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Impact of Traffic Pattern Variability on Road Noise Levels and Human Exposure: A Case Study in an Urban Site in Monastir City - Tunisia

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Abstract— **Road traffic noise annoyance has been classified among the major transportation negative externalities despite the implementation of various regulatory guidelines in different parts of the world. This paper aims to evaluate and examine the impact of road traffic conditions on road noise levels and population exposure in a busy road traffic metropolitan site in Tunisia. Through a comparative study, the standard French NMPB model was identified as the most suitable for predicting road noise levels, as it provided good accuracy compared to other traffic noise predictive models. The road traffic noise analysis displayed an average road noise level reduction of 3.18 dB(A) when the total traffic volume was reduced by approximately 52%. Moreover, statistics on road noise exposure depicted that the largest percentages of the population, 58.8% during rush hour and 62.5% during non-rush hour, were potentially exposed to moderate road noise levels ranging from 55 to 64 dB(A). In addition, 12.5% and 23.5% of the population were exposed to high road noise levels between 65 and 64 dB(A) during rush and non-rush hours, respectively. However, during rush hour, 12.5% of the population was potentially exposed to very high road noise levels exceeding 75 dB(A).**

Keywords— **Road Traffic, Noise Level, Simulation, Population Exposure, Case Study**

I. INTRODUCTION

Along with demographic expansion as well as economic prosperity, the demand for transportation has also recorded a significant rise, resulting in a huge escalation in the number of motor vehicles using the road networks. In large urban areas, this situation causes serious congestion problems, particularly during peak traffic periods. The most obvious negative externalities of road traffic congestion are the increase in travel time, reduction in road safety, fuel overconsumption, exacerbation of atmospheric pollution, and traffic-induced noise annoyance.

Currently, urban traffic noise pollution is classified as one of the most critical problems that threatens life quality, especially in large metropolitan areas, as it accounts for 80% of all common noise sources ([1], [2]). For instance, the European Environment Agency [3] indicated that the total number of people exposed to day-evening-night road traffic noise levels of 55 dB(A) or higher is estimated to be 113 million. In the same context, a European Union publication stated that more than 40% of the population in EU countries is exposed to noise levels above the legal limit of 55 dB(A). Besides, during the daytime, 20% are exposed to noise levels exceeding 65 dB(A), and more than 30% are exposed to levels higher than 55 dB(A) at night [4].

An increasing environmental issue, road noise pollution has been linked to a variety of evidence-based negative impacts such as insomnia, sleep disturbance, annoyance, learning impairment, stress, headaches [5]-[9] and numerous other dangerous human health effects [10]-[15].

In modern planning, noise protection is one of the fundamental requirements that should be respected before performing any kind of project aiming to install new infrastructure (roads, railroads, and airports). In environmental studies, noise impact assessment is an essential key for risk evaluation, identification of noise sources, simulation of mitigation measures, evaluation of the exposed population, and urban planning [16]-[24]. According to the European Directive 2002/EC/49, relating to the assessment and management of environmental noise, noise impact studies are mandatory for all agglomerations with more than 250 000 inhabitants and for all major airports, roads, and railways [25]. Compliance with these standards guarantees that noise-related considerations are incorporated into the planning and design process, aiming to reduce adverse impacts on people and environment.

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Noise forecasting is an essential component of the environmental impact assessment process. Currently, there are three main approaches to estimate traffic noise levels: statistical models, machine learning models, and the most popular approach based on the use of numerical predictive models [26]. When dealing with numerical models, all physical aspects related to propagation, reflection, and noise attenuation are taken into consideration. It is also important to note that in the case of road noise studies, applying these methods requires, in general, knowledge of road traffic variables such as traffic mix, average fleet velocity, and vehicular flow rate. Usually, these variables are measured on the roadside or calculated by using road traffic flow models.

As road noise prediction models are of concern, there are several available ones to predict the sound levels from road traffic [27], [28]. Most of the early basic models are simple, and they need only some traffic variables, including vehicular flow rate, average speed, heavy vehicle percentage, and distance between source and receptor. Among these models, we can quote those proposed by Burgess [29], Griffiths and Langdon [30], Fagotti and Poggi [31], French C.S.T.B. [32], and Quartieri et al. [28].

