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Assessment of Road Traffic Noise: A Case Study in Monastir City

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Abstract

In the last two decades, Tunisia has witnessed a sharp increase in the number of vehicle users which gave rise to higher road traffic noise levels especially in urban areas. This type of noise causes adverse effect on humans, such as sleeping disorder, annoyance, hearing disorder, etc. Therefore, it is crucial to evaluate traffic noise levels in populated areas in order to highlight problematic areas, so that architects and engineers can find solutions to reduce noise impacts. This paper presents a case study of traffic noise levels at four main roads in the city of Monastir- Tunisia and it also investigates the performance of traffic noise models. In the first part, it is found that the measured noise is mostly due to traffic noise and its levels exceeded the limits recommended by both the World Health Organization (WHO) and the Tunisian environmental standards. In the second part, the study compares the performance of five known traffic noise models: Griffith and Langdon, Burgess, French CSTB (Centre Scientifique et Technique du Batiment), Fagotti and the Italian CNR (Consiglio Nazionale delle Ricerche). It found that the French CSTB model outperforms the others when applied to the measured sites.

Keywords: Road traffic noise; traffic noise; equivalent sound level; statistical noise level; noise exposure level;

1. Introduction

Road traffic noise has been identified as one of the main factors in the increase of noise pollution in urban areas and can cause serious degradation of quality of life [1, 2]. This problem is becoming more significant due to the continuous increase in traffic volumes and the use of heavy vehicles inside urban roads. In addition, the inadequate urban planning of many cities, especially in third world countries, makes things worse since many residential areas and business centers are built close to the main roads of the metropolitan without buffer zones or adequate sound proofing [3]. The harmful impacts of road traffic noise exposure are well-known [4]. It can include productivity losses due to poor concentration, interference with communication, reduction in enjoyment of activities. Moreover, there are psychological and physiological health effects, such as nuisance, loss of well-being, sleep disturbance, fatigue and hearing impairment, etc [4]. Many research studies have been conducted on road traffic noise in many countries [5- 17]. However, very few studies have investigated noise pollution in Tunisia, and none was done in the city of Monastir which is a known coastal city. Monastir is a medium size city with growing population from 67,730 in 2002 to 93,300 in 2014 [18-19]. It has expanded continuously in all directions in the last three decades. The city has been subjected to daily continuing road traffic and commercial activities due to overall increase in prosperity, fast development, and an increase in the economy growth. Therefore, it is important to assess the noise level in this city. This research conducted a case study at four main roads in the city of Monastir- Tunisia where the traffic noise levels were collected and analyzed. The study also investigates the performance of five common models that are for traffic noise estimation.

The paper is organized as follows. Section 2 introduces some background information about noise measurements and traffic noise descriptors and it also presents a brief description of five well-known traffic noise models. The methodology used in this study is described in Section 3 and the results are discussed in Section 4. Finally, the last section concludes the paper.

2. Background Information

Noise is defined as an unwanted sound that may interfere with normal activities [20]. It may also cause annoyance and harm to human beings [3]. However, traffic noise is due mainly to the sound produced by vehicles' engine, exhaust, and tires. Engine and exhaust noise are usually dominant if vehicle speeds are under 50 km/hr, otherwise, the tire noise is louder [20]. Thus, the traffic noise in highways is generally dominated by tire noise, while the traffic noise in local roadways is typically

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dominated by engine and exhaust noise. In what follows, noise measurements and traffic noise descriptors were discussed. It is proceeded by presenting the Tunisian standards for noise levels. Finally, the five road traffic noise models that are used for comparison were described, which are namely: Griffith and Langdon, Burgess, French CSTB (Centre Scientifique et Technique du Batiment), Fagotti, and the Italian CNR (Consiglio Nazionale delle Ricerche).

2.1. Noise measurements and traffic noise descriptors

Noise is measured in terms of sound pressure using logarithmic scale with units of decibel (dB) since the range that the human listeners can detect is very wide [3]. For traffic noise studies, it is more common to use the A-weighted decibel (dBA) as the unit of measure in order to best approximate the way the average person hears sounds. Thus, the dBA scale reduces the strength of very low and very high audio frequencies which are not audible by humans [20]. Noise levels can range from 0 dBA, barely audible, to about 120 dBA which is painful to human ears. The typical range for human speech is the mid 60 dBA range while quiet suburban environments are often in the 40 to 50 dBA range [21]. Another feature of the measured noise is its fluctuation with time since it is never constant. To address the changes of noise over time, traffic noise is assessed using the equivalent sound level (L_{Aeq}) which is defined as the average noise level over a given period of time and it is measured in dBA [21]. When noise measurement is taken over a time period, it is common practice to add the measurement duration to the subscript. For example, the symbol $L_{Aeq,1}$ is used to denote a 1-hour L_{Aeq} measurement [4]. It is also possible to express the noise levels during times of the day, such as daytime (L_D), evening-time (L_E) or night-time (L_N). In this paper, the daytime is considered from 7:00 to 20:00, the evening time is from 20:00 to 22:00 and the night-time is from 22:00 to 7:00. Based on [13], the equivalent noise level for day, evening and night is denoted by L_{DEN} and is defined by

