St. Dev.	1.3	0.6	2.9	1.1	1.3	1.8	0.9	1.8
Variance	1.8	0.3	8.6	1.2	1.7	3.2	0.8	3.3
Range	5.1	1.9	13.1	3.8	5.8	4.8	3.8	7.0
Min.	66.6	74.0	63.5	74.7	71.2	71.6	69.5	65.8
Max.	71.7	75.9	76.6	78.5	77.0	76.4	73.3	72.7

4.2. Hourly Noise Levels

The equivalent hourly noise level data collected at the eight intersections are tabulated in Table 6. The primary land use in the surrounding areas of all the intersections was found to be residential, and the WHO guideline stipulated a maximum of 53 dB(A) noise level for residential areas during daytime [13]. Accordingly, 100% of the measured 256 hourly noise level data ($L_{AFeq \cdot 1h \cdot}$) on both weekdays and weekends at all eight sites exceeded the local and the WHO's allowable noise level thresholds of 55 dB(A) and 53 dB(A), respectively. For further analysis, the noise levels in Table 6 were color-coded (green $\rightarrow$ yellow $\rightarrow$ red) based on the range of their values. This helped in the process of identification of interesting and recurring patterns within the data sets. Accordingly, various shades of green, yellow, and red colors indicated values above 53 dB(A). Shades of green indicated that values were above 60 dB(A), yellow colors indicated moderately higher values above 70 dB(A), and shades of red color indicated that values were close to 80 dB(A).

Out of the total 256 h, comparatively lower levels of traffic noise were observed during the early morning hours of the weekend at location 3 and morning and afternoon hours at location 2. The reason could be attributed to the usually low traffic volume expected during the early morning hours of weekends and not particularly the intersection type. The weekday traffic noise level was found to be maximum (80.6 dB(A)) at location 5 and minimum (65.7 dB(A)) at location 3. Noise levels were mostly above 75 dB(A) at location 4, location 5, and location 6. Likewise, noise levels during weekends at the same sites were also much higher compared to other locations. The noise levels at location 2 and location 3 on both weekdays and weekends were mostly around 65 dB(A); whereas, weekday and weekend noise levels at location 1, location 7, and location 8 were around 70 dB(A). The overall noise levels were higher on weekdays; however, the opposite was also true in some other cases, indicating that factors other than the expected lower volume of traffic on weekends could be impacting the noise levels observed.

Table 6. Weekday and weekend hourly noise levels, $L_{AFeq \cdot 1h \cdot}$, dB(A).

Location		1	2	3	4	5	6	7	8
Weekday									
Morning	6:00–7:00	73.0	68.2	67.4	77.9	75.5	76.8	72.0	73.3
	7:00–8:00	72.8	71.0	66.4	76.1	75.2	76.1	71.1	73.7
	8:00–9:00	73.1	71.6	65.7	77.3	75.8	76.1	71.9	72.8
	9:00–10:00	73.5	72.6	69.4	77.2	75.7	75.9	71.1	72.4
	10:00–11:00	74.5	70.8	68.7	77.6	76.2	75.4	71.4	73.0
Afternoon	11:00–12:00	73.3	71.1	68.6	78.3	76.4	76.2	71.9	73.8
	12:00–13:00	72.5	70.6	67.9	77.4	76.3	76.4	70.3	72.4
	13:00–14:00	74.8	70.7	67.6	77.5	80.3	75.8	71.1	74.0
	14:00–15:00	73.2	71.8	66.8	76.9	76.9	76.2	72.0	74.9
	15:00–16:00	75.9	69.8	66.6	76.9	75.9	76.3	71.6	72.1
Evening	16:00–17:00	76.4	69.6	66.6	78.7	75.6	76.9	72.4	71.7
	17:00–18:00	73.1	69.4	67.5	78.2	75.1	76.3	71.5	71.2
	18:00–19:00	73.7	68.4	69.1	77.5	74.8	76.2	71.0	71.8
	19:00–20:00	74.4	69.1	66.4	77.1	80.6	76.2	71.5	71.5
	20:00–21:00	70.9	69.6	68.7	77.2	74.8	76.7	69.1	70.2
	21:00–22:00	74.0	69.7	66.5	76.9	75.9	75.7	69.6	69.1
Weekend									
Morning	6:00–7:00	66.6	62.4	63.5	74.7	71.2	71.6	70.4	65.8
	7:00–8:00	68.4	63.1	64.3	75.0	72.6	71.7	70.3	66.7
	8:00–9:00	68.8	63.2	65.4	76.7	75.6	72.7	70.1	67.6
	9:00–10:00	69.1	64.3	67.2	77.0	74.7	72.6	71.2	68.1
	10:00–11:00	69.4	63.7	66.7	77.9	74.4	72.7	70.5	68.6
Afternoon	11:00–12:00	68.5	64.9	66.2	78.3	74.9	72.6	71.4	70.0
	12:00–13:00	70.1	64.7	69.1	78.5	74.2	74.4	69.5	70.1
	13:00–14:00	71.2	65.0	67.8	77.0	77.0	75.1	70.1	70.2
	14:00–15:00	71.1	64.3	76.6	76.7	74.2	75.8	70.7	71.6
	15:00–16:00	71.7	64.3	69.4	77.7	74.8	76.1	71.9	71.3
Evening	16:00–17:00	71.5	67.4	68.3	76.6	75.7	76.1	73.3	69.2
	17:00–18:00	70.4	69.4	66.8	77.6	74.7	76.4	71.0	68.3
	18:00–19:00	70.4	67.5	67.7	76.1	74.4	75.5	71.5	69.5
	19:00–20:00	69.9	67.2	66.7	76.0	74.9	75.9	70.3	69.1
	20:00–21:00	70.0	68.2	66.1	76.1	74.1	75.6	71.0	68.2
	21:00–22:00	69.3	69.9	65.7	75.9	73.7	76.3	69.9	72.7
Color scales (dB(A))		≥53 dB(A), max. allowed					60.0	70.0	80.0

4.3. Distribution of Hourly Noise Levels

The histogram in Figure 2 depicts the frequency of occurrence or distribution of all $L_{AFeq \cdot 1h \cdot}$ values, that is, 16 hourly noise level data per day per site. Depending on the range of $L_{AFeq \cdot 1h \cdot}$ values, five equally sized (5 dB(A)) bins/buckets/intervals were created starting from 60 dB(A) to 85 dB(A). The mean values of weekday, weekend, and combined data were 74.4, 72.9, and 73.7 dB(A), respectively. The histogram appeared to be mostly symmetrical about the mean values and had a bell shape. Consequently, the three data sets seemed to be almost normally distributed as the majority of the data were concentrated around the middle bin (70–75 dB(A)).