Through the past few years and following even more extensive research, more developed and comprehensive models have appeared. Most of these noise level calculation models are regional and specific to countries such as ASJ in Japan [33], GIS in China [34], CORTN in the UK [35], CNR in Italy [36], RLS-90 in Germany [37], FHWA in the USA [38], Nord 2000 in the Nordic countries [39], StL-86 and SonRoad in Switzerland [40], ERTC in Thailand [41], and NMPB-roads in France [42]. Besides others have been developed for the European Union, such as Harmonoise [43] and the most recent model, CNOSSOS-EU [44]. It is worth noting that the aspects related to sound propagation in CNOSSOS-EU are the same as those in the NMBP-roads method. An expanded review, along with a detailed comparison between several of these models, can be found in [45]-[50].

In a comparable setting, numerous traffic noise modelling software packages have been developed in various regions of the world. These software packages, whether commercial or open-source, integrate one or more road noise prediction models. In our knowledge, at present the most widely used noise prediction software is CadnaA (Computer Aided Noise Abatement), SoundPLAN, Predictor-LimA, TNM (Traffic Noise Model), MithraSIG, NoiseMap, Noise 3D, and IMMI software [51]-[53]. Likewise, noise prediction models have also been integrated into geographic information system (GIS) software via extensions and plugins such as ArcGIS, OrbisGIS, and QGIS [54], [55]. For instance, QGIS software has a powerful plugin called OpeNoise, which allows users to predict the noise levels generated by a point source or a line source (road) at fixed receiver points and structures.

Traffic conditions, road types, vehicle characteristics, and driving style as well as human behaviors are the main factors that affect traffic noise levels [56]. Among road traffic factors, on can cite traffic volume, traffic speed, traffic mix, traffic jams, and bottle necks. The most important determining factor is the traffic volume, as the most other factors are considered to be a result of the traffic volume fluctuations. Despite the strong dependency, the relationship between traffic volume and road noise level is non-linear and is controlled by a number of factors which are related to traffic conditions.

In several emerging countries, such as Tunisia, impact studies related to noise transportation are generally not taken into consideration during the design and planning phases of new transportation infrastructure. Besides, the lack of specific models for predicting road traffic noise as well as the absence of urban noise monitoring and assessment strategies usually result in exceeding recommended noise levels, especially in metropolitan environments. However, it is possible to reduce the discomfort caused by road traffic and build more livable and sustainable urban settings by applying urban noise monitoring and assessment practices.

The main focus of this paper is to investigate how variations in road traffic conditions affect noise levels and human exposure in a Tunisian urban site characterized by heavy road traffic. First, the methodology section will outline the specific urban site chosen for the study and provide details about the traffic data collected. It will also expose the criteria used to select a suitable model for predicting noise levels at the chosen site. Second, in the results and discussion section, authors will present and discuss the main outcomes obtained, including the distribution of road noise levels and their impact on human exposure. Finally, the conclusion will summarize the key findings and suggest some convenient recommendations.

II. METHODOLOGY

A. Site description

The study area belongs to the governorate of Monastir, a coastal city located in the center-east of Tunisia, and approximately 162 kilometers southeast of the capital city, Tunis. The selected location is an urban area with heavy road traffic. Residences, schools, cultural centers, banks, and commercial centers are the main buildings on the site. As shown by Figure 1, there are two major streets: the first is TaiebMhiri Street (TMS), which provides access to the other neighboring cities, including Sousse, Kairouan, and Mahdia. The second is known as Remada Street (RS), linking the urban agglomeration of Remada to the city's center.

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Fig. 1 Top view of the study area from Google earth

Table 1 provides some parameters of the selected area. It measures 300 m by 600 m, with an average elevation above sea level of around 17 meters. The height of edifices ranges from 3 to 21 meters. The percentage of the lot area that is covered by buildings, also called the building coverage ratio (BCR), is roughly 48%. The site's road network consists of single- and multi-lane roads with widths ranging from 3 to 7 meters.

TABLE I
SITE PARAMETERS

Parameter	**Value**
Latitude	35°46'03.30''N
Longitude	10°49'19.44''E
Elevation above sea level	17 m
Dimensions of area	300 m × 600 m
Building Coverage Ratio (BCR)	48 %
Building heights	3-21 m
Road widths	3-7 m

The central intersection is an urban four-legged roundabout, unsignalized and priority controlled. Figure 2 illustrates the geometric layout of this roundabout. Entries A1 and A3 are double-lane approaches, whereas entries A2 and A4 are both single-lane approaches. The geometric pattern also includes splitter islands and a non-mountable central island with a diameter of 14 meters. Furthermore, the main geometrical features of the central roundabout are given in Table 2. It is important to indicate that despite the enhancements made by road planners to improve traffic flow at this intersection, there are still issues with traffic congestion and queues, particularly during high traffic periods.

