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SIMULATION OF ROAD TRAFFIC NOISE POLLUTION IN KRAGUJEVAC USING QGIS SOFTWARE

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RESEARCH ARTICLE

ABSTRACT: Noise is characterized as an environmental problem that represents an exceptional danger to human health. With increased urbanization and motorization, road traffic has been identified as the dominant source of noise in urban areas. The traffic noise originates from vehicle exhaust and braking systems, devices for giving sound signals, engine operation, or as a result of contact between the wheels and the road. In urban areas, the intensity of traffic noise depends on the speed of the vehicle, the flow of traffic, and the surface on which the vehicles are moving.

This study aims to monitor traffic noise using the device Brüel & Kjær 2250 on the territory of the city of Kragujevac at specific locations along the roads and during peak hours. Based on the numerical modeling of traffic noise in the Quantum GIS software (abbr. QGIS), it is possible to identify impacts of noise pollution as well as deviations of real noise values from the permissible noise limits. Serbian law regulates that the highest noise level along city roads can be 65 dB (A). The final results obtained by this research can be used to assess the current state of environmental noise pollution, which can be taken into account in the future process of transport planning in the city of Kragujevac.

KEY WORDS: road traffic noise, noise pollution, monitoring, QGIS

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SIMULACIJA ZAGAĐENJA BUKOM SAOBRAĆAJA U KRAGUJEVACU POMOĆU PROGRAMSKOG PAKETA QGIS

REZIME: Buka je okarakterisana kao ekološki problem koji predstavlja izuzetnu opasnost po zdravlje ljudi. Sa povećanom urbanizacijom i motorizacijom, drumski saobraćaj je prepoznat kao dominantan izvor buke u urbanim sredinama. Saobraćajna buka potiče od izduvnih i kočionih sistema vozila, uređaja za davanje zvučnih signala, rada motora ili kao rezultat kontakta između točkova i puta. U urbanim sredinama intenzitet saobraćajne buke zavisi od brzine vozila, protoka saobraćaja i površine po kojoj se vozila kreću.

Ova studija ima za cilj praćenje saobraćajne buke pomoću uređaja Bruel & Kjær 2250 na teritoriji grada Kragujevca na određenim lokacijama duž saobraćajnica i tokom časova vršnih opterećenja. Na osnovu numeričkog modeliranja saobraćajne buke u softveru Quantum GIS (skraćeno QGIS), moguće je identifikovati uticaje zagađenja bukom, kao i odstupanja stvarnih vrednosti buke od dozvoljenih granica buke. Srpski zakon definiše da najviši nivo buke na gradskim putevima može biti 65 dB (A). Konačni rezultati dobijeni ovim istraživanjem mogu se koristiti za procenu trenutnog stanja zagađenja životne sredine bukom, što se može uzeti u obzir u budućem procesu planiranja transporta u gradu Kragujevcu.

KLJUČNE REČI: buka drumskog saobraćaju, zagađenje bukom, monitoring, KGIS

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INTRODUCTION

In recent years, there has been a significant increase in the world population. According to the latest available report of the United Nations (abbr. UN), the world population reached 7.7 billion in 2019 [1]. Population growth has led people to move from rural to urban centers, which has affected the development of urbanization. Today, 55.3% of the total world population lives in cities. Globally, over 80 percent of economic activity is concentrated in cities [2]. The expansion of cities and the increase in the number of inhabitants in them also caused an increase in the use of motorized transport, i.e., an increase in individual travel to achieve mobility of the population.

The urbanization and motorization phenomenon has significantly contributed to the excessive burden on the environment. This phenomenon leads to the emergence of numerous environmental problems that affect the all living beings' quality of life. Precisely, the quality of life of the world's population is disturbed because of dominant environmental problems. Aside from the air quality, as the most dominant environmental problem stands out the increased noise level in the environment.

Noise can be defined as any unwanted sound of different types and intensity occurring in the living and working environment. If the comparison of noise with other environmental pollutants is carried out, it can be concluded that it as a pollutant is particular because of its effect that can have temporary or permanent consequences for human health. Constant exposure to this environmental pollutant has implications on people's physical and mental health and can cause acute and chronic acoustic trauma. The pyramid of noise effects is shown in Figure 1.