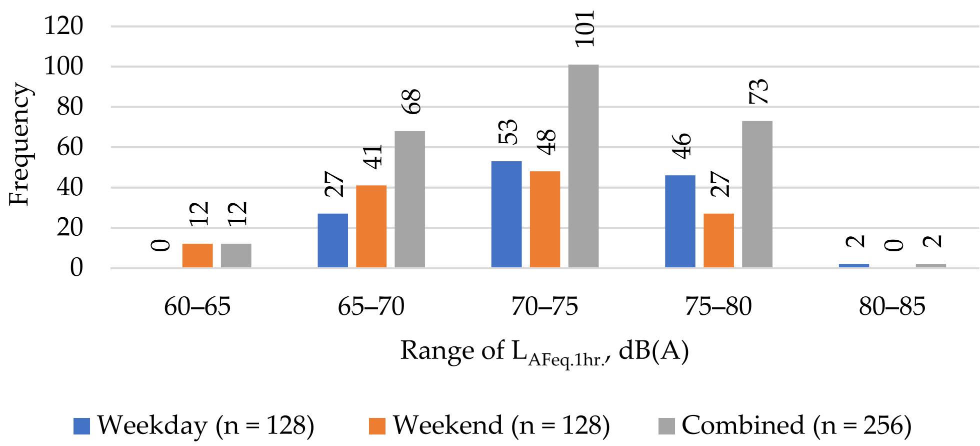


Figure 2. Hourly noise level ($L_{AFeq\cdot 1h\cdot}$) histogram.

Nonetheless, the weekday values ranged between 65 to 85 dB(A) while the weekend values ranged between 60 and 80 dB(A). Overall, weekdays had higher percent frequencies on the higher bin values (70–75, 75–80, and 80–85), whereas the weekend percent frequencies were higher on the lower side of the bins (60–65 and 65–70). Combined percent frequencies were also comparatively higher on the higher side of the bins. Regardless, 39% of all the values were in the middle bin (70–75 dB(A)), 29% were in a higher bin (75–80 dB(A)), and 27% were in the lower bin (65–70 dB(A)), indicating that all the noise level values measured not only exceeded the WHO's allowable threshold of 53 dB(A) but did so with high values.

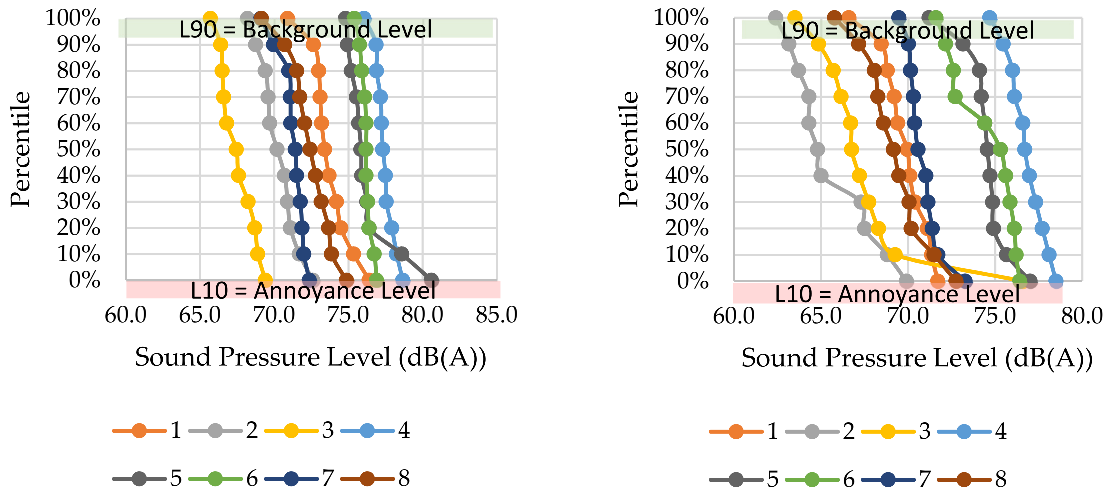
4.4. Noise Pollution Indices

To find the annoyance noise levels and the background noise levels from the hourly noise level measurements collected at each site for 16 h, statistical analysis was used. The resulting weekday and weekend $L_{An,1h\cdot}$ values found as percentiles were plotted against the corresponding noise levels as shown in Figure 3a,b. The weekday statistical distribution of the noise levels shows that the background noise levels at location 3, the quietest site, were between 65.7 dB(A) and 66.4 dB(A) based on $L_{A90,1h\cdot}$ data. On the other hand, the annoyance noise levels due to traffic at the noisiest site, location 5, were between 78.6 dB(A) and 80.6 dB(A) due to $L_{A10,1h\cdot}$ noise data. Likewise, from the weekend statistical distribution of the noise levels illustrated in Figure 3b, it was observed that the background noise levels at the quietest site, location 2, were between 62.4 dB(A) and 63.2 dB(A) due to $L_{A90,1h\cdot}$ data. On the contrary, based on the $L_{A10,1h\cdot}$ data, the annoyance noise levels due to traffic noise at the noisiest site, location 4, were between 78.1 dB(A) and 78.5 dB(A).