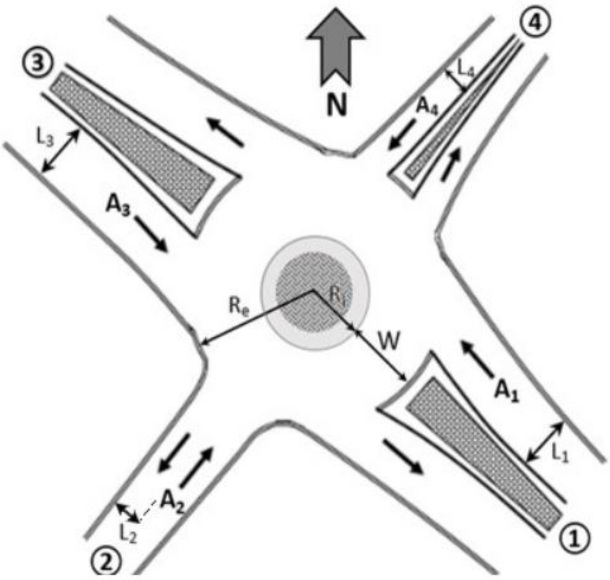

Fig. 2 Geometry layout of the studied intersection

TABLE 2
ROUNDABOUT GEOMETRICAL FEATURES

Approach width (m)				Radius (m)		Circulatory width (m)
L_1	L_2	L_3	L_4	R_i	R_e	W
7	3.5	7	3.5	7	17	10

B. Road traffic data collection

Traffic volumes were counted manually on each leg of the central intersection with the help of a video retrieved from a digital camera on Tuesday, April 12, 2022, before noon. Table 3 provides detailed road traffic count results for each leg. As can be seen, the highest traffic volumes were observed during rush hour, from 07:30 a.m. to 08:30 a.m. During this period, traffic patterns revealed a notable peak, with a high level of traffic congestion and excessive queue durations observed on all approaches. On the other hand, from 9:30 a.m. to 10:30 a.m., the road traffic profile showed a noticeable decline, resulting in smooth traffic flow without congestion problems.

A road traffic count was also performed on the local arteries within the study area. It was found that the vehicle flow rates, including light and heavy vehicles, ranged from 5 to 288 veh/h during the rush hour and from 4 to 113 veh/h during the non-rush hour. Besides, given their relatively low proportion when compared to light and heavy vehicles, two-wheelers such as motorcycles and mopeds were not included in this traffic count.

At the four-legged roundabout, ensuring traffic balance implies that the sum of vehicular flux (Q_i^{in}) entering each leg of the roundabout be equal to the sum of vehicular flux (Q_i^{out}) exiting from each leg. Hence, the road traffic balance equation at this intersection can be expressed as follows:

$$\sum_{i=1}^{4} Q_i^{in} = \sum_{i=1}^{4} Q_i^{out} \qquad (1)$$

The total traffic volume accessing the roundabout during rush hour was 4093 vehicles per hour, while during non-rush hour it was 1794 vehicles per hour, which means a traffic volume reduction of over 50%. It is worth noting that in both hours, the highest volumes were recorded on high-capacity sections, which are legs 1 and 3.

Road traffic is the main local noise emission source in this area. The existence of significant human activity strongly exposed to traffic-related noise pollution, as well as the lack of urban noise monitoring stations, prompted the selection of this site for investigation.

TABLE 3
ROAD TRAFFIC COUNTS FOR RUSH AND NON-RUSH HOURS

Road traffic count during rush hour (veh/h) **07:30 a.m. - 08:30 a.m**					
Roundabout		Leg 1	Leg 2	Leg 3	Leg 4
Entrance $(Q_i^{in})_{i=1,2,3,4}$	LV*	1187	853	1300	547
	HV**	63	45	69	29
Exit $(Q_i^{out})_{i=1,2,3,4}$	LV	1178	429	1661	619
	HV	62	23	88	33
Secondary roads	LV	From 5 to 273 veh/h			
	HV	From 0 to 15 veh/h			

