Noise Mapping using GIS: A Case Study from Amman

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Abstract: This study aims at creating a contour map that shows the noise intensities and variations at Al-Shaheed Street. The study will emphasize the impacts of traffic on the generated noise in the area. The study will also attempt to understand the physiological and psychological effects of noise on people and understand the relationship between noise and public health. L_{eq} values ranged between 60 dB (A) and 77 dB (A), L_{10} values ranged between 64 dB (A) and 80 dB (A) while L_{90} ranged between 51 and 77 dB (A). The equivalent noise levels in the presence of barriers showed a noticeable decrease. Same is for L_{10} and L_{90} where these two terms are lower for the points in the presence of barriers with values range between 66 dB (A) and 69 dB (A), 56 dB (A) and 58 dB (A) respectively than those for the locations without barriers where L_{10} and L_{90} values were in the ranges between 75 dB (A) and 77 dB (A), 71 dB (A) and 74 dB (A) respectively. The study also compared the L_{eq} of the measured noise levels values with the local and international standards and found that it exceeds the permissible limits. The study reveals that there is similarity in the trend for both daily traffic volume and Noise levels pattern since increasing daily traffic volume values results in higher noise levels values. on the average 27 % reduction in medium heavy vehicles results in 3 % reduction of noise levels, 25 % reduction in buses results in 3 % reduction of noise levels of the studied section of Al-Shaheed Street, and 25.5 % reduction in light vehicles results in 2.5 % of noise levels. A questionnaire was distributed to 122 residents to highlight the relationship between noise and public reaction to noise. 89 % of the respondents believe that noise affects their productivity and 73 % think that noise can affect their academic achievement. 83% of the respondents said that noise make them feel stress and worry. Also 58 % of the respondents believe they can cope with noise. The questionnaire revealed that the residents believe they were more exposed to noise on Sunday and Thursday.

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Keywords: Contour map; traffic noise; barriers; light vehicles; buses; heavy vehicles.

1. Introduction

Noise is unwanted sound; it is one of the worries of the world, especially in urban areas of developing and developed nations. Recently, noise has become an environmental problem that affects people's lives, performance, and health. Sound is formed by the oscillation of air and can be detected by the human ear. Humans are able to hear sounds within the frequency range of 20 Hertz (Hz) to 20,000 Hz. Sound is expressed in decibels, dB (A), which is a logarithmic scale (Kluijver and Stoter, 2003).

Traffic noise is perceived as one of the biggest environmental problems. Many studies demonstrate a relation between exposure to noise and the negative effects on public health. Noise may severely impair quality of life; disturb sleep, interfere with speech intelligibility, or possibly give rise to both social and psychological problems (Niemann and Maschke).

The European Union Directive (END) defines noise mapping in more specific terms as "the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator's" (European Union Directive 2002/49/EC).

In Amman, Al-Shaheed Street is a major arterial that has traffic continuously flowing during both day and night. People living on the sides of this highway and its surrounding areas are subjected to an increasing number of distracting sounds. While traffic is a major source of noise in this site, it is also generated from the nearby factories and celebrations halls adjacent to the study area.

2. Literature Review

Noise is unwanted sound and a serious cause of global worry, especially in urban areas of developing and developed nations (Banerjee et al, 2009). Also Murphy defined environmental noise as unwanted or harmful outdoor sound created by human activities (Murphy et al, 2006). Davis and Masten (as cited in (Jamrah et al, 2006)) stated three valid reasons to explain why noise pollution has not been materialized in a similar fashion as have air and water

pollution problems. These reasons are summarized in the definition and perception of noise as a subjective experience, short decay time, and difficulty to associate cause with effect when it comes to health impacts.

Dursun conducted a study on Konya city in Turkey, an investigation was carried out on the effect of the application of city plan on noise pollution. The noise pollution map of Konya city in Turkey using GIS has been presented with the 366 sampling points selected on main roads in the city centre. A marked effect of increasing building levels on indoor noise pollution has been also found near the main roads (Dursun et al, 2006).