4.5. Mean Morning, Afternoon, and Evening Noise Levels

The mean morning (5-h), afternoon (5-h), and evening (6-h) noise level values on weekdays and weekends are summarized in Table 7. This table was also color-coded similar to Table 6. Accordingly, shades of green color were for values above 60 dB(A), shades of yellow were for values above 70 dB(A), and shades of red were for values below 80 dB(A). An overall inspection of Table 7 shows that the lowest mean values for noise levels on weekdays occurred at location 3 followed by location 2. Location 4 had the highest mean values followed by location 5 and location 6. On the other hand, on weekends, the lowest mean values were found at location 2 followed by location 3 and location 8. Similar to weekdays, location 4 again had the highest mean values of noise levels followed by location 5 and location 6.

Moreover, on weekdays, the mean afternoon noise levels exceeded the mean morning and the mean evening noise level values at most sites. Nonetheless, all the mean values were close to one another and ranged between 65 dB(A) and 80 dB(A). The overall maximum and minimum noise levels noticed on weekdays were the mean evening noise level (77.6 dB(A)) at location 4 and the mean evening noise level (67.6 dB(A)) at location 3.



(**a**) (**b**)

Figure 3. (**a**) Distribution of weekday noise levels at all sites (16 h per site); (**b**) distribution of weekend noise levels at all sites (16 h per site).

Table 7. Mean morning, afternoon, and evening noise levels.

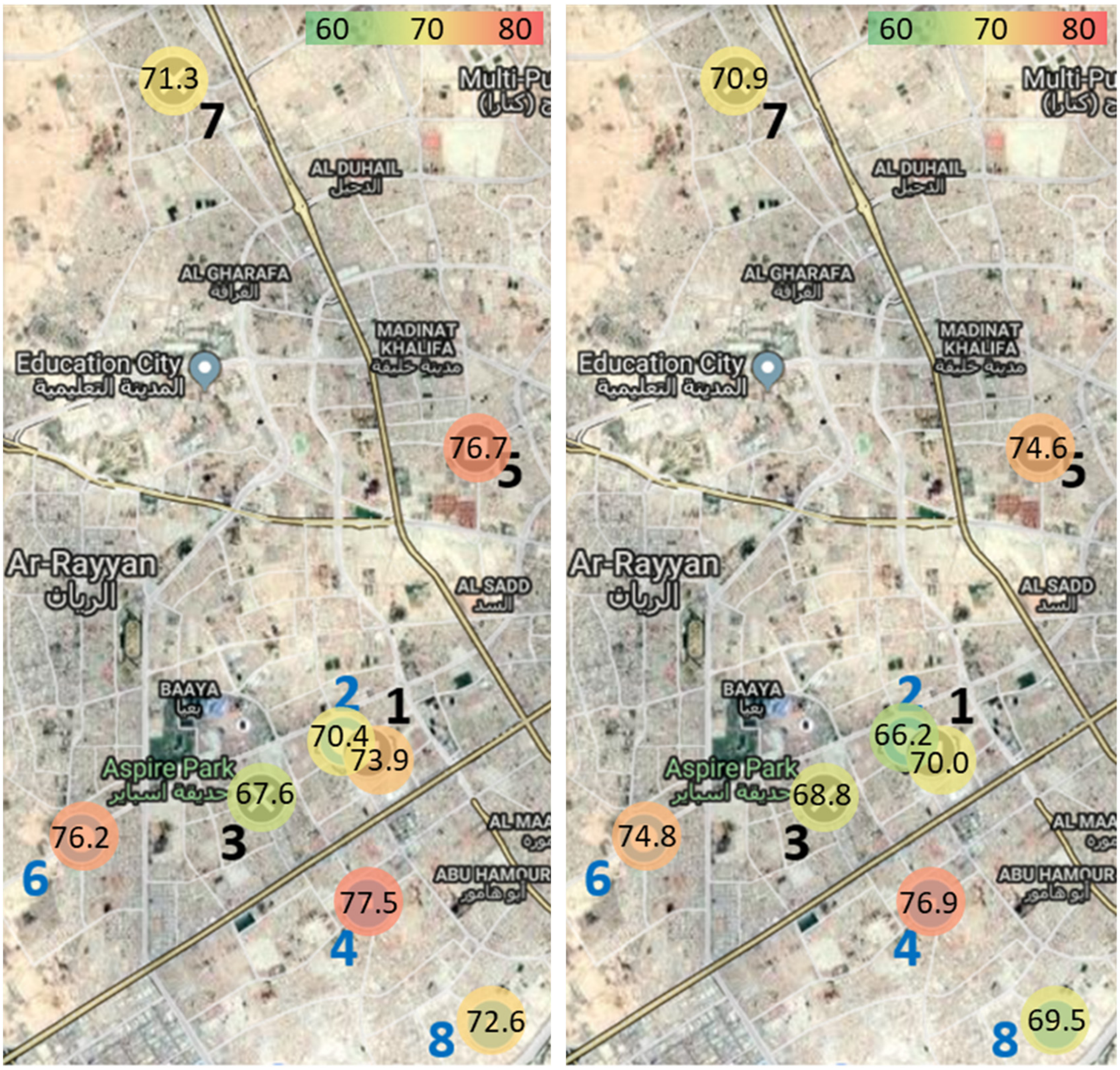
Location	Weekday			Weekend		
	$L_{AFeq\cdot Morning}$, dB(A)	$L_{AFeq\cdot Afternoon}$, dB(A)	$L_{AFeq\cdot Evening}$, dB(A)	$L_{AFeq\cdot Morning}$, dB(A)	$L_{AFeq\cdot Afternoon}$, dB(A)	$L_{AFeq\cdot Evening}$, dB(A)
1	73.4	74.1	74.1	68.6	70.7	70.3
2	71.1	70.8	69.3	63.4	64.6	68.4
3	67.7	67.6	67.6	65.6	71.6	67.0
4	77.3	77.4	77.6	76.4	77.7	76.4
5	75.7	77.5	76.7	74.0	75.2	74.6
6	76.1	76.2	76.4	72.3	75.0	76.0
7	71.5	71.4	71.0	70.5	70.8	71.3
8	73.1	73.5	71.0	67.5	70.7	69.8
Color scales (dB(A))	$\geq$53 dB(A), max. allowed			60.0	70.0	80.0

On the other hand, on weekends, the mean evening noise levels mostly exceeded the mean afternoon and the mean morning noise levels. In this case, the noise levels ranged between 60 dB(A) and 80 dB(A). Similar to weekdays, the maximum mean noise level (77.7 dB(A)) was again observed at location 4 but for the mean afternoon noise level instead of the evening. The minimum mean noise level (63.4 dB(A)) was observed for the mean morning noise level at location 2.