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Road traffic count during non-rush hour (veh/h) **09:30 a.m. - 10:30 a.m**					
Roundabout		Leg 1	Leg 2	Leg 3	Leg 4
Entrance $(Q_i^{in})_{i=1,2,3,4}$	LV*	499	479	561	217
	HV**	11	10	12	5
Exit $(Q_i^{out})_{i=1,2,3,4}$	LV	466	196	754	340
	HV	10	4	17	7
Secondary roads	LV	From 4 to 108 veh/h			
	HV	From 0 to 5 veh/h			

** LV: Light Vehicle < 3.5t – ** HV: Heavy Vehicle ≥ 3.5t*

C. *Model evaluation metrics*

The selection of a road noise predictive model is essentially based on its performance and accuracy. Four statistical metrics were employed to evaluate the performance of each preselected model, including the correlation coefficient (r), the coefficient of determination (R^2), the root mean squared error (RMSE), and the accuracy (Acc) [57].

The linear correlation between two sets of data is measured by the correlation coefficient (r). It is defined as:

$$r = \frac{\sum_{i=1}^{n}\left(L_{eqi}-\bar{L}_{eq}\right)\left(L^{*}_{eqi}-\bar{L}^{*}_{eq}\right)}{\sqrt{\sum_{i=1}^{n}\left(L_{eqi}-\bar{L}_{eq}\right)^{2}\sum_{i=1}^{n}\left(L^{*}_{eqi}-\bar{L}^{*}_{eq}\right)^{2}}} \quad (2)$$

A statistical metric used to evaluate the goodness of fit of a regression model is the coefficient of determination (R^2). It is given by the following relation:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(L_{eqi}-L^{*}_{eqi}\right)^{2}}{\sum_{i=1}^{n}\left(L_{eqi}-\bar{L}_{eq}\right)^{2}} \quad (3)$$

A measure of the disparity between the measured and predicted model values is the root mean squared error (RMSE). It is calculated as:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(L^{*}_{eqi}-L_{eqi}\right)^{2}} \quad (4)$$

A statistical metric that quantifies the correctness of model predictions with an acceptable error is the accuracy (Acc). It is evaluated by the following equation:

$$\mathrm{Acc} = \frac{100}{n}\sum_{i=1}^{n} c_i \quad (5)$$

$$c_i = \begin{cases} 1, \text{if } \left|L^{*}_{eqi}-L_{eqi}\right| \le e \\ 0, \text{otherwise} \end{cases} \quad (6)$$

In the above expressions L^{*}_{eqi} and L_{eqi} denote the measured and predicted traffic noise level values for the i^{th} measurement in the dataset, respectively, while $\bar{L}^{*}_{eq}$ and $\bar{L}_{eq}$ denote the mean value of the measured and predicted noise levels, n is the number of experimental measurements, and e=±1dB(A) is the acceptable error value.

D. *Road traffic noise model selection*

In this subsection, three well-known traffic noise prediction models commonly used in noise assessment studies were tested: the French NMPB-2008 model, the Italian CNR model, and the German RLS90 model. The choice of these three models was justified by the notable resemblance between the traffic patterns and infrastructure in Monastir (Tunisia) and those shown in many cities located in southern European nations, particularly Italy and France.

It is worth noting that, for the sake of brevity, the mathematical formulation of each model has not been included here. However, a more detailed review of these predictive models and their corresponding mathematical formulations can be found in [27].

Table 4 provides some field measurements relative to road traffic volumes (Q(veh/h)), heavy vehicle percentages (P (%)), as well as related equivalent noise levels (Leq). It should be noted that all measurements have been collected from the studied site at a distance of 5 m from each leg of the central roundabout.

Traffic measurements such as traffic volumes and heavy vehicle percentages were also used as inputs by the three above-stated models in order to compare and select the most adequate one for road traffic noise level calculation.

TABLE 4
MEASURED AND CALCULATED NOISE LEVELS BY NMPB-2008, CNR AND RLS90 MODELS

Q (veh/h)	P (%)	**Noise levels [dB(A)]**			
		Measurements (L^{*}_{eqi})	NMPB (L_{eqi})	CNR (L_{eqi})	RLS90 (L_{eqi})
660	1,6	74,98	71,75	70,11	71,95
480	0,8	69,5	68,56	68,57	69,54
690	11 ,3	73,96	72,30	71,92	71,37
510	10,6	68,79	69,27	70,51	70,04
830	23,4	78,65	76,25	74,39	75,45
640	19,3	70,92	71,90	72,58	71,23
740	18,7	70,92	71,39	73,14	71,84
580	15,4	70,13	71,08	71,70	70,71

A plot of the estimated noise levels versus the measured values is given in Figure 3. It can be seen that for low traffic volumes, the three traffic noise models provided good results compared to measured levels. However, the discrepancy becomes relatively more important when traffic volumes increase, although overall, the NMPB-2008 model gave better results on average.