Berg (as cited in (Dursun et al, 2006)) stated that there are important factors affecting noise level values such as: continuity of traffic flow, dimension of the road, position of the road, road surface materials, and type of signal system. In addition, disobeying traffic rules, irregular stop and move of vehicles (especially minibuses), unpermitted parking on the road, and use of the small motor vehicles for freight are considered as noise- causing problems for the traffic flow (Dursun et al, 2006). Furthermore, noise is attributed to driver behavior; for example: frequent braking and/or use of horns.

A study was carried out by Banerjee to compute the temporal and spatial distribution of road traffic induced noise pollution in an urban environment by monitoring and mapping of the entire Asansol city of West Bengal, India. A total of 35 locations were selected for data collection, classified as: industrial, commercial, residential, sensitive, or mixed areas according to the national regulatory standards. Noise was measured and recorded during morning and night hours. The computed data were mapped into GIS. The study reveals that present noise level in all the locations exceeds the prescribed limit. Based on the findings, the population in this industrial town is exposed to significantly high noise levels, which were caused mostly by road traffic. The study reveals that vulnerable establishments like schools and hospitals were subjected to significantly high noise level throughout the day and immediate mitigating measures are required to alleviate the problem (Banerjee et al, 2009).

Noise pollution is a major problem in urban environments, affecting human behavior, well-being, productivity and health (Maisonneuve et al, 2009). Many studies illustrate a link between exposure to noise and negative effects on public health (Farcas and Sivertun, 2009). Nelson reported that long term exposure to high occupational noise can result in permanent hearing loss (Nelson, 1987). Also adverse effects due to exposure to noise may include interference with speech communication and decreasing children's learning skills. Nevertheless, noise has been reported to affect the auditory system, sleep quality, heart rate stress related ischaemic heart disease, including various impacts on the mental and cardiovascular systems (Mato, and Mufuruki, 1999).

Kluijver and Stoter stated the consequences to the health that can be caused by noise as follows (Kluijver and Stoter, 2003):

1. Loss of hearing (levels exceeding 85 dB (A) and a long exposure time).
2. Stress related health effects like hypertension, cardiovascular problems, influence on birth weight.
3. Sleep disturbance.
4. Decreasing performance.

The German Environment Agency carried out a survey which was especially for children, where 1048 children were randomly selected from all over Germany. Blood pressure was measured under standardized conditions at clinical study centers. During home visits, children and their parents were asked about leisure activities, housing conditions, and environmental factors, including traffic exposure of their homes. It was found that the children whose room was facing a street with low traffic had the lowest blood pressure readings. The highest readings were found in the group where the children's rooms were facing a street with a ‘high or extremely high traffic’ volume. The results show that road traffic noise at home is a stressor that could affect children's blood pressure (Babisch et al, 2009).

3. Methodology

Noise levels were measured at 26 locations and Noise level measurements in some locations were carried out in the presence of existing concrete barrier like buildings to find the effect of barriers on the noise readings. Temperature and relative humidity were also measured at those locations. Maximum and minimum noise value, Leq, and percentile levels L_{10} (1 hr) and L_{90} were also calculated through four recording stations; Morning, afternoon, evening and night.

Noise levels were entered to the ArcMap environment and colored contour maps were generated to show the most affected zones with noise effects. The traffic was classified into 5 categories: light vehicles, buses, medium heavy vehicles, long heavy vehicles, and combination heavy vehicles. The Traffic Noise Index (TNI) is a method used to estimate annoyance responses due to traffic noise and it was calculated for the 26 locations with or without barriers. The relationship between Leq and both L10 and L90 was studied by graphing their values and find the linear relationship between those two terms. Daily traffic (vehicles/day) and measured noise levels (dB (A)) at the different 26 recording stations were graphed to find the patterns that these two variables

follow, and determine the contribution of traffic to the noise levels detected.

A questionnaire was prepared as a complementary part of this study, the questionnaire aims at measuring subjective reactions to noise, obtaining some indication of the annoyance caused by sound and understanding the psychological evaluation of the individuals to their environment. Additionally, the social survey attempts to identify the extent of noise as a health hazard, and to investigate the consequences of noise pollution on the quality of life of the residents.