Noise can originate from a variety of outdoor and indoor sources. Traffic represents a significant source of noise in urban centers. Noise generated by traffic causes at least 10,000 cases of premature death, hypertension occurs in 910,000 inhabitants and closes by 43,000 hospital admissions per year in countries belonging to the European Union [4]. For this research, only the noise caused by road traffic is analyzed. Road traffic is the most dominant source of noise in cities. More than 40% of the European population is exposed to road traffic noise at levels exceeding the permissible noise limits [5]. The problem of traffic noise is made even more complicated by traffic conditions in the city, i.e., the fact that the number of vehicles on the streets is higher than the number for which the roads are designed.

Due to the above problems that noise creates, it is necessary to find the most optimal way to manage traffic noise. Road traffic noise management is becoming one of the most complex processes under the responsibility of urban planners and public health professionals. For that reason, one of the main aims of this paper is to estimate the population's exposure to a high noise level caused by road traffic among urban buildings in the city of Kragujevac at three specific locations (abbr. SL) is considered. That estimation can facilitate the prediction of traffic noise in the city of Kragujevac. Assessment of noise levels in this paper was performed using two methods: actual measurements of traffic noise using devices Brüel & Kjær 2250 and openNoise Mobile App and simulation of noise pollution using QGIS software and its special plugin opeNoise.

Simulation of road traffic noise pollution can display that its intensity varies in different locations of the city. The level of road traffic noise pollution depends on the noise source's location, the receiver, and the existing obstacles [6]. Noise mapping in this paper serves to understand how traffic noise pollution varies in space and how it can be reduced. The primary purpose of mapping noise traffic in QGIS software is to identify locations exposed to noise levels above the permitted limit values. According to mapping noise, it is possible to define activities that should be undertaken to reduce noise levels to protect public health (barriers, building design, sound insulation, land-use planning, personal protective equipment, etc.).

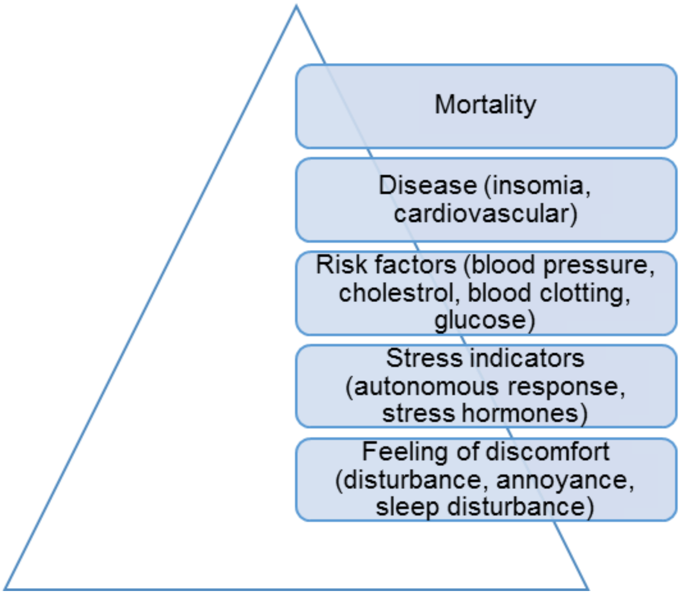


Figure 1 The pyramid of noise-induced health effects [3]

1. NOISE REGULATIONS

As already mentioned, noise is characterized as one of the primary environmental problems and pollutants in the environment. For that reason, it is necessary to manage noise following appropriate standards and legislation. It is generally known that the European Union is a world leader in defining legal directives, which refer to the protection of the population from the harmful effects of noise. In the 1980s, noise management activities as pollutants began in Europe. Noise management activities are performed following legal regulations and standards. One of the first documents, which is considered valid in the field of noise management, is the "Green Paper - Future Noise Policy," published by the European Commission in 1996. The "Green Paper" states that any future anti-noise strategy must be based on the fact that no person should be exposed to noise levels that can endanger its health and quality of life [7]. By publishing this document, opportunities have been created to improve actions related to noise exposure assessment, noise mapping, and harmonization of noise indicators in the environment.