$$L_{DEN} = 10 \times log_{10}\left(\frac{1}{24}(13 \times 10^{L_D} + 2 \times 10^{L_E+5} + 9 \times 10^{L_N+10})^{1/10}\right) \quad (1)$$

It is the average noise exposure throughout a 24-hour day, and it can be used to reasonably represent the correlation of the community responses [12].

Another useful set of parameters for the traffic noise are the n-percent noise exceeded level, L_n, which are known as the statistical noise levels. L_n is defined as the sound pressure level exceeded for *n* percent of the time, and the widely used statistical noise levels are L_{10}, L_{50} and L_{90} [22]. L_{10} and L_{90} are commonly referred to as the average maximum level and the background level respectively [4]. L_{90} is also referred to an indicator of long-lasting noise in a specified area [12]. In addition, many researchers make use of the maximum and the minimum detected sound levels, L_{max} and L_{min}, in their analysis [12, 13].

2.2. Standards for noise levels

Several countries have established standards for noise levels that determine the maximum permissible limits for equivalent sound levels in different areas and for different time periods. Based on the standards adopted by the municipality of Tunis, the capital city of Tunisia [23], Table 1 shows the maximum permissible limits for selected areas. These limits are compatible with the recommendations of World Health Organization (WHO) [24] and will be used in the analysis.

Table 1. Maximum permissible noise limits in Tunis for selected areas [23]

Zones	Permissible limit for L_{Aeq} in dBA		
	Day	Evening	Night
Hospitals and rest areas	45	40	35
Suburban residential areas with low road traffic.	50	45	40
Urban residential areas	55	50	45
Urban or suburban residential areas near important roads and with some workshops, business center and shops	60	55	50
Areas with commercial activities.	65	60	55
Areas with predominantly heavy industry.	70	65	60

2.3. Road traffic noise models

Many models were proposed for the estimation of road traffic noise in different environments. In this study, the performances of five well known models are compared based on road traffic noise measurements. These models include: Griffith and Langdon, Burgess, CSTB, Fagotti and CNR. This section presents briefly the expression for each model.

The Griffiths and Langdon model [25, 26] proposed the evaluation of equivalent level starting from the percentile level as follow:

$$L_{eq} = L_{50} + 0.018(L_{10} - L_{90})^2 \quad (2)$$

where the statistical percentile indicator are expressed as:

$$\begin{cases} L_{10} = 61 + 8.4 \log Q + 0.15\, P - 11.5 \log d \\ L_{50} = 44.8 + 10.8 \log Q + 0.12\, P - 9.6 \log d \\ L_{90} = 39.1 + 10.5 \log Q + 0.06\, P - 9.3 \log d \end{cases} \quad (3)$$

Q is traffic volume in vehicles per hour and d is the distance from observation point to center of the traffic lane, in feet; and P is the percentage of heavy vehicles.

The Burgess model [25, 27] uses the following expression for the sound level

$$L_{eq} = 55.5 + 10.2 \log Q + 0.3P - 19.3 \log d \quad (4)$$

The CSTB model [25], suggested a predictive formula based on the average acoustic level (L_{50}) with the following expression:

$$L_{eq} = 0.65L_{50} + 28.8 \quad (5)$$

where the value of L_{50} is given by:

$$L_{50} = \begin{cases} 11.9\log Q + 31.4 \text{ , for urban road and highway with Q<1000 vehicles/hour} \\ 15.5\log Q - 10\log L + 36 \text{ , for urban road with buildings near the edge} \end{cases} \quad (6)$$

where L is the road width, in meters, near the measurement point.

Fagotti *et al.* proposed the following formula [25]

$$L_{eq} = 10\log(Q_L + Q_M + 8Q_P + 88\,Q_{Bus}) + 33.5 \quad (7)$$

where Q_L, Q_P,Q_P and Q_{Bus} are the traffic volumes of the light and heavy vehicles, motorcycles and buses respectively

For the CNR model, the equivalent sound level in dBA is given by [25]

$$L_{eq} = \alpha + 10\log(Q_L + \beta\,Q_P) - 10\log\left(\frac{d}{d_0}\right) + \Delta L_V + \Delta L_F + \Delta L_B + \Delta L_S + \Delta L_G + \Delta L_{VB} \quad (8)$$

where Q_L and Q_P represent the traffic flow in one hour for light and heavy vehicles respectively, d_0 is a reference distance of 25 meter and d is the distance between the lane center and the observation point on the road's edge. The parameters ΔL_V, ΔL_F, ΔL_B, ΔL_S, ΔL_G and ΔL_{VB} represent the correction factors which depend respectively on: mean flux velocity, presence of reflective façade near the observation point, or in opposite direction, types of pavement, road's gradient and presence of traffic lights or slow traffic. These correction factors are well defined in [25].