4. Results and Discussion

4.1 Survey Results

From the social survey, 89% of the respondents said that noise has a noticeable effect on their productivity, while 11% said it has no effect. While 83% of the respondents felt stress and worry because of noise, the remaining 17% consider noise not a cause of stress or worry. The survey also considered the effect of noise on the respondents and it reveals that most of the respondents with a percentage of about 40% replied that they experience general discomfort. 29% experience Stress, and this percentage is very close to the percentage of respondents who felt headache because of noise (around 24.6%), while approximately 7% of the respondents stated that noise has no effect on them.

To measure the sensitivity of the respondents to noise, the survey asked them to determine their sensitivity to noise on a scale from 1 to 10 (1 being least sensitive); most of the respondents were between 7 and 8 on the scale; which is considered high sensitivity. The respondents were mostly disturbed in their sleep because of the noise due to traffic at a percentage of approximately 35%. While around 34 % are disturbed at least once a week, and 22% are disturbed at least once a month, and the rest 8.2 % are not disturbed at all. This indicates the great effect of traffic noise on the sleep quality of the residents living near the street. The survey also asked the respondents about how the noise affects their life; it was found that most of them have general discomfort and that pose 48% of the respondents. Also 29 % experience loss of the ability to sleep because of noise, and 11% are being unable to watch TV as well as those who experience wake from sleep, and around 3 percent said they are not affected by noise and can do all activities as usual.

Respondents are mostly exposed to noise at noon with a percentage of 31% and then at evening and morning with close percentages of 30.3% and 30%, respectively. This result could be related to the times of going to work and getting back home from work for a large layer of people; especially for auto-commuters. Al-Shaheed Street has many celebration halls on the main road and these halls hold their parties at evening and the use of digital audio players and sound amplifier devices aggregates the volume of sound which makes the area noisier; on top of the existing traffic noise. Under this exposure to high noise levels, the survey asked about the ability to cope with noise, 58% answered that they can cope with this high noise level and practice their activities as usual because they got used to this noise. While 42% cannot cope with the noise and encounter some difficulties in living normally. These results give us an indication that it is not easy for people to cope with noise, which proves that noise is a major big problem.

Most of the respondents said that they are mostly exposed to noise on Sunday and Thursday; this can be seen clearly from the close percentages of 38% and 36% respectively which is a relatively high percentage relatively when compared to the rest of the rest days' percentages. Those high percentages for Sunday and Thursday could be explained by the beginning and the end of the week where Jordanians from outside Amman commute in/out of the city. Another factor is that Thursday is a preferred day in the Jordanian community to hold celebrations and wedding parties as it is the weekend so the celebration halls in this area would play a significant role in the elevated noise levels on Thursday weddings. Approximately 73% of the respondents think that the academic achievement is affected by noise due to the disturbance that occurs while they are trying to concentrate in studying.

Around 28% of the respondents said that traffic is the main source of noise in the area, then comes the noise caused by planes with a percentage of 21% followed by the noise of military aircrafts with a percentage of 13%. Other sources are very close to each other. Most of the respondents considered traffic noise as extremely annoying with a percentage of 14%. While 8% of the respondents consider it very annoying, and 4% consider it annoying and the rest 1.4% find it a little annoying. When considering the noise coming from planes, most of the responses found it annoying with a percentage of 8% while 4% of the responses found military aircrafts also disturbing. The extent of disturbance depends mainly on the listeners; so that if the listeners like the sound, then they will not be annoyed.

The respondents were asked to choose the actions that they consider effective in reducing and minimizing the adverse effects of noise. The highest percentage was for moving residential areas away from highway with a percentage of 19% of the total responses. Then the respondents suggested adhering to the specified road design speed and those made up 16% of answers. Expanding green areas comes next with a percentage of 15% of the total responses.

4.2 Recorded Noise Levels

L_{eq}, L_{max}, L_{min}, the statistical noise level L_{10}, background noise level L_{90} and TNI were measured for 24-hours, morning, afternoon, evening, and night periods respectively for all 26 recording stations. The range values for the L_{eq}, L_{max}, L_{min}, the statistical noise level L_{10}, the background noise level L_{90}, and the TNI during the different study periods are show in Table (1). L_{eq} values ranged between 60 dB (A) and 77 dB (A). The maximum noise level values for the different recording periods ranged between 66 dB (A) and 91 dB (A). The minimum noise level values around 40 dB (A) and reached a maximum of 72 dB (A). L_{10} values ranged between 64 dB (A) and 80 dB (A), while L90 ranged between 51 and 77 dB (A).