Based on the document "Green Book - Future noise policy," the European Commission formed a working group in 1998. The main reason for the formation of the working group was to define noise indicators that would be used in the European Union to describe all noise sources, and for its assessment, mapping, planning, and control. As a result of three years of work on the development of noise indicators, in 2002, The Environmental Noise Directive (abbr. END) 2002/49/EC was created. Directive 2002/49/EC of the European Parliament and the Council regulates activities relating to [8]:

– noise assessment through the development of strategic noise maps using harmonized noise indicators and methods,
– development of action plans for maintaining noise levels in environment that are within the permissible level,
– establishing a noise level database and
– ensuring that information on environmental noise and its effects are made available to the public.

Today, the list of European Union regulations in the field of noise protection includes 13 acts of different legal force, among which the most important is Directive 2002/49/EC. Two international projects, "Harmonise" and "Imagine," have emerged from the mentioned Directive. The purpose of these projects was to develop a harmonized noise impact assessment methodology in all EU Member States. The methods defined by these projects are not officially proposed for noise assessment. It is currently recommended that "Common Noise Assessment Methods in Europe (abbr. CNOSSOS-EU)" developed in 2012 by the European Commission be used for noise assessment. The focus of this methodology is on the evaluation of road, rail, and air traffic noise, as well as industrial noise [9].

To form documents at the local, regional and national levels that relate to the current state of environmental noise pollution and whose purpose is to create - remediation of public health, it is essential to know accurate data on annual values of noise indicators. The noise indicator is an acoustic quantity that describes the noise in the environment [10]. When assessing noise levels, it is crucial to consider the variations of noise levels for 24 hours. According to those variations, three fundamental indicators appear:

•daily noise level measured from 6 am - 6 pm (LA_{day}),
•evening noise level measured from 6 pm – 10 pm (LA_{evening}), and
•night noise level measured from 10 pm – 6 am (LA_{night}).

Based on the above indicators, it is possible to evaluate LA_{den} indicator, which represents a standard European indicator. LA_{den} serves to define the average noise level throughout the day, evening, and night, to which a citizen is exposed during the year. This indicator is determined by mathematical relation 1 [11]:

$$LA_{den} = 10\log\frac{1}{24}\left(12\times10\times\frac{LA_{day}}{10} + 4\times10\times\frac{LA_{evening}+5}{10} + 8\times10\times\frac{LA_{night}+10}{10}\right) \quad (1)$$

The defined indicator is characterized, such as annually sound pressure level expressed in dB(A). These values are derived from the sound pressure level in dB, applying the so-called A-weighting.

2. NOISE REGULATIONS IN THE REPUBLIC OF SERBIA

The Republic of Serbia, as a candidate for membership in the European Union, needs to harmonize its legislation and bylaws with EU legislation. During Serbia's integration into the EU, the area of noise is not at the top of the priority of actions. Still, the government manages to harmonize the appropriate legal regulations with Directive 2002/49/EC. The essential legislation in the field of noise management in Serbia is laws, regulations, and rulebooks. Besides, determination of the value of fundamental noise indicators performs following the standards SRPS ISO 1996-1 and SRPS ISO 1996-2 [12]. Relevant documents from the analyzed area are shown in Table 1.

Table 1 *Noise legislation in the Republic of Serbia*

Name	**Place and year of publication**
Law on Noise Protection	Official Gazette of RS, No 36/2009 and 88/2010
Regulation on noise indicators, limit values, noise indicators assessment methods, annoyance and harmful effects of environmental noise	Official Gazette of RS, No 75/2010
Rulebook on methodology for determining the acoustic zone	Official Gazette of RS, No 72/2010
Rulebook on the methods of noise measurement, content and scope of the noise measurement reports	Official Gazette of RS, No 72/2010
Rulebook on the methodology for the action plan development	Official Gazette of RS, No 72/2010
Rulebook on the conditions to be fulfilled by a professional organization for noise measurement, and documentation to be submited with application for acquirinf the authorisation for noise masurement	Official Gazette of RS, No 72/2010
Rulebook on the content and method of development of noise maps and the manner of their presentation to the public	Official Gazette of RS, No 80/2010
Rulebook on noise emitted by the equipment used in the open space	Official Gazette of the RS, No 01/2013
SRPS ISO 1996-1: 2016 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures	Institute for Standardization of Serbia, 2010
SRPS ISO 1996-2: 2010 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of sound pressure levels	Institute for Standardization of Serbia, 2010

It is important to emphasize that Directive 2002/49/EC has only been partially transposed by the Law on Environmental Noise Protection and its accompanying bylaws. At the same time, its full implementation is planned by the end of 2021 [13].