3. Methodology

Traffic noise measurements were carried out along four main important roads in Monastir: Avenue of 14 January 2011, Taieb Mhiri Avenue, Environment Avenue and Supreme Fighter Avenue. These roads cross at the roundabout El-Nafoura as shown in Figure 1, and they lead to many public buildings, government and company offices. Hence, it features high traffic flow during peak hours, which causes significant increase in noise emissions. In this study, zone 1 refers to the Supreme Fighter Avenue which extends for about 600 m from the El-Nafoura roundabout to the next main cross section. Similarly, zone 2, zone 3 and zone 4 refer respectively to the Avenue of 14 January 2011, Environment Avenue and part of Taieb Mhiri Avenue. These zones extend for 600m, 3 km and 300m respectively.

The measurements of the A-weighted instantaneous sound pressure level were made at one spot in each zone as shown in Figure 1. The instrument used is a programmable sound level meter of type TES-1352H made by the TES Electrical and Electronics Corporation. It was held at a height 1.5 m above the ground and with 2 m away from the side of the road and at a distance not less than 1 m away from any other reflecting object. In addition, the microphone was pointed at the circulating vehicles and the instrument was set on the *A* frequency weighting and slow time weighting. All measurements were done during working days and under acceptable weather conditions in February 2017. The data are recorded at intervals of one second and for 24 hours period for each road. For this study, the equivalent sound level is computed for every hour at each location in order to compare the noise variation during one full-day. In addition, the noise indicators L_D, L_E, L_N and L_{DEN} are calculated along with L_{10}, L_{50} and L_{90}.

In order to compare the performance of the five traffic noise models discussed earlier, measurements of the traffic volumes, *Q*, and percentage of heavy vehicles, *P*, were also carried out along the four zones for two periods of time: 11:00-12:00 and 19:00-20:00. These measurements were conducted at a distance *d*=5m from the center of the roads.

Figure 1. Map showing the four zones in the city of Monastir where the measurement were conducted [28].

4. Results and Discussion

The first part of this section presents the results obtained from the measured data and analyzes the computed traffic noise level statistics. In the second part, it investigates the performance of the five road traffic noise models based on the measured data.

4.1. Traffic noise level statistics

The 24-hour noise levels measured in the four zones are shown in Figure 2 along with the noise limits set by the Tunisian environmental standards. The figure shows that the noise levels are higher during the day specially from 07:00-8:00 and lower during the night. This is expected since most people go to work during the day and that there are less activities and mobility during the night. It is also observed that the measured noise level is higher than the Tunisian standards except during early morning around 2:00-4:00. The highest noise level is measured in zone 3 where it exceeds 75 dBA from 7:00-14:00. This is due to higher traffic density with vehicles exceeding an average speed of 40km/h in zone 3. However, vehicles in zones 1, 2 and 4 cannot exceed an average speed of 30 km/h since these roads have short distances less than 600 m and there are many shops along these roads. That explains why less noise is observed in these streets although the traffic is sometimes comparable to zone 3.

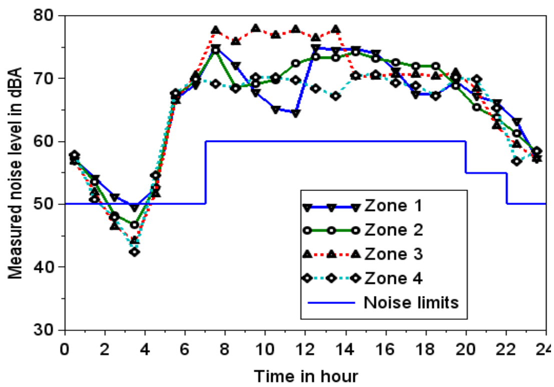

Figure 2. The plots of 24-hour noise levels at four streets in Monastir compared with Tunisian Environmental standards

