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URBAN NOISE MAPPING: THE IMPACT OF TRAFFIC NOISE LEVEL IN THE ENVIRONMENTAL NOISE POLLUTION

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ABSTRACT

The European Union proposes noise protection measures adopted in accordance with European legislation, emphasizing environmental noise pollution as an important environmental problem. The legislation imposes European Directive 2002/49/EC, which aims to establish a common basis for addressing noise problems in Europe through noise maps which are a powerful tool for controlling the population exposure to environmental noise. In this paper, a noise map generation based on using the vehicle flows on four boulevards that enclose a living area in the center of Skopje, the capital city of North Macedonia is described. For this purpose, statistics on the flow of vehicles on the boulevards are provided by Traffic Management and Control Center. The noise simulations were created using a noise propagation model in IMMI as simulation software. The initial map was additionally validated by performing short-term measurements at the intersections of these boulevards in order to come to a conclusion of the impact of the traffic noise pollution in the overall environmental noise situation. The advantage of having this map representation of traffic noise allows for a more accurate view of the actual environmental noise circumstanes in the city center, determining more quickly the causes of high noise levels and, consequently, any mitigation action required.

Keywords— urban noise mapping, traffic noise pollution, noise exposure

1. INTRODUCTION

In the past few years due to the expanding urbanization and overpopulation of the cities, the amount of people exposed to high noise levels worldwide has drastically increased. Among the many factors that interfere with the levels of noise, one of the most steadily uprising is the traffic noise pollution. The European Union, through the Directive 2002/49/EC **[1],** has established foundations that require creation of noise maps of the cities as a model of predictive calculation of the noise propagation. This has been widely adopted in the European countries in terms of preparing action plans to establish community measures for assessment and control of noise emitted by the main sources, such as the traffic noise. Namely, the noise mapping techniques together with the correlated standards, include creating traffic noise maps based on data for the traffic density combined with actual measurements of the noise level in terms of simulating and verifying the traffic noise situation in the cities **[2]**.

A common strategy in order to conduct the street traffic flow analysis and to obtain a traffic noise predictive map is gathering information for the traffic flow for a particular area and time periods in the city of interest **[3]**. This can be conducted through manual measurements of the number of vehicles on a certain road or easily, by obtaining automated traffic flow information **[4]**. A solution for best possible estimation and prediction of the traffic noise pollution provided by this kind of data is proposed in **[6]**, where accordingly the map is created for the most specific conditions, meaning for the "optimum" days that are the most representative of the weekly sound level in the area of interest. In order to perform the traffic noise simulation and calculate the propagation model, different noise calculation software (CadnaA, IMMI, SoundPlan, etc.) can be used as explained respectively in **[7, 8, 9].** Furthermore, the L_{den} (equivalent level to day-evening-night) needs to be identified which according to the standard **[5]** is the basic noise descriptive parameter considered "annoyance" indicator. The equivalent sound level (L_{eq}) from the traffic flow depends on three specific variables: the average velocity of flow, the relating height to the urban context and the material relating to the road surface which need to be taken into consideration as an input in the simulation software when creating the map. Thus created predictive map for a chosen area, fed with the statistics for the number of vehicles per hour in a certain day, is a visual representation of the noise dispersion caused by the traffic flow. The problem with such an implementation of this technique is that the information about the traffic data might not be always correct and quantitatively available (number of vehicles per hour) or qualitatively (types of vehicles, time representativeness and accuracy) for all roads in the city **[10].** In such cases, the software calculates the sound propagation based on the given incorrect or insufficient input, which can result with wrong values for the indicators. Therefore, in agreement with the recommendations of the EU WG3 "Computation and measurements" **[12],** series of outdoor measurements need to be conducted in order to validate the results from the predictive traffic noise maps **[11].**

In the city of Skopje, North Macedonia, as a non-European country, there has been no previously conducted research using the noise mapping approach for monitoring the noise situation. In this paper, a methodology for creating a traffic noise map for a noise polluted area in the center of the city using a traffic flow statistics obtained from the Traffic Control and Management Center and its' validation process is presented, in order to examine the traffic flow noise impact in the overall noise situation. The aim of this study is to compare the results obtained from the traffic flow noise map generated based on traffic data analysis of four main boulevards that border the chosen area in the city, with the results obtained through actual acoustic measurements with a hand-held sound level meter. This gives a significant advantage in this field because it will provide conclusions for the noise submission of the residential population in this area which as the most frequent area in the city.