Following the mentioned legal documents, noise limit values have been defined in the Republic of Serbia. The permissible noise limits represents the highest allowed value of noise indicators (LA_{day}, $LA_{evening}$, and LA_{night}). Depending on some criteriums (the noise source, an outdoor or indoor space, space's use, etc.), the permissible noise limits differ.

As the aim of this paper is to simulate traffic noise pollution at specific locations in the Kragujevac city, table 2 shows only the limit values of noise indicators in the outdoor space.

Table 2 *Limit values of outdoor noise indicators [10]*

Zone	**Use of space**	**Level of noise dB (A)**

		LA_{day} / $L_{evening}$	LA_{night}
1.	Leisure and recreation areas, hospital zones, cultural and historical spots, large parks	50	40
2.	Tourist areas, small settlements and villages, camps and school zones	50	45
3.	Purely residential districts	55	45
4.	Combined business and residential districts, combined commercial and residential districts and playgrounds	60	50
5.	The city center, craftsman, commercial and administrative areas with housing, zones along highways, main roads and city traffic arteries	65	55
6.	Industrial, storage and service areas and transport terminals without residential buildings	At the border of this zone, the noise must not exceed the limit value in the zone with which it borders	

As already explained, noise indicators are physical quantities that describe noise in the environment. If the value of the indicators is higher than the values given in the previous table, then the noise harms human health, and it is considered that the population at that location is endangered by noise.

3. CASE STUDY: TRAFFIC ROAD NOISE IN KRAGUJEVAC

The city of Kragujevac belongs to the group of medium-sized cities, with 179,417 inhabitants [14]. During the past decades, the increase in traffic capacity on city roads affects that most residents in cities live in acoustically non-conformal zones. Thus, it is necessary to identify deviations of noise levels in Kragujevac comparing the real and the maximum allowed levels to simulate noise pollution from traffic.

Based on the analysis, it is concluded that the traffic-geographical position of the Kragujevac city is exceptionally favorable. This statement is explained by the city's position in the traffic corridor, which connects the southern, southwestern, and western parts of the country with the northeastern and northern areas of Serbia. State roads of I and II order and municipal roads form the road network of the city of Kragujevac. Namely, on the road network, there are city arterial highways, city roads, and collecting roads.

For this research, city roads are essential, which are intended for medium and long city’s trips. They connect collection roads with highways and residential zones with the city center and other facilities, serving most of the local traffic and introducing intercity’s roads in the city [15].

Motorized and non-motorized road traffic takes place on city roads in Kragujevac. In recent years, there has been an increase in motorized traffic load. In addition to the increase in the number of passenger vehicles daily, there is also an increase in freight traffic and public passenger transport. The street network in the city area have inappropriate profiles, making it impossible for pedestrian and bicycle traffic to run smoothly, which is characterized as non-motorized traffic.

In Kragujevac's territory, the traffic regime is not restrictive, and most of the roads operate in a two-way regime. On the city traffic network, direct intersections are regulated by light signals or by horizontal signalization.

The purpose of the movement of passengers is diverse. However, in the peak period of the day, the purposes of movement related to going to work and the school have a very dominant share of almost 95 % of the total movement.

The increase in traffic load also caused an increase in traffic noise emissions. The emission level of traffic noise on the Kragujevac territory depends on the following factors [16]:

- traffic load (number of vehicles / h),
- traffic flow structures (passenger, freight, buses, etc.),
- vehicle speeds,
- traffic flow management (braking, acceleration),
- characteristics of streets (road surface layer, ascent, curvature),
- techniques' conditions of vehicles (engine insulation, tires, exhaust systems),
- driving style and engine load.