The noise levels L_D, L_E, L_N, and L_{DEN} are shown in Table 2 for the four zones. For the daytime noise level, L_D varies from 69.4 to 75.3 dBA and is higher than the permissible level by 9.4 to 15.3 dB. It is also observed that L_D is higher in zone 3 than in the other zones. This is due to higher traffic densities and higher spatial velocity in zone 3. For the evening time, L_E varies from 64.7 to 68.1 dBA and is higher than the permissible level by 9.7 to 13.1 dBA. This variation is lower than the daytime since less traffic is observed. For the night time, L_N has almost the same value of 63 dBA in the four zones and it is higher than the permissible level by 13 dBA. This is an indication that the traffic density is quite low during the night and its impact is minimal. In general, the measured noise levels near these four streets exceed the permissible noise limits by at least 9 dBA but not more than 15.3 dBA. This might affect people living in the buildings and shops along these streets. In addition, the measured noise levels in Table 2 show clearly that zone 3 has the highest noise level during the day. During the evening, zone 4 has the highest level whereas during the night the noise levels are close in all four zones. The day-evening-night values, L_{DEN} varies from 71.4 to 74.3 dBA and it shows that the average noise exposure throughout a 24-hour day is higher in zone 3. These values are considered lower in comparison with the measured noise levels at many cities such as Cairo [13], Islamabad [13] and IKEJA [17].

Table 2. Computed values of L_D, L_E, L_N and L_{DEN} in the four zones in dBA

	L_D	L_E	L_N	L_{DEN}
Zone 1	72.0	66.7	62.6	72.2
Zone 2	72.2	64.7	62.9	72.3
Zone 3	75.3	66.4	63.0	74.3
Zone 4	69.4	68.1	63.0	71.4
Standard levels	60	55	50	62.14

The commonly used statistical noise levels L_{10}, L_{50} and L_{90} are computed for one-hour period during the afternoon and the results are listed in Table 3. For all these levels, zone 3 has the highest values and the sound levels exceed 81, 77.8 and 74.1 dBA for 10%, 50% and 90% of the time respectively. To improve the environmental conditions in zone 3, it is recommended to introduce some restrictions, such as lowering the speed limit, and banning horns and trucks.

Table 3. Statistical noise levels computed for one-hour period for the four zones

	L_{10}	L_{50}	L_{90}
Zone 1	77.9	74.1	70.9
Zone 2	76.9	72.2	67
Zone 3	81	77.8	74.1
Zone 4	74.1	69.8	66.2

4.2. Comparison between five models for the road traffic noise levels

This section compares the performance of five traffic noise models discussed in Section 2. For this purpose, the Root Mean Squared Error (RMSE) is used as a criterion for selecting the model that produces minimum RMSE. Based on the definition presented by [29], the RMSE can be expressed as

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(L_{eq} - \hat{L}_{eq}\right)^2} \tag{9}$$

where L_{eq} and $\hat{L}_{eq}$ are the measured and the estimated road traffic noise levels respectively. The number of measurements is denoted by n. In order to evaluate this equation, measurements of Q, P and L_{eq} were conducted at a distance $d=5m$ from the centre of each road for two periods of time and the outcome is shown in Table 4. The RMSE is computed for each model using the corresponding equations from (2) to (8) and the measured values of Q, P and d. The result is shown in Table 5 which clearly indicates that the CSTB model outperforms the other four models. Therefore, the CSTB model can be used to estimate road noise levels in Monastir based on the available traffic data. This means, noisy areas can be identified in this city and the relevant experts can find solutions to reduce the impact of road traffic noise.

Table 4. Measured values of *Q*, *P* and L_{eq} at each zone for two periods of time.

	Time	*Q* (Veh/h)	*P* (%)	Measured L_{eq}(dBA)
Zone 1	11:00-12:00	660	1.6	74.98
	19:00-20:00	480	0.8	69.5
Zone 2	11:00-12:00	690	11.3	73.96
	19:00-20:00	510	10.6	68.79
Zone 3	11:00-12:00	830	23.4	78.65
	19:00-20:00	640	19.3	70.92
Zone 4	11:00-12:00	740	18.7	70.92
	19:00-20:00	580	15.4	70.13

Table 5. Computed RMSE for the five traffic noise models

	Griffith & Langdon	Burgess	CSTB	Fagotti	CNR
RMSE	2.47	1.94	1.23	3.40	2.73

5. Conclusion

This study conducted measurement of traffic noise in four main roads in the city of Monastir. It is found that the noise levels are generally higher than the limits set by the Tunisian environmental standards and the WHO. In addition, the measured noise levels show clearly that zone 3 and zone 4 have the highest noise level during the day and during the evening respectively, whereas the noise levels in all four zones have close values during the night due to extremely low traffic volume. It is recommended to introduce some restrictions, such as lowering the speed limit, and banning horns. The study also compares between five known traffic noise models and found that the CSTB model outperforms the other models. As a result, this model can be used to estimate road noise levels in the city using road traffic data.

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