4.6. Daytime Noise Levels

Heat maps for the weekday and weekend daytime (6:00–22:00) noise level values at the intersections were generated (see Figure 4a,b) using color scales similar to Tables 6 and 7.

As shown in Figure 4, the weekday daytime noise levels at most of the eight sites were higher than those on the weekends except at location 3 where the weekend noise level exceeded the weekday noise level by only 1.2 dB(A)). On weekdays (see Figure 4a), the minimum (67.6 dB(A)) and the maximum (77.5 dB(A)) daytime noise levels were observed at location 3 and location 4, exceeding the WHO's allowable noise level threshold of 53 dB(A) by 14.6 dB(A) and 24.5 dB(A), respectively. On weekends (see Figure 4b), the minimum (66.2 dB(A)) and the maximum (76.9 dB(A)) daytime noise levels exceeded the threshold by 13.2 dB(A) and 23.9 dB(A) at location 2 and location 4, respectively. In other words, location 3 and location 2 generated the lowest daytime traffic noise on the weekday and weekend, respectively, and location 4 generated the highest daytime traffic noise on both days compared to the other six intersections.



(**a**) (**b**)

Figure 4. (**a**) Map of weekday daytime noise levels, $L_{AFeq \cdot Day}$ (dB(A)); (**b**) map of weekend daytime noise levels, $L_{AFeq \cdot Day}$ (dB(A)).

The heat maps (see Figure 4a,b) could be used by policymakers and urban planners to locate high noise risk zones on the city's map, determine or modify land use accordingly, or mitigate high noise levels in the identified areas so that they conform to the allowable noise limits designated in those areas. For instance, based on the noise rating scale [16] and noise risk zone criteria [17] (see Table 1), two weekday sites (locations 2 and 3) and more than half of the weekend sites (locations 1, 2, 3, 7, and 8) could be said to have severe noise exposure (66 dB(A)–70 dB(A)) with tolerable risk (66 dB(A)–71 dB(A)). Three out of the eight weekday sites (locations 1, 7, and 8) and three out of the eight weekend sites (locations 5 and 6) were found to have moderately severe exposure (71 dB(A)–76 dB(A)) with low-risk noise (71 dB(A)–76 dB(A)). However, three weekday sites (locations 4, 5, and 6) and only one weekend site (location 4) had severe noise exposure (≥ 76 dB(A)) corresponding to moderate noise risk (76 dB(A)–81 dB(A)).

4.7. Daytime Residual Noise Levels

Figure 5 illustrates the daytime (mean 16-h) weekday and weekend noise level residual ($L_{AFeq\cdot Daytime}$–53 dB(A)) values at the eight locations. The residual values were found to be mostly higher on weekdays compared to weekends. Moreover, the daytime weekday and weekend traffic noise levels at each of the intersections exceeded the WHO's acceptable daytime noise level threshold of 53 dB(A) by at least 14.6 dB(A) and 13.2 dB(A), respectively. In other words, all the residual values at all the sites were greater than 5 dB(A), indicating that the differences in the noise levels at these sites from the WHO's allowable threshold of 53 dB(A) were readily perceptible to an observer [54]. Moreover, since the residuals at locations 1, 2, 3, 7, and 8 were above 10 dB(A)), they were expected to be perceived as at least twice as loud. The residuals (above 20 dB(A)) at 4, 5, and 6 were expected to be much more perceptible and sound about four times louder.

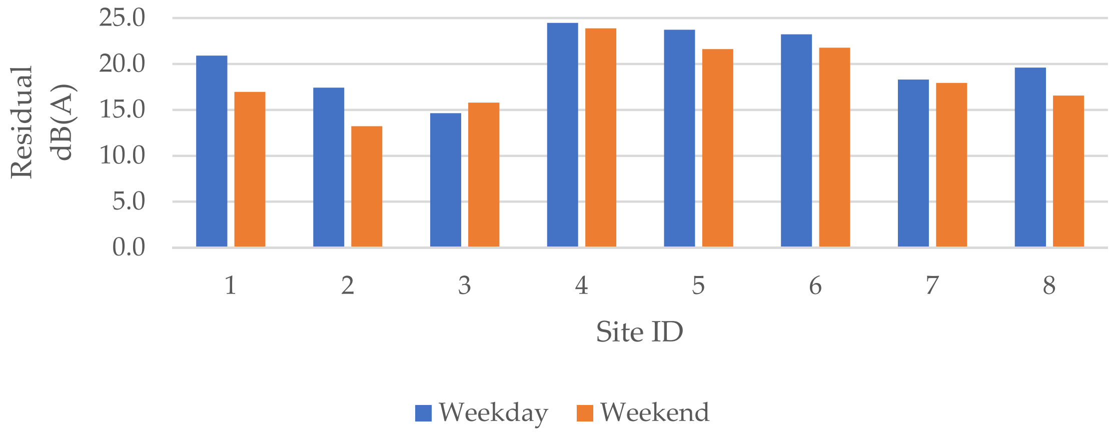


Figure 5. Daytime residual noise levels, $\Delta L = (L_{AFeq\cdot Daytime}–53)$ dB(A).

4.8. Noise Levels across Other Major Cities

In a noise level study done in downtown areas of three major cities in the U.S. namely New York City, Los Angeles, and Atlanta, the mean traffic noise levels found at all three cities were above the U.S. EPA's recommended mean 24-h noise level exposure limit of 55 dB(A), that is, 69.2 dB(A), 66.4 dB(A), and 65.1 dB(A), respectively [30]. In another noise study conducted in New York City, the mean noise level found was equal to 73.4 dB(A) [31]. Moreover, in a study exploring cyclists' exposure to road traffic noise in Montreal, Canada, the mean road traffic noise exposure level was found to be 70.5 dB(A) [34], exceeding the WHO's acceptable noise threshold of 53 dB(A) for daytime noise levels by 17.5 dB(A).