Noise determination in Kragujevac performed at six measuring points considered to be the busiest in the city. The measurement is performed by organizations that meet the requirements for environmental noise measurements. In Kragujevac, the organization that meets those conditions is the Institute of Public Health. During the measurement, the day and night noise level is monitored, as well as the number of heavy and light vehicles. The results of noise measurements on an annual basis are forwarded to the Environmental Protection Agency of the Republic of Serbia. At the same time, the local self-government publishes them in the Environmental Bulletin. All recent measurements of noise levels in Kragujevac showed exceedances during the observed period. Measured values of noise levels could harm the health of citizens [15].

4. SPECIFIC LOCATIONS IN KRAGUJEVAC

The subject research is based on measuring the parameters of road traffic noise at three specific locations on the territory of the city of Kragujevac. Measurements were performed at three locations in the city where it was estimated that the impact of noise caused by traffic, as well as other communal activities, was the greatest. The listed locations are:

- SL1 - a four-way intersection of streets: Nikola Pašić and Dr Zoran Đinđić,
- SL2 - a four-way intersection of streets: Radoje Domanović, Kralja Milana, Milentija Popović and Potporučnika Govedarice,
- SL3 - a four-way intersection of streets Bulevar Kraljice Marije and Daničićeva.

Figure 2 shows the analyzed locations in the broader area of the city.

Figure 2 *Analyzed locations in the broader area of the city*

The locations selected for the subject research are characterized by very intensive road traffic. Near the analyzed locations, there are residential buildings with high housing density, business facilities, scientific and educational institutions, health, and other public institutions, such as the administrative building of the local self-government unit in Kragujevac.

Figure 3 presents four approaches to intersections that include possible directions of traffic flows through the intersection, marked with arrows and numbers (1, 2, 3, and 4).

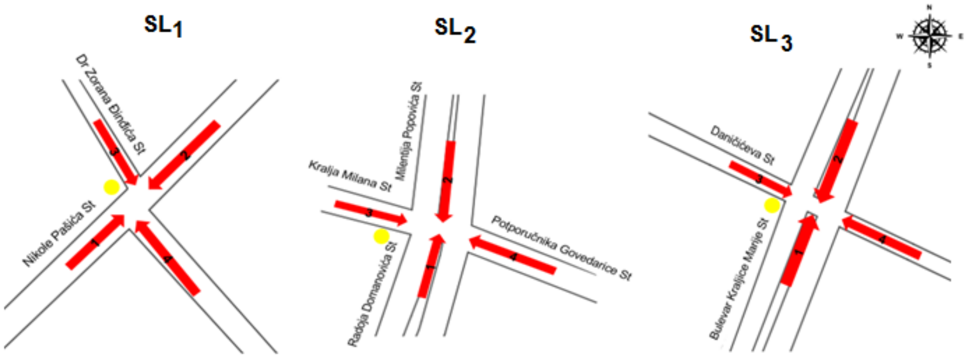


Figure 3 *Traffic directions at the analyzed locations*

The basic characteristics of the analyzed roads are shown in Table 3.

It is already said that the emission level of traffic noise depends on factors such as traffic load. Consequently therefore, when modeling noise levels in urban areas is performed, besides the characteristics listed in the table, one of the essential characteristics of road traffic is the load on the road or the traffic flow. The flow of traffic can be most easily defined as the number of vehicles that pass through the center of the analyzed intersection in a unit of time. This characteristic of road traffic can be determined by traffic-counting. Traffic-counting is extremely important when planning traffic in cities and creating spatial and urban plans. Thanks to the counting of traffic, which can be manual and automatic, data on the intensity and structure of traffic flows are obtained. Besides, traffic counting is important for planning the future size of roads and intersections.

For this research, manual traffic counting was conducted at specific locations. Vehicle frequency measurement was performed according to the specified flows, i.e., traffic direction for each intersection (1,2,3 and 4). The counting was static, i.e., the counting of vehicles passed through a particular section of the road in a specific time interval was performed. A simple counting pattern was used for counting, on which a mark was placed after the vehicle passed, depending on the direction of movement and the type of vehicle.

The vehicle counting pattern is shown in Figure 4.