The paper is structured in that manner that in section 2, the procedure of obtaining input data for traffic flow information and the selection of the representative area is explained. Further in section 3, the process of validation of the obtained traffic noise map throughout a series of actual measurements is described and in section 4 the results thereof are discussed. At the end, in section 5, the conclusions of the conducted work are definitely not left out.

2. TRAFFIC-FLOW ANALYSIS METHOD

Recently, the changes in infrastructure, as well as the raise in population and tourist density in Skopje, the capital city of North Macedonia, have caused an increase of the traffic volume and frequency of people across the city. Many vehicles form long columns resulting in congestion on the streets and often exceed the permissible noise limit during the day and night period. According to statements from the residents, during the night hours, loud and irritating sounds of motorcycles and cars can be heard mainly on the boulevards, moving at speeds faster than allowed, contributing to the volume and duration of noise. This is proved true according to the latest available information from the State statistical office, in a five-year period, from 2013 to 2018, the number of registered vehicles in the city has raised for 15 % (Fig. 1).

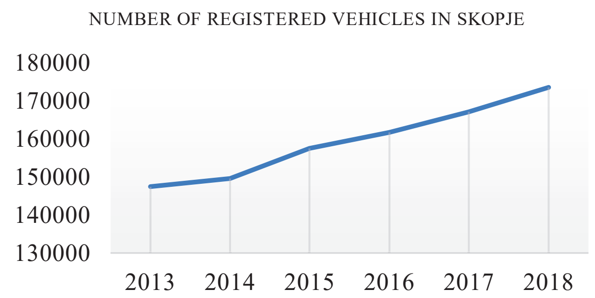


Figure 1: Latest statistics for the number of registered vehicles in the last 5 years according to the State statistical office

Besides some noise measurements conducted from the Government that were mainly focused on the noise coming from the catering facilities such as restaurants, coffee places and clubs, no other information specifically about the traffic noise level situation in the city of Skopje has ever been provided. The assessment of the traffic noise pollution according to **[1]** consists of determination of the equivalent level of automobile noise in a specific area in the city on a given day, based on the vehicle flow on a particular roads section resulting in visual presentation on a noise map created in a noise mapping software.

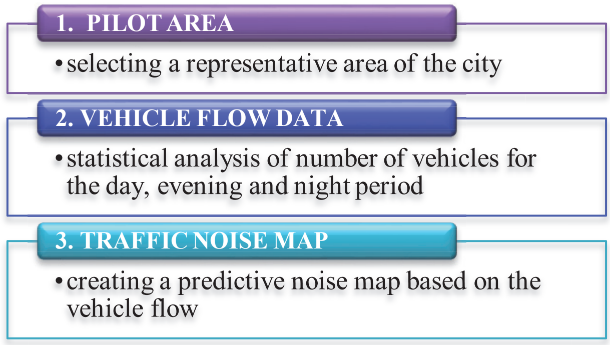


Figure 2: Methodology for creating a predictive traffic-flow noise map

The aim of the traffic-flow analysis method is to create a predictive noise map based on a statistical data for the number of vehicles which can be conducted following the three main steps **[3]** given in Fig. 2. This methodology was used in the city of Skopje for providing a traffic noise map for a particular area in the city, which is exposed in the following sections.

2.1 Pilot area

Few years ago, a software company placed in the city of Skopje has implemented a low-budget sensor network across the city which measures some dynamic environmental parameters such as air pollution, temperature and humidity, as well as the noise level. The collected data from the sensors is uploaded to an online platform called Skopje.pulse.eco which is available to the public, presenting the noise level at 21 points across the city. Because of the low accuracy and high uncertainty of the low-budget sensors, the data obtained could not be used for conducting the strategic mapping procedure. This platform is used in order to analyze the trend of changes of the noise pollution during the 24 hour in all locations across the city simultaneously and the obtained information from the sensors are used as an indicator for detecting the areas in the city that are most exposed to higher noise levels. Because of the sensors inaccuracy, the values from the sensors data are not used, but only the comparison of the fluctuations in the noise level in all measurement points is monitored. After a longer period of monitoring and analyzing these data, it is concluded that the highest value of the noise is indicated on the measuring point which is located in the “Debar Maalo” neighborhood, an old residential area in the city center. The “Debar Maalo” neighbourhood, given its 10.000 inhabitants spread on an area of 0.4 km^2, is bordered with four main boulevards in the city: Partizanski Odredi, Kliment Ohridski, Ilinden and Roosevelt (Fig.3). This is a particularly crowded area not only due to the number of it’s inhabitants, but also to the huge number of visitors during the whole day. Apart from the large number of coffee places and restaurants in the immediate vicinity of residential buildings that work until the late night hours, the traffic frequency is high due to the main boulevards and other roads in the interior part of the area.