The statistical noise levels (L_{10} and L_{90}) and the equivalent continuous noise level (L_{eq}) are linearly related to each other according to the following relationship: $L_{10} = 0.7622\ L_{eq} + 18.721$ with a correlation coefficient $R^2 = 0.99$ (highly correlated) and $L_{90} = 1.2254\ L_{eq} - 20.11$; with a correlation coefficient $R^2 = 0.95$ (highly correlated). Figure (1) illustrates that the correlation between L_{eq} and L_{10} is better than L_{eq} and L_{90}.

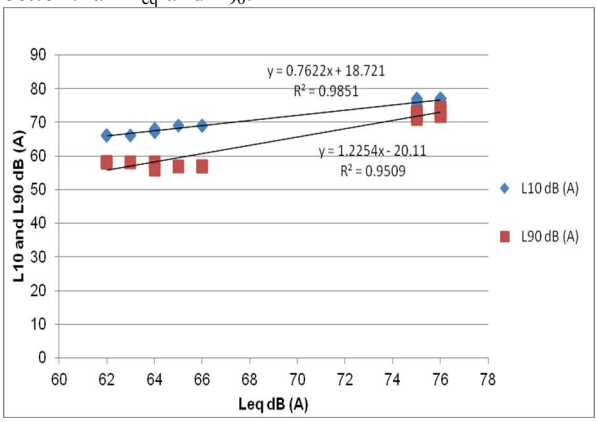

Figure 1. Linear relationship between L_{10} and L_{90} and L_{eq} on Al-Shaheed Street

Table 1. L_{eq} L_{max} , L_{min} , L_{10} and L_{90} of the study periods in dB (A)

	24 hour	Morning	Afternoon	Evening	Night
L_{eq}	62-76	60-77	62-77	64-76	62-75
L_{max}	70-91	66-88	69-91	70-89	66-84
L_{min}	40-59	40-59	46-72	48-71	40-60
L_{10}	66-77	64-80	65-80	66-77	64-78
L_{90}	56-74	51-77	59-75	56-74	58-72

In order to evaluate the effect of using barriers in the area as a reducing measure for the elevated noise levels, two records were taken for the same building; one in front of the façade and another in the rear façade of the building; making the building acts as a concrete barrier. Figure (2) shows the locations of the buildings that were included in this measure.

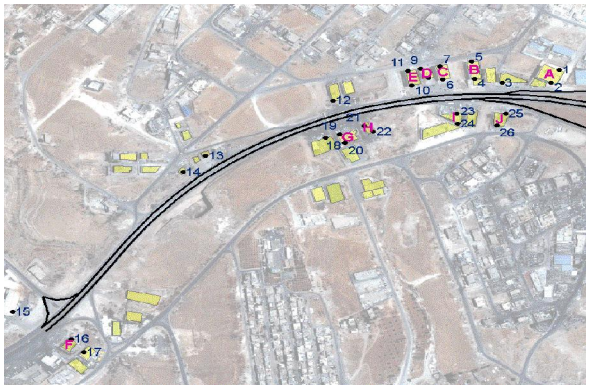

Figure 2. The locations of the studied buildings on Al-Shaheed Street

The equivalent noise levels in the presence of barriers show a noticeable decrease. Leq values range was between 75 dB (A) and 76 dB (A) in absence of barriers with an average value of 76 dB (A) while it was between 62 dB (A) and 66 dB (A) with an average value of 64 dB (A), Equivalent noise levels (L_{eq}) in its average drop by a percentage of 19 %. Same is for L_{10} and L_{90} where these two terms are lower for the points in the presence of barriers with values range between 66 dB (A) and 69 dB (A), 56 dB (A) and 58 dB (A) respectively than those for the locations without barriers where L_{10} and L_{90} values were in the ranges between 75 dB (A) and 77 dB (A), 71 dB (A) and 74 dB (A) respectively. The traffic noise index (TNI) indicates that the locations with the barriers experience higher annoyance. These locations experience TNI in the range between 60 and 75 in the presence of barriers and between 54 and 59 in the absence of barriers. This is may be referred to the difference between L_{10} and L_{90} in the presence of barriers where it is higher than that in the absence of barriers.