Table 3 *Characteristics of analyzed roads*

	SL_1	**SL_2**	**SL_3**
Geographical characteristics	The terrain on approaches 1,4,2 is flat, while approach 3 is under a slope,	The terrain of approaches 1 and 3 is flat, while approaches 2 and 4	The terrain of approach 1 is flat, while approaches 2, 3, and 4 are falling

	i.e., an ascent depending on the movement's direction.	are falling or rising, depending on the direction of movement.	or rising depending on the direction of movement.
Characteristics of the space/ objects in the analysed area	Residential buildings, catering facilities, business facilities, public buildings, etc.	Residential buildings, catering facilities, business facilities, educational institutions, etc.	Residential buildings, catering facilities, business facilities, etc.
Characteristics of the road	Two-way traffic takes place on the approaches to all traffic routes. Approaches 1,2, and 4 have three lanes, while approach 3 has two lanes per road. The main surface of the road is asphalt. Vertical traffic lights regulate traffic at the intersection.	Two-way traffic takes place on the approaches to all roads. The number of lanes is four for directions 1, 2, and 4, while direction 3 has three lanes. The main surface of the road is asphalt. Vertical traffic lights regulate traffic at the intersection.	Two-way traffic takes place on the approaches to all roads. The number of lanes is four for roads 1 and 2, while directions 3 and 4 have three lanes. The main surface of the road is asphalt. Vertical traffic lights regulate traffic at the intersection.

Traffic-counting is conducted at specific locations along the roads and during peak hours. Peak hours hour with the most significant volume of traffic during working hours of the day. In the Republic of Serbia, the peak hour is 8 - 10 % of the total daily traffic and occurs in the morning from 7 – 8 o'clock and the afternoon from 15 – 16 o'clock. The measured traffic load during peak hours is shown in Figure 5.