Similarly, South American cities such as Cartagena in Columbia [11], Valdivia in Chile [35], and Curitiba in Brazil [36] also had traffic noise levels that exceeded the local and the WHO's allowable noise thresholds. For instance, the average noise level found in a city in Chile was 68 dB(A), exceeding the WHO's 16-h daytime noise level threshold of 53 dB(A) [35]. In the noise assessment study done in Curitiba, Brazil, the mean community noise level observed near roadways was reported to be 73.1 dB(A), 20.1 dB(A) above the WHO's allowable noise threshold of 53 dB(A) [36]. Moreover, in the noise study done in Cartagena, Columbia [11], noise levels at six out of the eight studied intersections did not comply with the local limit of 70 dB(A) specified for urban areas classified under intermediate and restricted noise [19]. Additionally, all the intersections exceeded the WHO's allowable noise threshold of 53 dB(A), and the values of the measured traffic noise levels ranged between 63.9 dB(A) and 80.9 dB(A) 80% of the time.

Likewise, traffic noise levels in many Asian cities have also been found to exceed the limitations set by their respective governments. For example, in a noise study done in

Dhanbad city in the Jharkhand state of India, the mean noise level (87.2 dB(A)) observed exceeded the permissible noise levels specified by the Central Pollution Control Board of India (CPCB) [18,57]. In another noise pollution study conducted in India, L_{eq}. was collected at intersections located in commercial, residential, industrial, and silence zones. The measured average daytime noise levels at these sites were 77.10 dB (A) (industrial), 71.40 dB (A) (commercial), 58.0 dB (A) (residential), and 56.13 dB (A) (silence zone), that is, 2.1 dB(A), 6.4 dB(A), 3.0 dB(A), and 6.13 dB(A) above the permissible noise level limits specified by the Central Pollution Control Board of India (CPCB) for each zone type [2].

Moreover, to assess road traffic noise pollution in Karachi, Pakistan, data were collected at 308 sites mostly located around severely congested intersections for two weeks from 6:30 to 24:00 [27]. The mean noise level found in this study was also above the WHO's allowable threshold of 53 dB(A) for daytime outdoor noise. On the other hand, in Jordan, a total of 4745 1-min L_{eq}. noise samples were collected at 40 signalized intersections [38]. In this study, the mean 1 min equivalent traffic noise levels observed was 76.1 (dB(A)), which was above the WHO's recommendation noise level threshold of 53 dB(A) for daytime exposure.

In addition to this study, noise levels originating from roadways have been studied in only two other cities in the Middle East, that is, Sharjah and Dubai, United Arab Emirates (U.A.E). In the Sharjah noise study, around 420 hourly equivalent noise level (L_{eq}.) measurements were collected from three different road sites. Consequently, the mean L_{eq}. value was 65.8 dB(A) which exceeded the WHO's daytime noise limitation of 65 dB(A) [39]. In the Dubai noise study, 24-h average sound levels ($L_{Aeq,24h}$.) were collected at seven sites located near Dubai International Airport, one of the busiest airports in the world, to compare noise exposures due to road traffic, aircraft, and combined sources [40]. Results suggested that, at most sites, the range of road traffic noise exposure (67.2 dB(A)~71.1 dB(A)) was more dominant than the aircraft (55.6 dB (A)~71.3 dB (A)), and the combined (69.6 dB(A)~74.7 dB(A)) noise exposure ranges. Nonetheless, like in Sharjah, the mean noise exposure levels due to road traffic at all the seven sites in Dubai exceeded the WHO's allowable threshold of 53 dB(A).

To sum up, like most other major cities, the overall mean noise level (73.9 dB(A)) found in the city of Doha exceeded the local and the international noise thresholds. Hence, addressing noise pollution issues through the implementation of a variety of strategic urban noise management policies is crucial for both developed and developing countries.

5. Discussion

In this study, an investigation was carried out to determine whether the equivalent traffic noise levels at intersections in the city of Doha were below or above the local and the WHO's acceptable daytime noise level thresholds of 55 dB(A) and 53 dB(A), respectively. The results showed that the mean (16-h) weekday and weekend noise levels at all the sites exceeded both the allowable noise thresholds by at least 14.6 dB(A) and 13.2 dB(A), respectively. Hence, the noise level increments (above 5 dB(A)) from the WHO's allowable threshold were found to be readily perceptible at all the sites. The mean weekday noise levels mostly exceeding the mean weekend noise levels could be an indication that the usually higher weekday traffic volumes in the city were most likely to be the cause [8].

On weekdays, it was observed that the mean afternoon noise levels mostly exceeded the mean morning and the mean evening noise levels. However, the maximum and the minimum weekday noise levels observed were the mean evening (77.7 dB(A)) and the mean evening (67.6 dB(A)) noise levels at location 4 and location 3, respectively. On the other hand, on weekends, the mean evening noise levels mostly exceeded the mean afternoon and the mean morning noise levels. Additionally, in this case, the maximum and the minimum weekday noise levels observed were the mean afternoon (77.7 dB(A)) and the mean morning (65.6 dB(A)) noise levels at location 4 and location 3, respectively. The comparatively lower mean morning noise levels on both the weekdays and weekend suggested that traffic volumes were probably lower during the early hours of the day.

The varied distribution of the noise levels across the eight locations indicated that the observed noise levels were most likely dependent on the traffic volume, intersection type, and other site characteristics and not on the proximity of one site or intersection type to another. This suggested that factors other than the intersection type and the number of lanes such as traffic volume and composition could be contributing to the noise level variations observed among the different locations [11].

The noise levels within the city were compared with the traffic noise levels reported in some other major cities across the world. The noise levels found within the city of Doha were not unlike those found in other major cities around the world with most noise levels exceeding local and international noise level thresholds [2,11,17,23,25,27–36,38–40]. Hence, addressing noise pollution issues is crucial for both developed and developing countries. Accordingly, a variety of strategic urban noise reduction and management policies need to be implemented to mitigate the high traffic noise levels observed in the city. The findings of this study are thus expected to aid governments, transport engineers, urban planners, and policymakers to come up with solutions and policies to control and mitigate current and future traffic noise pollution in Doha and other similar cities in the region.