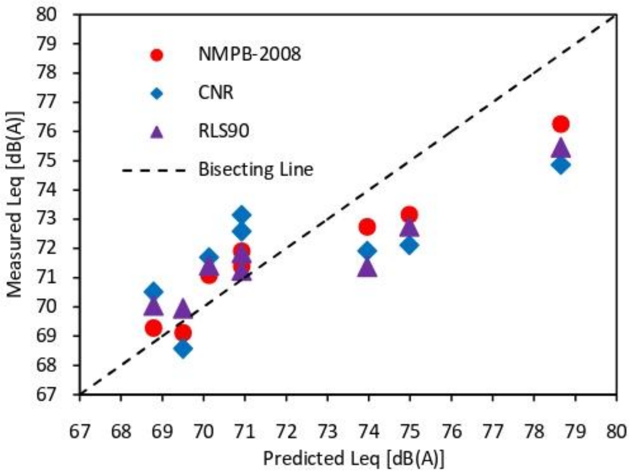


Fig. 3 Measured versus predicted traffic noise levels by NMPB-2008, RLS90, and CNR models

Table 5 depicts the calculation results of the correlation coefficient (r), the coefficient of determination (R^2), the root mean squared error (RMSE), and the accuracy (Acc) for the three-road traffic noise prediction models. In fact, it is well known that good model precision is implied by a lower value of RMSE and higher values of r, R^2, and Acc. As can be observed, the lowest RMSE value and the highest r, R^2, and Acc values are shown for the NMPB-2008 model. Henceforth, the French outdoor NMPB model will be used to estimate the traffic noise levels in the urban site under consideration since it gave the best results on all the performance measures. Besides its performance, the standard NMPB prediction model was recommended by the European Community as the reference method for predicting urban traffic noise in European countries [58], [59], as it is among the best model to reflect the nature of urban noise.

TABLE 5
COMPARISON OF THE PERFORMANCE CRITERIA FOR THE THREE SELECTED TRAFFIC NOISE PREDICTIVE MODELS

	Traffic Noise Prediction Model		
	NMPB	CNR	RLS90
r	0.9624	0.7234	0.9228
R^2	0.9264	0.5234	0.8517
RMSE	1.66	2.73	1.90
Acc [±1 dB(A)]	62.5 %	12.5 %	37.5 %

III. RESULTS AND DISCUSSION

A. *Road traffic noise analysis*

In this section, we will present and analyze the road noise level prediction results. The findings will be compared during two different traffic periods (rush and non-rush hours) to showcase how road traffic congestion affects sound levels and human exposure.

The road noise mapping was performed using the cross-platform desktop GIS software: QGIS 3.28.1-Firenze. The QGIS plugin OpeNoise 2.0, created by the Italian Environmental Protection Agency of Piedmont and released on GitHub on July 2022, allows to compute the noise levels generated by road sources and then create noise maps using an interpolation method based on the inverse distance weighting technique.

The NMPB-1996 (traffic flow) was packaged in the OpeNoise plugin. The NMPB-1996 is the old version of the French NMPB-2008 model, having the same noise propagation principle but with some reconsiderations. Traffic data (traffic volumes, traffic composition, traffic type, and average speeds), road characteristics (surface type and slope), and buildings (geometry, height, and number of residents) are the basic inputs to perform a road noise simulation.

One of the fundamental steps for predicting road noise levels is the importation of the site map into the appropriate projected coordinate system, which is, in our case, Carthage-North Tunisia / EPSG: 22391. Based on the site map, two essential QGIS layers were created: the first layer defined the buildings, while the second layer defined the roads, which constitute the emission sources of the noise. At this level, it was mandatory to input the traffic data for each road direction using the QGIS attribute table.

The basic steps of the road noise simulation with the OpeNoise plugin are:

1) generating a grid as receiver points;
2) calculating road noise levels in all receivers;
3) creating contour levels;
4) estimating noise exposure.

Figure 4 displays all the fundamental steps to perform a road noise simulation project in the QGIS environment.