Figure 3: "Debar Maalo" area and the four bordering boulevard

Recently, a numerous construction activities have been taking place in the neighborhood as well, which further increases the noise level and disturbs the residents. On the other hand, besides the residential and catering facilities, the "Debar Maalo" neighborhood also contains facilities such as primary school, kindergarten, two faculties and a library that are gathering thousands of people daily, but at the same time require a quite ambient and noiseless environment. Therefore, the "Debar Maalo" neighborhood is adopted as a representative area of the city of Skopje and the noise measurements in "Debar Maalo" are taken as baseline for the development of a predictive traffic noise map further in this work.

2.2 Vehicle flow data

Considering the traffic noise as a major factor affecting the increased noise level in the "Debar Maalo" neighborhood that is selected as a representative settlement in the city, traffic noise analysis based on the intensity of the vehicle flow normalized in time (hours) is performed. For this purpose, statistic data for the vehicle flow on the four boulevards that border "Debar Maalo" is requested. The data is provided from the Traffic Control and Management Center, which is a state institution obliged to monitor the traffic density across the city roads through network of sensors set on every crossroad in the city. The provided data involve statistic values for the number of vehicles per hour for 24h period. Firstly, an analysis of the traffic flow during every season (spring, summer, autumn and winter) is conducted and it is concluded that the most loaded with traffic intensity is the winter period, comparing to other three seasons. Considering this information, the month and the day of the week that are most exposed in each location in winter are explored, because creating a map for this scenario provides most realistic results about the maximum noise exposure. Therefore, the day that has shown a highest number of vehicle frequency in that time period is noted for further analysis.

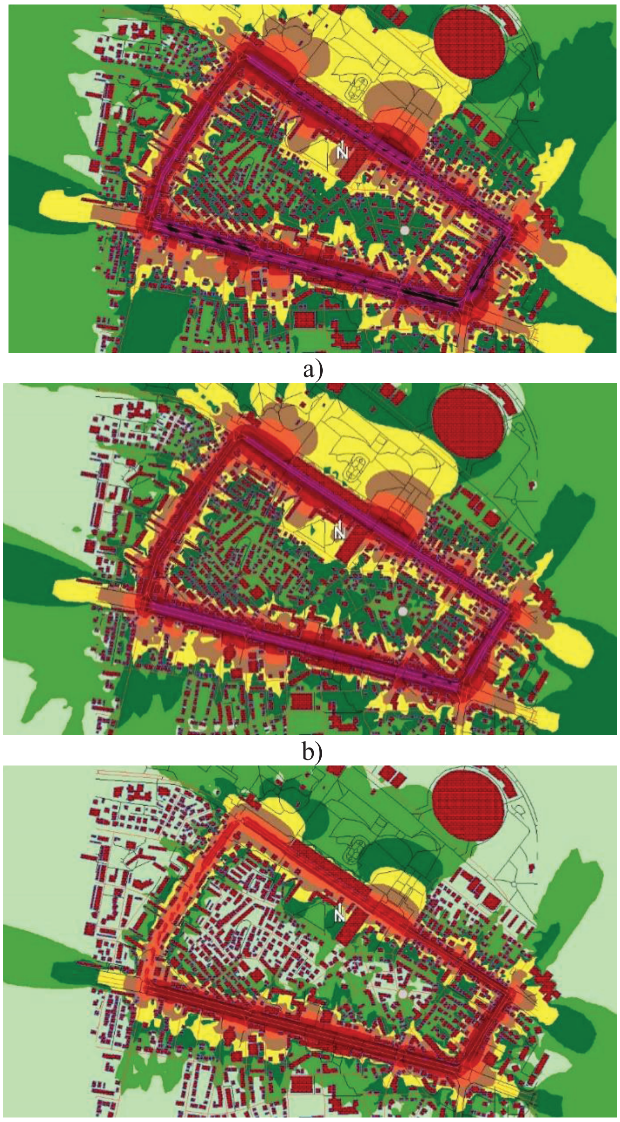
Table 1: Average number of vehicles for the three periods of the day selected