5.1. Limitations and Future Research Directions

The data collection period was limited to 16 h of daytime (6:00–22:00) since the peak morning, afternoon, and evening traffic hours were expected to fall within this period. In this study, daytime noise levels were assumed to be more critical than nighttime noise levels. Therefore, future studies could focus on measuring traffic noise levels in Qatar during the nighttime and compare them to the local and WHO's standards. The study also used eight sites only. In the future, a larger-scale noise level study could be conducted in Qatar with more data points taken around major city blocks, intersections, and road sections during daytime and nighttime to further validate the findings of this study and to compare the differences in noise levels based on the time of the day. The findings of such a study could also help determine the main reasons behind the excessive traffic noise levels found in Qatar. In addition, the data could be used to generate a detailed traffic noise map of the city. This would aid in the identification of high noise risk zones within the city so that present and future land use could be modified and planned accordingly. Additionally, analysis of traffic noise level data along with other relevant data collected at a high number of locations could help determine the relative impact of the noise contributing factors such as traffic volume, speed, and composition, pavement surface texture, number of lanes, traffic speed, and meteorological conditions.

5.2. Recommendations

To reduce excessive traffic noise levels in Qatar, sustainable urbanization that incorporates traffic noise-reducing policies and strategies need to be implemented in the country. For years, developed countries like the UK, USA, and Australia have identified traffic noise generated on roads to be an issue of public health and welfare. Consequently, these nations have developed a range of traffic noise policies targeting a reduction of traffic noise levels at the source level by controlling and limiting vehicle usage by creating environmental awareness, introducing sustainable means of public transport, or encouraging walking or cycling. Additionally, their governments have also stipulated traffic noise management guidelines for designing roadways and planning land use for areas that are noise-sensitive [58].

Hence, the first step towards reducing noise pollution levels in Qatar could be through discouraging and limiting the main source of excessive traffic noise levels in the city: the use of automobiles. To do this, the government needs to introduce public awareness campaigns regarding the adverse environmental and health effects of excessive traffic noise generated due to heavy dependence on this mode of travel. At the same time, more sustainable alternatives such as public buses, metro, cycling, and walking need to be made more attractive and accessible to the population by urban planners and policymakers [59–62].

Finally, noise mitigation strategies need to be applied through the introduction of noise reduction vegetation zones in the city and the installation of noise barriers where needed [63–67]. Furthermore, better urban and land-use planning combined with the implementation of more efficient traffic management schemes such as diverting traffic from heavily congested road networks using the latest technologies could also help reduce excessive traffic noise generated in the adjacent areas.

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References

1. WHO. *Environmental Noise Guidelines for the European Region*; WHO: Copenhagen, Denmark, 2018.
2. Raman, M.; Chhipa, R.C. Study of Noise Pollution at Major Intersections in Jaipur City. *Int. J. Eng. Sci. Technol. Res.* **2014**, *3*, 74–80.
3. Ouis, D. Annoyance from Road Traffic Noise: A Review. *J. Environ. Psychol.* **2001**, *21*, 101–120. [CrossRef]
4. Begou, P.; Kassomenos, P. Exposure to the road traffic noise in an urban complex in Greece: The quantification of healthy life years lost due to noise-induced annoyance and noise-induced sleep disturbances. *Environ. Sci. Pollut. Res. Int.* **2020**, *28*, 12932–12943. [CrossRef] [PubMed]
5. Tangermann, L.; Vienneau, D.; Hattendorf, J.; Saucy, A.; Künzli, N.; Schäffer, B.; Wunderli, J.M.; Röösli, M. The association of road traffic noise with problem behaviour in adolescents: A cohort study. *Environ. Res.* **2022**, *207*, 112645. [CrossRef]
6. WHO; Regional Office for Europe. *Burden of Disease from Environmental Noise*; WHO: Copenhagen, Denmark, 2011.
7. Cai, Y.; Ramakrishnan, R.; Rahimi, K. Long-term exposure to traffic noise and mortality: A systematic review and meta-analysis of epidemiological evidence between 2000 and 2020. *Environ. Pollut.* **2020**, *269*, 116222. [CrossRef]
8. Hegewald, J.; Schubert, M.; Lochmann, M.; Seidler, A. The Burden of Disease Due to Road Traffic Noise in Hesse, Germany. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9337. [CrossRef]
9. Shaaban, K.; Khalil, R.F. Investigating the Customer Satisfaction of the Bus Service in Qatar. In Proceedings of the 2nd Conference of Trans-portation Research Group of India, Agra, India, 12–15 December 2013. Available online: http://gateway.webofknowledge.com/gateway/Gateway.cgi?GWVersion=2&SrcAuth=ORCID&SrcApp=OrcidOrg&DestLinkType=FullRecord&DestApp=WOS_CPL&KeyUT=WOS:000335889700090&KeyUID=WOS:000335889700090 (accessed on 1 January 2022).
10. Shaaban, K. Who Is Going to Ride the Upcoming Metro in Qatar? In *Advances in Intelligent Systems and Computing*; Springer: Berlin/Heidelberg, Germany, 2019; Volume 786.
11. Quiñones-Bolaños, E.E.; Bustillo-Lecompte, C.F.; Mehrvar, M. A traffic noise model for road intersections in the city of Cartagena de Indias, Colombia. *Transp. Res. Part D Transp. Environ.* **2016**, *47*, 149–161. [CrossRef]
12. Environment Protection Authority Victoria. *EPA Annual Report 2017–18*; Sustainability Victoria: Melbourne, VIC, Australia, 2018.
13. Berglund, B.; Lindvall, T.; Schwela, D.H.; World Health Organization Occupational and Environmental Health Team. *Guide-Lines for Community Noise*; World Health Organization: London, UK, 1999.
14. Banerjee, D. Road Traffic Noise and Self-Reported Sleep Disturbance: Results from a Cross-Sectional Study in Western India. *Noise Vib. Worldw.* **2013**, *44*, 10–17. [CrossRef]
15. Acoustic Glossary L-Definitions, Terms, Units, Measurements; Gracey & Associates: Upper Dean, UK. Available online: https://www.acoustic-glossary.co.uk/definitions-l.htm (accessed on 1 September 2018).
16. Pandya, G.H. Urban Noise—A Need for Acoustic Planning. *Environ. Monit. Assess.* **2001**, *67*, 379–388. [CrossRef]
17. Banerjee, D.; Chakraborty, S.K.; Bhattacharyya, S.; Gangopadhyay, A. Evaluation and Analysis of Road Traffic Noise in Asansol: An Industrial Town of Eastern India. *Int. J. Environ. Res. Public Health* **2008**, *5*, 165–171. [CrossRef]
18. CPCB. *Noise Pollution Regulations in India*; CPCB: Delhi, India, 2001.
19. MAVDT. *Resolución 0627 de 2006. Norma Nacional de Emisión de Ruido y Ruido Ambiental*; MAVDT: Bogota, Colombia, 2006.
20. SCENR. *Qatar State Environmental Protection Law 2002*; SCENR: Doha, Qatar, 2002.
21. Hammer, M.S.; Swinburn, T.K.; Neitzel, R.L. Environmental Noise Pollution in the United States: Developing an Effective Public Health Response. *Environ. Health Perspect.* **2014**, *122*, 115–119. [CrossRef]