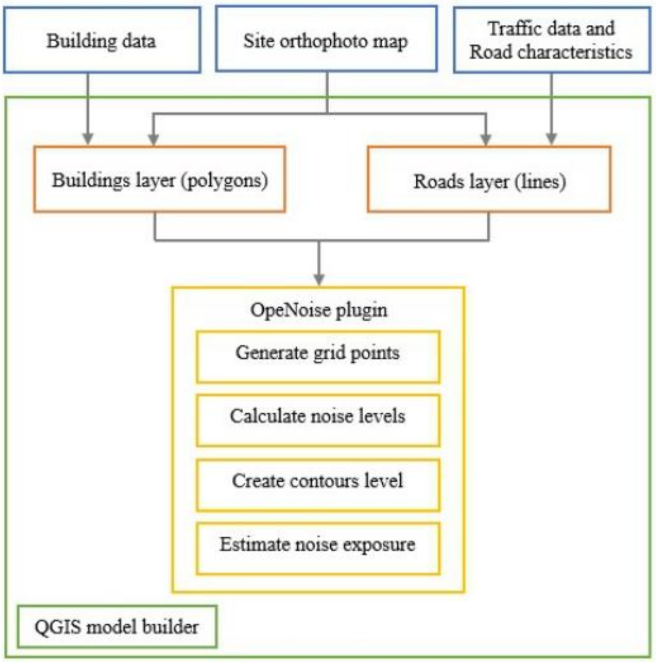


Fig. 4 Basic steps involved in a road noise simulation project within the QGIS environment

Table 5 provides all the required parameters for the road noise simulation. The grid size was 60×120 meshes with a spatial resolution of 5m×5m. Each mesh center was considered a receptor point located 2 m above ground level.

The road surface, composed of smooth asphalt, is flat. Traffic and climatic parameters during the two-studied hours are also provided in Table 6.

TABLE 6
PARAMETERS SETTINGS FOR ROAD NOISE SIMULATION

Parameter	**Value / Type**	
Grid size	120 × 60 = 7200 points	
Grid resolution	5 m × 5 m	
Receiver height	2 m	
Road surface category	Smooth asphalt	
Road slope	Flat ≤2%	
Traffic and climatic parameters	Rush hour	Non-rush hour
Averagespeed ranges (km/h)	20 – 50	50 – 70
Traffic type	Pulsed	Continuous
Temperature (°C)	15.2	18.6
Relative humidity (%)	82	67

Figure 5 depicts a digitalized map of the surveyed domain, providing a visual representation of the arrangement of buildings and the analyzed road stretches. As mentioned earlier, the buildings in this area consist of residences, schools, shopping areas, banks, and cultural centers, with heights ranging from 3 to 21 meters. The buildings that are most susceptible to road noise exposure are situated along the two-major roads: TaiebMhiri and Remada streets.

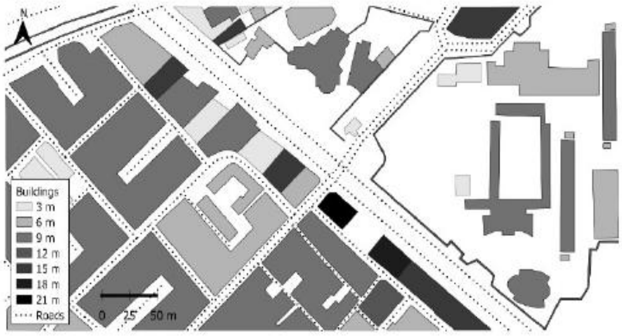
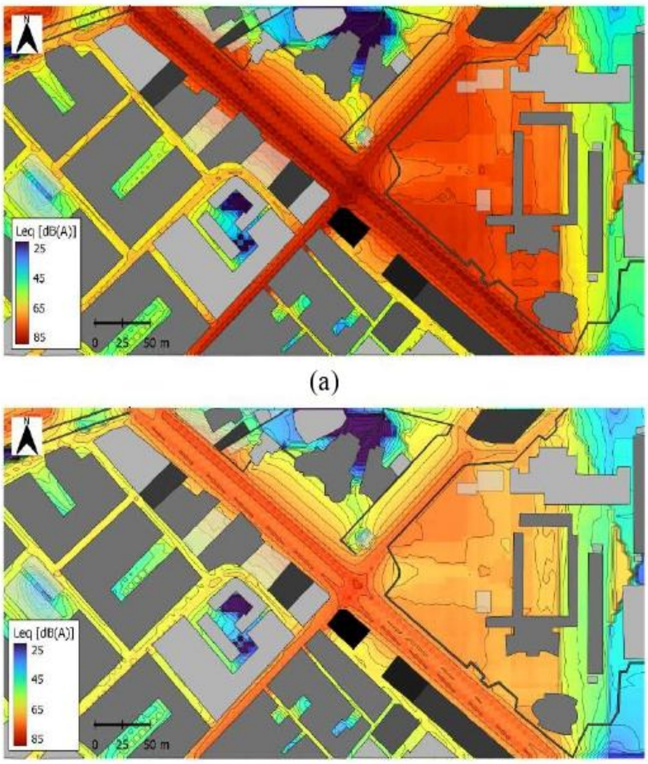