4.3 Temperature and Humidity

Temperature was found to be directly proportional to noise values during the different recording periods with a highest correlation value in the evening period. Relative humidity appears to be inversely proportional to noise levels with the highest correlation coefficient in the evening period too. These results coincide with the results of the questionnaire; where most people said that they find it noisier in summer rather than winter and also the high values of correlation factor between temperature and noise in the evening goes in the same way with the high percentage of respondents who said that they are mostly exposed to noise in the evening periods.

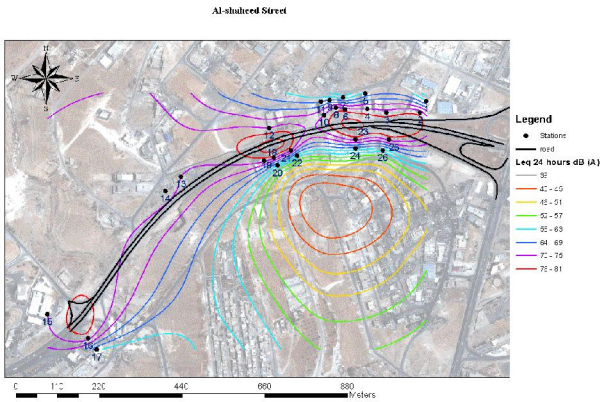

Figure 3. Contour noise map for 24 hour period on Al-Shaheed Street

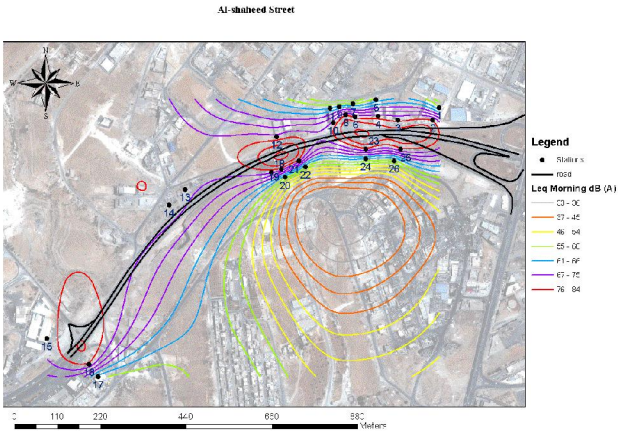

Figure 4. Contour Noise map for Morning Period on Al-Shaheed Street

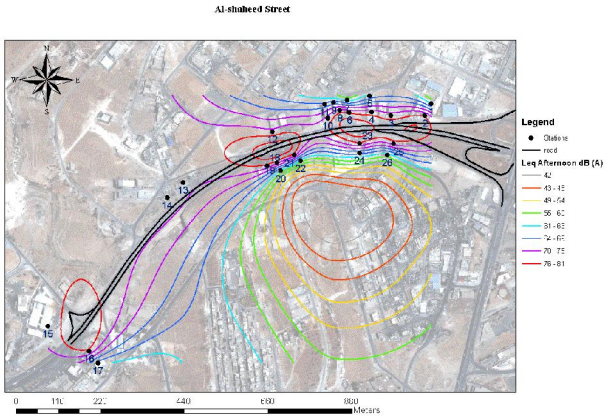

Figure 5. Contour Noise map for Afternoon Period on Al-Shaheed St

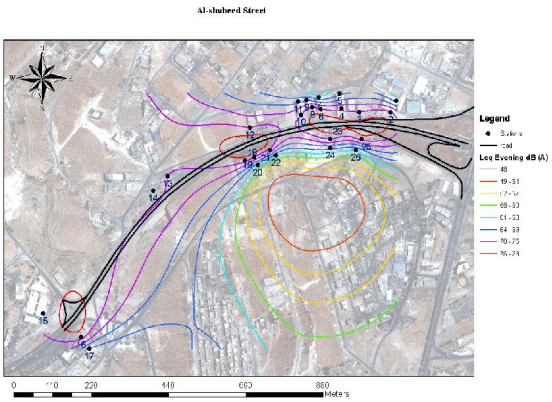

Figure 6. Contour Noise map for Evening Period on Al-Shaheed Street

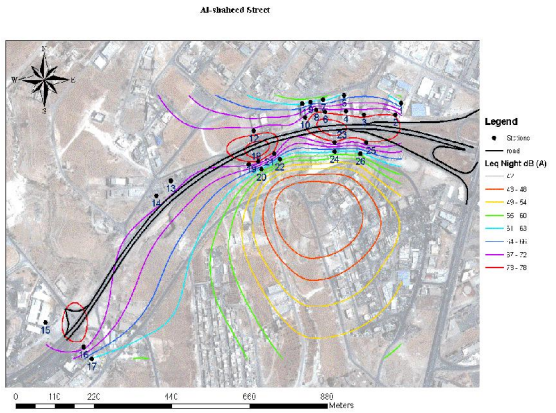

Figure 7. Contour Noise map for Night Period on Al-Shaheed St

4.4 Comparing with EPA and Jordanian standards

According to the EPA standards, the maximum acceptable Leq for outdoor living areas at night is 42 dB (A), while the minimum noise level value for all of the 26 recording stations was 62 dB (A) and this value exceeded the EPA standards. If we compare either minimum or maximum noise level values of the different 26 stations is the different four recording periods with the Jordanian standards, we can see that those values exceeded the acceptable