22. US Environmental Protection Agency. *EPA Identifies Noise Levels Affecting Health and Welfare*; US Government Printing Office: Washington, DC, USA, 1974.
23. King, G.; Roland-Mieszkowski, M.; Jason, T.; Rainham, D.G. Noise Levels Associated with Urban Land Use. *J. Hered.* **2012**, *89*, 1017–1030. [CrossRef]
24. Prasanchuk, S. Noise pollution. Its effect on health and hearing—Thailand as a case study. In *PDH Informal Consultation on the Prevention of Noise-Induced Hearing Loss*; World Health Organization: Geneva, Switzerland, 1997.
25. Obaidat, M.T. Spatial Mapping of Traffic Noise Levels in Urban Areas. *J. Transp. Res. Forum* **2011**, *47*, 1711. [CrossRef]
26. Ahmed, K.I.; Pandya, G.H.; Stoilova, K.; Stoilov, T.; Babisch, W.; Beule, B.; Kokowski, P. Analysis of traffic noise in a road intersection configuration. *Appl. Acoust.* **2016**, *12*, 1–8.
27. Mehdi, M.R.; Kim, M.; Seong, J.C.; Arsalan, M.H. Spatio-temporal patterns of road traffic noise pollution in Karachi, Pakistan. *Environ. Int.* **2011**, *37*, 97–104. [CrossRef]
28. Vilas, P.; Prashant, N.P. Measurement and Analysis of Noise at Signalised Intersections. *J. Environ. Res. Dev.* **2015**, *9*, 662.
29. Arif, A.M.; Ali, M.A. Differentiating Sources of Noise at Busy Road Intersections in Dhaka City. *Int. Proc. Chem. Biol. Environ. Eng.* **2014**, *78*, 6–10.
30. Lee, E.Y.; Jerrett, M.; Ross, Z.; Coogan, P.F.; Seto, E.Y. Assessment of traffic-related noise in three cities in the United States. *Environ. Res.* **2014**, *132*, 182–189. [CrossRef]
31. McAlexander, T.P.; Gershon, R.R.M.; Neitzel, R.L. Street-level noise in an urban setting: Assessment and contribution to personal exposure. *Environ. Health* **2015**, *14*, 18. [CrossRef]
32. Seong, J.C.; Park, T.H.; Ko, J.H.; Chang, S.; Kim, M.; Holt, J.B.; Mehdi, M.R. Modeling of road traffic noise and estimated human exposure in Fulton County, Georgia, USA. *Environ. Int.* **2011**, *37*, 1336–1341. [CrossRef]
33. Carrier, M.; Apparicio, P.; Séguin, A.M. Road traffic noise in Montreal and environmental equity: What is the situation for the most vulnerable population groups? *J. Transp. Geogr.* **2016**, *51*, 1–8. [CrossRef]
34. Apparicio, P.; Carrier, M.; Gelb, J.; Séguin, A.-M.; Kingham, S. Cyclists' exposure to air pollution and road traffic noise in central city neighbourhoods of Montreal. *J. Transp. Geogr.* **2016**, *57*, 63–69. [CrossRef]
35. Sommerhoff, J.; Recuero, M.; Suárez, E. Community noise survey of the city of Valdivia, Chile. *Appl. Acoust.* **2004**, *65*, 643–656. [CrossRef]
36. Calixto, A.; Diniz, F.B.; Zannin, P.H. The statistical modeling of road traffic noise in an urban setting. *Cities* **2003**, *20*, 23–29. [CrossRef]
37. Ky, N.M.; Lap, B.Q.; Hung, N.T.Q.; Thanh, L.M.; Linh, P.G. Investigation and Assessment of Road Traffic Noise: A Case Study in Ho Chi Minh City, Vietnam. *Water Air Soil Pollut.* **2021**, *232*, 259. [CrossRef]
38. Abo-Qudais, S.; Alhiary, A. Statistical models for traffic noise at signalized intersections. *Build. Environ.* **2007**, *42*, 2939–2948. [CrossRef]
39. Hamad, K.; Khalil, M.; Shanableh, A. Modeling roadway traffic noise in a hot climate using artificial neural networks. *Transp. Res. Part D Transp. Environ.* **2017**, *53*, 161–177. [CrossRef]
40. Elmehdi, H.M. Using mathematical models to predict annoyance from combined noise sources in the city of Dubai. In *Inter Noise*; Citeseer: Melbourne, VIC, Australia, 2014.
41. Abdur-Rouf, K.; Shaaban, K. Comparing Traffic Noise Levels between Signalized Intersections and Roundabouts in an Urban Environment. *Transp. Res. Rec. J. Transp. Res. Board* **2022**, 03611981221088219. [CrossRef]
42. Abdur-Rouf, K.; Shaaban, K. Development of prediction models of transportation noise for roundabouts and signalized intersections. *Transp. Res. Part D Transp. Environ.* **2022**, *103*, 103174. [CrossRef]
43. Tageldin, A.; Sayed, T.; Shaaban, K. Comparison of Time-Proximity and Evasive Action Conflict Measures: Case Studies from Five Cities. *Transp. Res. Rec. J. Transp. Res. Board* **2017**, *2661*, 19–29. [CrossRef]
44. Shaaban, K.; Gaweesh, S.; Ahmed, M.M. Investigating in-vehicle distracting activities and crash risks for young drivers using structural equation modeling. *PLoS ONE* **2020**, *15*, e0235325. [CrossRef] [PubMed]
45. Ghanim, M.S.; Shaaban, K. A Case Study for Surrogate Safety Assessment Model in Predicting Real-Life Conflicts. *Arab. J. Sci. Eng.* **2018**, *44*, 4225–4231. [CrossRef]
46. Shaaban, K.; Abdelwarith, K. Understanding the association between cell phone use while driving and seat belt noncom-pliance in Qatar using logit models. *J. Transp. Saf. Secur.* **2020**, *12*, 292–308.
47. Elhassy, Z.; Abou-Senna, H.; Shaaban, K.; Radwan, E. The Implications of Converting a High-Volume Multilane Roundabout into a Turbo Roundabout. *J. Adv. Transp.* **2020**, *2020*, 5472806. [CrossRef]
48. Shaaban, K.; Gharraie, I.; Sacchi, E.; Kim, I. Severity analysis of red-light-running-related crashes using structural equation modeling. *J. Transp. Saf. Secur.* **2019**, *13*, 278–297. [CrossRef]
49. Shaaban, K.; Hamad, H. Critical Gap Comparison between One-, Two-, and Three-Lane Roundabouts in Qatar. *Sustainability* **2020**, *12*, 4232. [CrossRef]
50. Shaaban, K.; Shakeel, K.; Rashidi, T.H.; Kim, I. Measuring users' satisfaction of the road network using structural equation modeling. *Int. J. Sustain. Transp.* **2021**, 1–12. [CrossRef]
51. Shaaban, K.; Abouzaid, A.; Musleh, A.; Hout, M.F. An Investigation of Traffic Noise Levels Around a Major Hospital in Qatar. In *Proceedings of the International Conference on Applied Human Factors and Ergonomics, San Diego, CA, USA, 16–20 July 2020*; Springer: Cham, Switzerland, 2020; Volume 1212, pp. 354–360. [CrossRef]