Fig. 5 A digitalized sketch showing the building and road layers

Road noise mapping was performed for two-different traffic periods: rush hour and non-rush hour. Based on the inverse distance weighting (IDW) method, the OpeNoise plugin draws a contour layer starting from the previously calculated grid receiver points to produce the noise maps for the two-studied hours.

Figure 6 (a) illustrates the road noise map during the morning rush hour. It can be seen that the loudest road traffic was typically observed along the two-city's busiest roads, which are TaiebMhiri and Remada streets. Subsequently, buildings located on both sides of these two-streets are highly exposed to traffic noise levels reaching up to 85 dB(A). In the same way, Figure 6 (b) shows the road noise map during the non-rush hour. In this case, the highest road noise levels were also recorded along TaiebMhiri and Remada streets. However, compared to rush hour, the noise levels were reduced and did not exceed 78 dB(A). Throughout both hours, the lowest noise levels were observed along the side arteries, which experience the lowest road traffic volumes.



(a)

(b)

Fig. 6Noise level contours for (a) rush hour and (b) non-rush hour

The impact of road traffic noise requires a thorough understanding of the road noise level gaps between rush and non-rush hours. It aids in identifying regions that may need further noise mitigation measures, such as the construction of noise barriers, rearranging the design of the roads, or putting in place sound insulation measures for structures situated in high-noise areas. In this study, we have calculated the noise level gaps between the two hours at each grid point (i, j) according to the following equation:

$$\Delta L_{eq}(i,j) = L_{eq\_RH}(i,j) - L_{eq\_NRH}(i,j) \quad (7)$$

where $\Delta L_{eq}(i, j)$ denotes the noise level gap at the point receptor P(i, j). $L_{eq\_RH}(i, j)$ and $L_{eq\_NRH}(i, j)$ are the road noise levels during rush and non-rush hours at a grid point (i, j), respectively.

The average noise level gap over the whole domain was calculated by applying the following equation:

$$\overline{\Delta L_{eq}}(i,j) = \frac{\sum_{j=1}^{M}\sum_{i=1}^{N}(\Delta L_{eq}(i,j))}{N\times M} \quad (8)$$

N=120 and M=60 are the numbers of point grid (receptors) along x and y directions, respectively.

Figure 7 depicts the spatial distribution of the road noise level reductions over the whole studied domain. It is easy to note that the largest reductions were observed along the two-major streets, Taeib Mhiri and Remada. Furthermore, the maximum reduction values, ranging from 6.6 to 7.7 dB(A), were shown around approaches A1 and A3 of the central roundabout.

Fig. 7 Spatial distribution of the road noise level reductions over the whole simulation grid

Based on equation (8), the average road noise level gap was approximately 3.18 dB(A) when the total traffic volume was reduced by around 52%. This reduction aligns with the findings of the available literature, which stated that road noise levels increase by 3 dB(A) for every doubling of traffic volume [60]-[63]. Additionally, the present results were compared to those obtained by [64] in a previous study aimed to evaluate the road noise pollution in the city of Curitiba (Brazil) by using the Predictor soft noise. As depicted in Table 7, the comparison revealed a significant agreement between the two-results.