	Number of vehicles per hour		
	day (07-19)	evening (19-23)	night (23-07)
Partizanska	7452	5003	3082
Kliment Ohridski	2360	978	880
Ilinden	6550	4493	2004
Roosevelt	1413	974	348

Afterwards, the data for the number of vehicles on a chosen particular day is an input in the noise mapping software and the map was calculated according to the French National Method for Calculating Noise Indicators for Street Traffic [NMPB Routes], that classifies the equivalent noise level for the day time (from 7am-19 pm), evening time (from 19pm-23pm) and night time (from 23pm-7 am). The values for the number of vehicles for the three periods of the day are given in Table 1.

2.3 Traffic noise map

In order to create the predictive traffic noise map for the "Debar Maalo" area given the data for the number of vehicles for a particular day on the four border boulevards, the noise mapping software IMMI is used. This software package is used for professional and research purposes and is used for static mapping and prediction of environmental noise prevalence. For the calculations, IMMI takes the national guidelines and standards **[5]** into account. As an input for the basic map, the topography of the area using the GIS data provided from the software in an OpenStreet Maps map model is crucial. IMMI is an excellent solution for simulation, that allows the acoustic environment of a sector to be assessed, characterizing the sources and its surroundings. On the other hand, the correct input of the sound sources such as the traffic flow (number of vehicles) for the specific streets and periods of the day plays the most important role for the results relevancy. The base topographic sketch of the area is consisted of lines presenting the boulevards, roads and streets that border, or circulate inside the "Debar Maalo" area and geometric shapes presenting the buildings. This model of the topography map provides a good framework for defining the noise sources across the area given the correct coordinates of the streets and boulevards in 2D plain system. In such map, additional interventions before inserting the noise sources should be made in terms of defining the third dimension (height) of the objects as a part of the infrastructure across the area. Namely, for proper calculation of the sound propagation, the heights of the buildings are manually inserted into the model after conducting previous calculations of the individual objects heights in the area. The software offers a range of opportunities for modeling the noise sources according to the type of the source (point or line). The number of vehicles, average speed and types of vehicles characterizes the urban traffic noise and are required to be input in the software model. In this map, the number of vehicles for the four boulevards bordering the area over the three periods of the day (day, evening and night) from Table 1 is inserted in separate maps in order to recreate three different scenarios for the noise exposure. The average traffic speed on the boulevards is 50 km/h and the type of the vehicles was not differentiated. Having these parameters, the program calculates the noise maps dispersion models and the obtained results for the day, evening and night scenarios expressed in L_d, L_e and L_n are presented in Fig.5 as an indicator for the equivalent sound level. The calculation is visualized using the vehicle flow on the four main boulevards modeled in the software as line sources of noise.



a)

b)

c)

Figure 4: Predictive traffic noise maps of L_{eq} for "Debar Maalo" a) day period (L_d), b) evening period (L_e), c) night period (L_n))

The given noise map indicates highest noise levels (purple and red colored) on the boulevards and around them, which is normally due to the fact that the boulevards are used as noise sources. Also, can be noticed that the noise pollution reaches highest levels during the day period Fig.4 a) when the number of vehicles is drastically higher in comparison to the evening and night periods.

3. TEMPORAL SAMPLING METHOD

Actual measurements of the noise level on the previously determined points in the representative area are however needed not only to verify the model assumed with the software simulation but also for complementing the noise pollution assessment itself. This is achieved through local acoustic measurements of short duration or through long term monitoring in fixed measurement points. For the analysis of "Debar Maalo" area, four measuring points for acoustic measurements are defined (Fig.5).

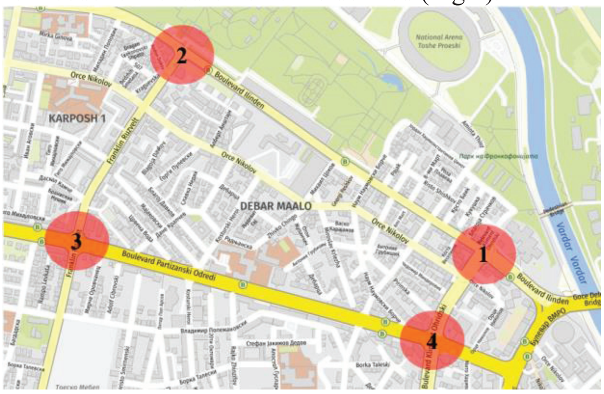


Figure 5: Location of the measuring points in "Debar Maalo"

The chosen points are located at the intersections between the four main boulevards that were modeled in the software as noise line sources. At each measuring point the noise level is represented by the Leq parameter in accordance with recommendations explained in **[5].** The acoustic measurements have been conducted by using a Bruel&Kjaer 2250 Class 1 sound level meter. The instrument is mounted at a height of 1.5 meters in the direction of a sound source 3.5 meters from the most exposed façade (Fig.6).