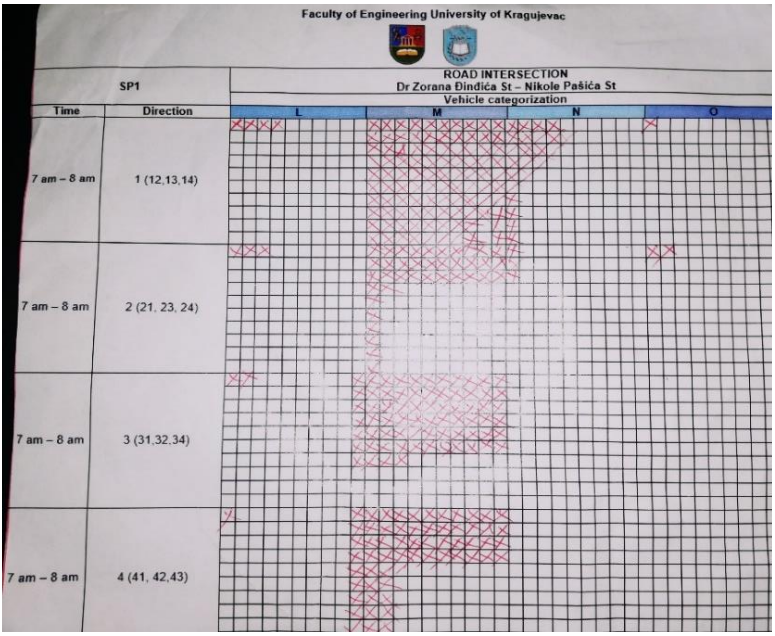


Figure 4 Representative form used for manual traffic-counting on SL1

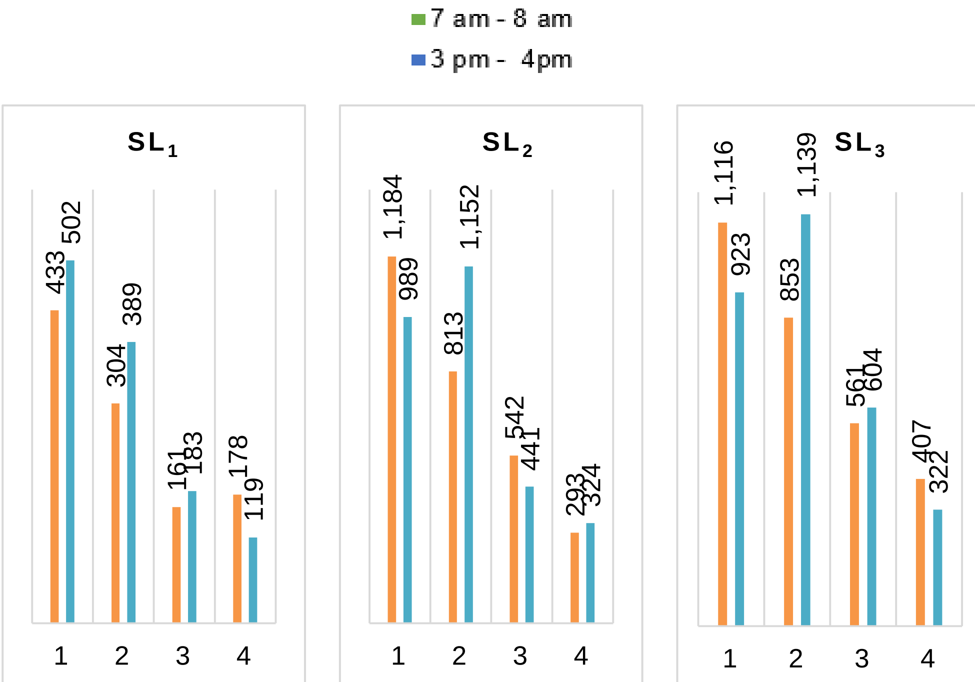


Figure 5 Counted traffic load during peak hours at specific locations

It is mentioned that the emission level of traffic noise also depends on traffic flow structures. So, the manual traffic-counting is conducted according to vehicle categorization. In the Republic of Serbia, vehicle categorization is defined by the Rulebook on

Classification of Motor Vehicles. The categories of vehicles that are used in this research are [17]:

- L – 2-wheel, 3-wheel and 4-wheel vehicles (mopeds, motorcycles, tricycles and quadricycles),
- M – passenger-carrying vehicles, abbr. PCVs (cars and buses),
- N – goods-carrying vehicles (lorries and vans), – trailers and semitrailers.

These categories are analyzed because the noise emission of different vehicle categories varies greatly. In the road vehicles, it can be distinguished the numerous sources of noise depends on the vehicle category. The primary sources of noise in the road vehicles are engine, powertrain, tires cooperating with the road surface, the flow of liquids and gases in systems and installations of the vehicle, a vibration of the vehicle and its components, etc. For that reason, the United Nation's Economic Commission for Europe (abbr. UNECE) has published regulations which are related to road vehicle noise. Regulations developed by UNECE defines limit values for pass-by noise of road vehicles. In the Republic of Serbia, limit values of allowed exterior noise emitted by different category of road vehicles in laboratory conditions are determined in Rulebook on the classification of motor vehicles and trailers and specifications for vehicles in road traffic.

Both the regulations of the European Union and the regulations of the Republic of Serbia do not define the limit values of noise emitted by O category of vehicles. It can be explained by the fact that this category of vehicles is pulled and not autonomous. However, the O category of vehicles is taken during this analysis because it has an impact on the overall traffic noise. That impact is visible through the cooperation of the wheels with the road surface and the airflow around the O vehicle.

The counted vehicle categories in the analyzed locations are given in Figure 6.