The projected overall population on the site, including students and residences, was estimated at 4560 people for assessing the potential human exposure to traffic noise levels. The four noise exposure classes were defined as follows:

- Less than 55 dB(A): low exposure;
- From 55 to 64 dB(A): moderate exposure;
- From 65 to 74 dB(A): high exposure;
- More than 75 dB(A): very high exposure

TABLE 7
COMPARISON OF THE PRESENT RESULTS WITH THOSE OBTAINED BY REFERENCE [64]

	Reference [64]	**Present work**
Study location	Curitiba (Brazil)	Monastir (Tunisia)
Type of area	Urban	Urban
Software package	Predictor 8.11	OpeNoise 2.0/QGIS
Traffic reduction (%)	50	52
Road noise level reduction [dB(A)]	3	3.18

Figure 8 displays the histograms of road noise exposure levels during rush and non-rush hours. As can be seen in both cases, the major part of population was exposed to noise levels greater than the new WHO standard threshold of 53 dB(A) as road traffic noise above this level is associated with adverse health effects [65]. The largest percentages of the population were potentially exposed to moderate noise levels ranging from 55 to 64 dB(A) with a proportion of 58.8% during rush hour and 62.5% during non-rush hour. In addition, 12.5% and 23.5% of the population were exposed to high noise levels between 65 and 74 dB(A) during rush and non-rush hours, respectively. However, 12.5% of the overall population was potentially exposed to very high noise levels exceeding 75 dB(A) only during rush hour.

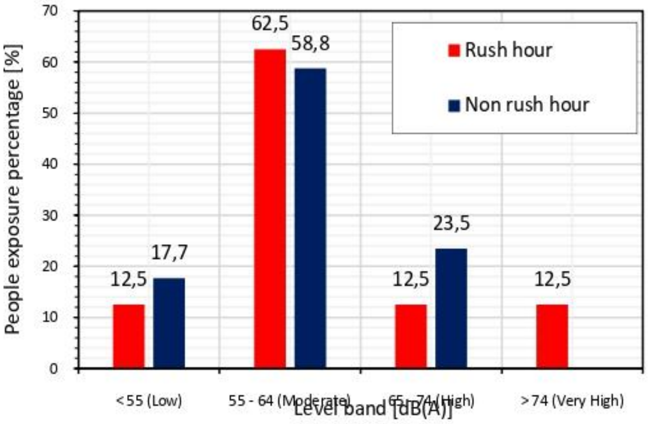


Fig. 8 Histograms of road traffic noise exposure levels during rush and non-rush hours

Although reasonably realistic results were obtained by the present investigation, it should be noted that there are some limitations related to the tool used in this research. Specifically, the OpeNoise plugin is limited to showing the noise propagation up to 1000 meters from a given noise source. As a consequence, this can limit the applicability and accuracy of calculations when dealing with higher noise levels, such as those generated by rail traffic.

IV. CONCLUSIONS

Road traffic noise disturbance has been recognized as one of the major negative transportation externalities that threaten life quality, especially in urban environments. In this fieldwork, numerous investigations have revealed a strong correlation between urban noise and traffic conditions, which remain the predominant factor that affects noise levels in metropolitan areas. In this paper, the effect of traffic conditions on both road noise levels and human exposure at a busy metropolitan Tunisian site has been investigated.

First, a description of the studied site as well as the road traffic data have been presented. Then, a comparative study was carried out to select the most adequate traffic noise predictive model for assessing the road traffic noise levels in the investigated area. Finally, the obtained results, along with a discussion, have been provided. Accordingly, the following findings were drawn:

i. The comparison between three standard transportation noise models showed that the French road noise prediction model (NMPB) was the most suitable to predict traffic noise level, as it provided good accuracy compared to the two other predictive models.

ii. The road noise simulation with the QGIS environment via the plugin OpeNoise 2.0 revealed that the average road noise gap between rush and non-rush hours was evaluated at 3.18 dB(A) for a total traffic volume reduction of around 52%.

iii. The highest proportions of the population, 58.8% during rush hour and 62.5% during non-rush hour,

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were potentially exposed to moderate noise levels ranging from 55 to 64 dB(A).

iv. 12.5% and 23.5% of the population were exposed to high noise levels between 65 and 74 dB(A) during rush and non-rush hours, respectively.

v. 12.5% were potentially exposed to very high noise levels above 75 dB(A) during the morning rush hour.

Considering the substantial growth of the car fleet worldwide, it is crucial today to regularly assess the road traffic noise levels for all urban sites, regardless of size, in order to guarantee a good quality of life and a clean environment. The findings of this work can provide valuable guidance for implementing road noise abatement measures, specifically targeting the reduction of noise disturbance caused by road traffic, especially during peak traffic hours. Appropriate measures can be designed and implemented to alleviate the problem, including traffic management strategies, road design optimization, noise barrier construction, and traffic volume reduction measures during high traffic periods. Ultimately, the study's outcomes can guide evidence-based decision-making and help improve the quality of life for those who are disturbed by road traffic noise, particularly during busy traffic periods.

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