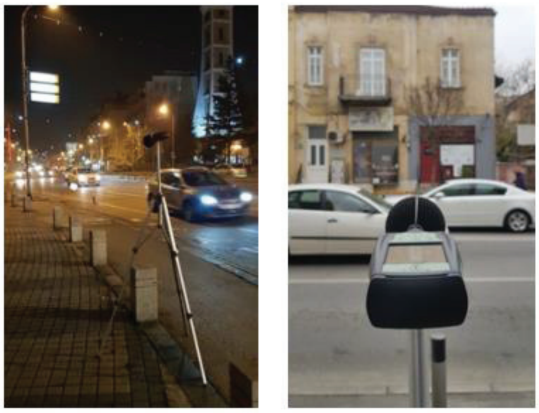


Figure 6: Photographs of the measurement setting

For each measurement point, the acoustic measurements are carried out 3 times during day, evening and night period by choosing 10-minute sampling interval that belongs in the specific period. The measured values for the equivalent sound level in Decibels [dB] are given in Table 2.

Table 2: Measured values for the noise level in the four intersections

	Measured equivalent noise level in [dB]		
Measurement point	L_d	L_e	L_n
1	73.4	72	70.3
2	66.8	66.7	64.6
3	73.6	70.6	66.7
4	69.8	69.8	68.7

4. RESULTS COMPARISON AND DISCUSSION

In order to validate the obtained results, an evaluation to determine the discrepancies between the modeled and measured noise level values on the four measurement points needs to be performed. The variable chosen for the analysis of the results is the continuous equivalent sound level (Leq) used as an "annoyance" indicator. In Fig. 7 are shown the values for the Leq indicator on the four measuring points provided from the two methodo