permissible limits for both day and night times; Leq for morning period ranges from 60 dB (A) to 77 dB (A), afternoon period range was between 62 dB (A) to 77 dB (A) and evening period range was between 64 dB (A) and 76 dB (A) and all are exceeding the acceptable day limit of 60 dB (A). Also the night acceptable limit for L_{eq} in the Jordanian standards is 50 dB (A) while the range of the L_{eq} in the study area was between 62 dB (A) and 75 dB (A) and this value is exceeding the acceptable limit specially if we bear in mind that sound intensity doubles with every increase of three dB.

4.5 Noise mapping results

ArcMap software was used to generate contour lines from the entered data for the different recording periods as shown in Figures 3 through 7.

4.6 Traffic Analysis Results

Figure 8 shows the percentages of different vehicles type at Al-Shaheed Street; the value was 86% for Light vehicles which comprises the majority of the traffic flow. Buses were around 11 %, while medium, long and combination heavy vehicles constituted only 3 % of the traffic flow.

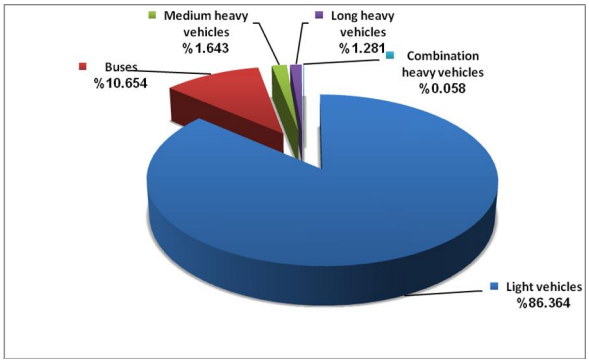

Figure 8. Vehicle Classification on Al-Shaheed Street

In order to understand the relationship between traffic and noise levels, Figure (9) shows corresponding daily traffic volume (passenger/day) and equivalent noise levels (Leq) for each recording station. The figure reflects the fact that there is similarity in the trend for both daily traffic volume and noise levels. It can be seen that when daily traffic volume values increases, noise levels values increases too.

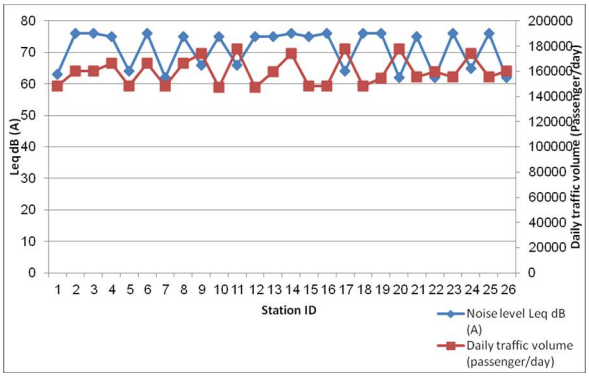

Figure 9: Daily Traffic Volume and Equivalent Noise Level for the 26 locations on Al-Shaheed Street