52. Shaaban, K.; Abouzaid, A. Assessment of Traffic Noise Near Schools in a Developing Country. *Transp. Res. Procedia* **2021**, *55*, 1202–1207. [CrossRef]
53. *Sound Level Frequency Weightings—Acoustic Glossary*; Gracey & Associates: Upper Dean, UK, 2022.
54. U.S. Department of Transportation—Federal Highway Administration. *Highway Traffic Noise Analysis and Abatement Policy and Guidance—Noise Fundamentals*; U.S. Department of Transportation—Federal Highway Administration: Washington, DC, USA, 2017.
55. ISO. Attenuation of Sound during Propagation Outdoors Part 1: Calculation of the Absorption of Sound by the Atmosphere. In *Acoustics*; International Organization for Standardization (ISO): Geneva, Switzerland, 1993.
56. ISO. Attenuation of Sound During Propagation Outdoors Part 2: General Method of Calculation. In *Acoustics*; International Organization for Standardization (ISO): Geneva, Switzerland, 1996.
57. Debnath, A.; Singh, P.K. Environmental traffic noise modelling of Dhanbad township area—A mathematical based approach. *Appl. Acoust.* **2018**, *129*, 161–172. [CrossRef]
58. Burgess, M.; MacPherson, J. Overview of Australian Road Traffic Noise Policy Acoust. *Aust.* **2016**, *44*, 227–234. [CrossRef]
59. Shaaban, K. Why Don 't People Ride Bicycles in High—Income Developing Countries, and Can Bike—Sharing Be the Solution? The Case of Qatar. *Sustainability* **2020**, *22*, 1–18.
60. Shaaban, K. Assessing Sidewalk and Corridor Walkability in Developing Countries. *Sustainability* **2019**, *11*, 3865. [CrossRef]
61. Shaaban, K.; Maher, A. Using the theory of planned behavior to predict the use of an upcoming public transportation service in Qatar. *Case Stud. Transp. Policy* **2019**, *8*, 484–491. [CrossRef]
62. Shaaban, K.; Siam, A.; Badran, A.; Shamiyah, M. A simple method to assess walkability around metro stations. *Int. J. Sustain. Soc.* **2018**, *10*, 1–19. [CrossRef]
63. Ow, L.F.; Ghosh, S. Urban cities and road traffic noise: Reduction through vegetation. *Appl. Acoust.* **2017**, *120*, 15–20. [CrossRef]
64. Van Renterghem, T.; Botteldooren, D.; Verheyen, K. Road traffic noise shielding by vegetation belts of limited depth. *J. Sound Vib.* **2012**, *331*, 2404–2425. [CrossRef]
65. Van Renterghem, T. Towards explaining the positive effect of vegetation on the perception of environmental noise. *Urban For. Urban Green.* **2019**, *40*, 133–144. [CrossRef]
66. Potvin, S.; Apparicio, P.; Séguin, A.-M. The spatial distribution of noise barriers in Montreal: A barrier to achieve environmental equity. *Transp. Res. Part D Transp. Environ.* **2019**, *72*, 83–97. [CrossRef]
67. Lee, H.P.; Lim, K.M.; Kumar, S. Noise assessment of elevated rapid transit railway lines and acoustic performance comparison of different noise barriers for mitigation of elevated railway tracks noise. *Appl. Acoust.* **2021**, *183*, 108340. [CrossRef]