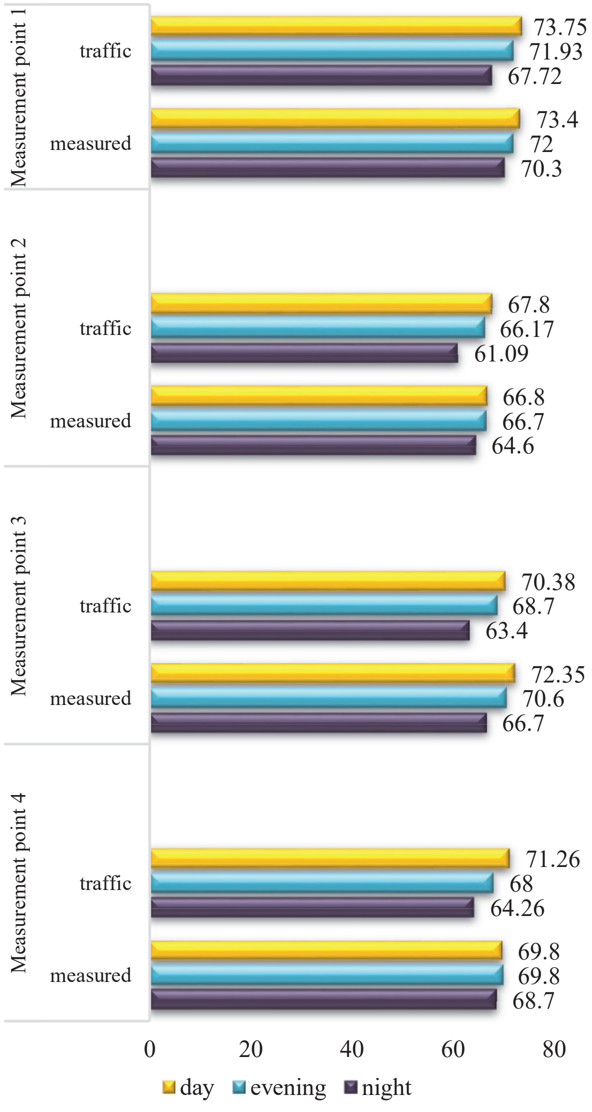


Figure 7: Leq for the 4 measuring points during the three periods of the day

The values given for traffic noise Leq are detected from the map calculations and the measured ones are read out from the sound level meter after the acoustic measurements. The outcome in Fig.7 demonstrate that the results provided from both methodologies for Leq indicator are exceeded for every measurement point in all three periods of the day given that the limit for Leq is 60 dB for day and evening, and 55 dB for night period **[1]**. The highest measured value is 73.4 dB during the day period in the measurement point 1 which is near to the Governmental building, which might occur due to the fact that this point is closest to the city center where there is a higher traffic frequency and circulation of people during the daytime period. The lowest value measured is 64.6 dB during the day in the measurement point 2, near the Zoo Garden, but it is still higher that the permitted 60 dB. These exceeded values confirm the initial conjecture that the area is seriously noise polluted and the residents are exposed to higher noise level than allowed. On the other hand, it is evident that the noise levels for the day period are higher than the values for the evening and night period in all four measurement points, which might lead to a conclusion that this might happen due to the higher traffic density during the day in comparison with the evening and night periods. Nevertheless, this can be misleading, regarding the fact that the values provided from the traffic noise map describe only the noise coming from the vehicles, meaning that other noise sources are not included in the overall noise value. Therefore, the differences between the values given from the map and those measured are calculated, that might lead to a better understanding of the impact of other noise sources into the overall noise situation. The differences between the measured and the values provided from the map are given in Fig. 8.

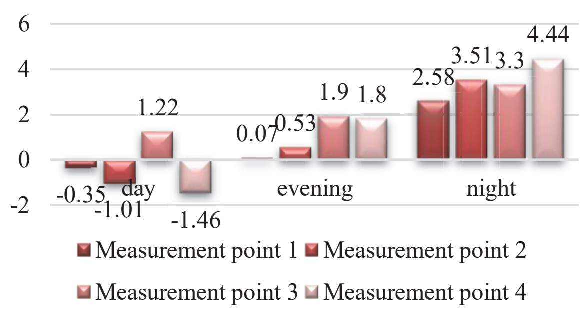


Figure 8: Differences in the results obtained from the two methodologies

From the results provided in Fig.8, can be concluded that the differences between the measured and simulated values being less than 2 dB for the day and evening period of the day, and for the night period the differences are reaching 4.4 [dB], meaning the measured values for the noise levels are higher than those read out from the traffic map. The evident dissimilarity of the measured and modeled values for Leq during the night period might occur due to the influence of other noise sources during the night period such as human speech or music, that can not be identified from the traffic noise map. On the other hand, the measurement uncertainty of the sound level meter and the accuracy of the model should be taken into consideration since they contribute to the overall results correctness. However, the validation of the results, leads to a conclusion that the major noise pollution problem in the area during the day and evening period is the noise coming from the traffic, whilst during the night period other noise sources might be considered presiding.

5. CONCLUSIONS

The noise map of the chosen area in the city of Skopje "Debar Maalo" constitutes a real important first step for a future work in the whole city for dealing the noise pollution problem. The technology of traffic noise mapping appears to be convenient since it allows, through easily accessible collection of traffic flow data to provide a visual representation of the noise situation and noise level distribution across the area at a very low cost, especially focusing on the issue with the traffic noise. On the other hand, the validation of this methodology with the traditional methodology based on acoustic measurements as explained in this study, provides a good solution for better understanding the causes for noise pollution and the impact of the traffic noise in the total noise level value. Correct representation of the topography and infrastructure of the area requires correct identification of many parameters in order to put a good base in the software itself is very helpful for the correct modeling. In parallel, a Class 1 sound level meter is required for accurate acoustic noise measurements in measurement points spread around the area where the traffic map is obtained. The results in this work demonstrate that the environmental noise, mainly the traffic noise is an important issue in "Debar Maalo" neighborhood in Skopje, North Macedonia. Discrepancies in the noise levels during the night period occur, which is believed to be due to the difference in noise source in the night period of the day in comparison with the day and evening period. This may lead to a conclusion that the traffic density during the night is lower, but other sources such as human speech or music might be dominant. Therefore, a further analysis of the presence of different types of noise sources and their impact should be conducted in order to provide a more accurate insight in the noise situation in the area.

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