It was found that medium heavy vehicles were the most contributing category to the noise levels; where a reduction of 23% results in 3% reduction in noise levels at recording stations that are on the main road without barriers and the same 3% reduction in noise levels were resulted from a reduction of about 31% in medium heavy vehicles at the recording stations with barriers. For buses, a reduction of 30% results in 3% reduction of noise levels on the main street, while a reduction of 20 % at the recording stations with barriers results in also 3 % of the noise levels. A reduction of 25 % in light vehicles, which is the largest vehicles' category, results in 2 % of the noise levels on the main road without barriers. While a reduction percentage of 26 % at recording stations with barriers results in 3 % reduction in noise levels.

5. Conclusion

The equivalent noise levels in the presence of barriers show a noticeable decrease. Same is for L_{10} and L_{90} where these two terms are lower for the points in the presence of barriers with values range between 66 dB (A) and 69 dB (A), 56 dB (A) and 58 dB (A) respectively than those for the locations without barriers where L_{10} and L_{90} values were in the ranges between 75 dB (A) and 77 dB (A), 71 dB (A) and 74 dB (A) respectively. The traffic noise index (TNI) in locations with the barriers experience higher annoyance. These locations experience TNI in the range between 60 and 75 in the presence of barriers and between 54 and 59 in the absence of barriers. This is may be referred to the difference between L_{10} and L_{90} in the presence of barriers where it is higher than that in the absence of barriers.

Temperature was directly proportional to noise values during the different recording periods with a highest correlation value in the evening period. Relative humidity appears to be inversely proportional to noise levels with the highest correlation coefficient in the evening period too. These results coincide with the results of the questionnaire; where most people said that they find it noisier in summer rather than winter and also the high values of correlation factor between temperature and noise in the evening goes in the same way with the high percentage of respondents who said that they are mostly exposed to noise in the evening periods.

According to the EPA standards, the maximum acceptable Leq for outdoor living areas at night is 42 dB (A), while the minimum noise level value for all of the 26 recording stations was 62 dB (A) and this value exceeded the EPA standards. If we compare either minimum or maximum noise level values of the different 26 stations is the different four recording periods with the Jordanian standards, we can see that those values exceeded the acceptable permissible limits for both day and night times.

There is similarity in the trend for both daily traffic volume and Noise levels pattern since increasing daily traffic volume values results in higher noise levels values. Peak hour, For morning period,

peak hour occur either between 8-9 a.m or 9-10 a.m, at afternoon the peak hour most likely occur between 2-3 PM or 3-4 PM and this hour was suggested as the time of leaving work for large number of employees. Peak hour for evening period occurs at different times, this may be explained by the different activities of people in this period of time, social visits, wedding parties, and going out for parks or restaurants. Night period has a peak hour from 10 PM to 11 PM for all different stations.

The vehicles categories numbers affect directly the noise levels; on the average 27 % reduction in medium heavy vehicles results in 3 % reduction of noise levels, 25 % reduction in buses results in 3 % reduction of noise levels of the studied section of Al-Shaheed Street, and 25.5 % reduction in light vehicles results in 2.5 % of noise levels. Buses seem to be the most contributing category to the noise levels.

Realizing the influence of noise on the environment and people, it becomes essential to reduce the effects of noise and suggest suitable mitigating measures. Therefore, it is recommended to:

- Locate residential buildings far from noise sources, and use barriers in front of buildings.
- Use Traffic Planning as a tool to reduce noise, and reduce speed limits. When designing new roads, planners should consider noise levels in the area. Many factors must be taken into account; such as the highway distance from existing and new developments, the landscape between roads and buildings, and the maximum allowable speed.
- As for heavy vehicle engine brake noise around residential areas, it can be reduced by:
  - ❖ Installing a muffler that is specially designed to reduce engine brake noise
  - ❖ Ensuring that the exhaust system is in good condition
  - ❖ Turning off noisy engine brakes in built up areas

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