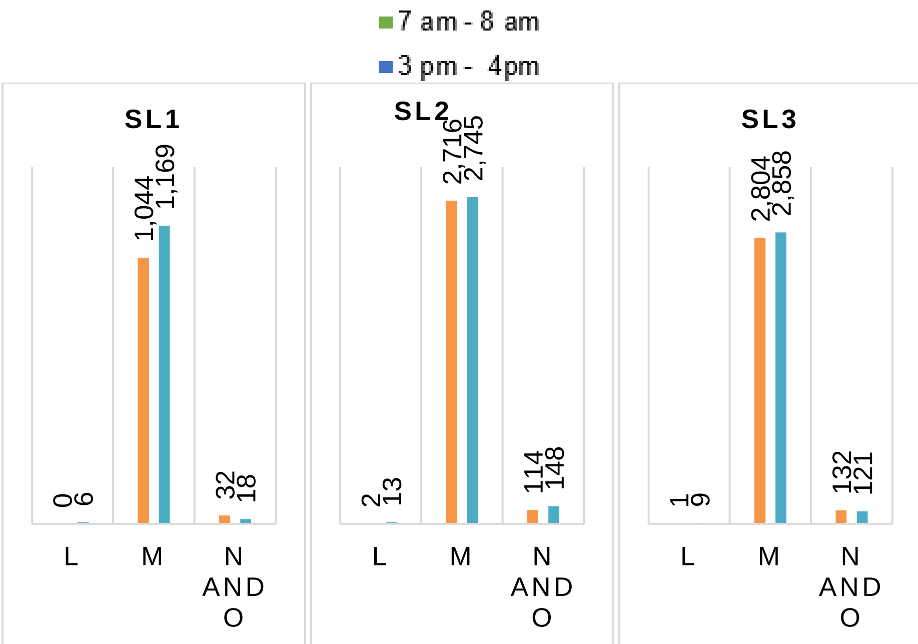


Figure 6 Counted traffic load according to vehicle categories

The traffic load on the Kragujevac's street network has a growth trend, with the share of PCVs in the structure of traffic flows more than 90%.

5. NOISE LEVEL MONITORING

To perform a simulation of noise pollution, it is first necessary to determine the sound pressure levels at the analyzed locations. The measurements were performed using appropriate types of equipment. Brüel & Kjær 2250 sound level meter and the Open Noise Mobile Application were used to measure the equivalent noise level (abbr. LAeq). LAeq is the equivalent sound level of the last range of time setted (0.5, 1 or 2 seconds), expressed in dB(A).

The measurement was performed continuously for 10 minutes along mentioned streets in the peak periods: in the morning from 7 - 8 o'clock and in the afternoon from 3 - 4 o'clock. By such measurement, LAeq values were obtained based on LAeq values with sampling rate of 1 second.

The position of the phonometer used was as in Figure 7. Namely, the noise measurement was performed at a height of 1.5 m, while the distance of the phonometer from the edge of the road was 1.5 - 2 m. Phonometer was distanced 1.2 - 2 m from the nearest building in the area. The phonometer's position was identical in all three locations, i.e., on the corner of the street, which is directed to the south-west. The measuring points at analyzed locations are marked with yellow points in Figure 3. These points were chosen arbitrarily by the authors.

Based on the next figure, it can be seen that the height of buildings is not taken into consideration during noise level monitoring as well as modeling.

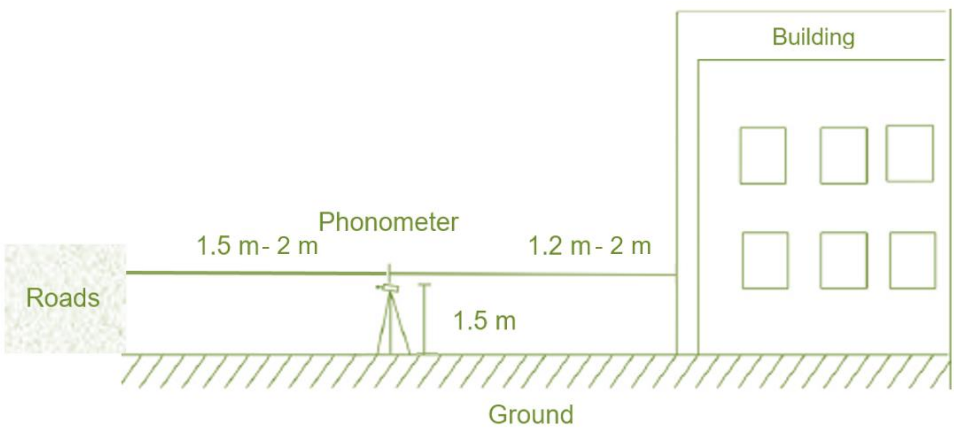


Figure 7 Position of the phonometer during monitoring

At specific location 1, the morning's noise level varies from 46.9 dB (A) to 80.1 dB (A), which is shown in Table 4. During the noise measurement that lasted 10 minutes, the equivalent noise level was 69.6 dB (A), which will be taken into account when simulating noise pollution. At the same specific location, in the afternoon, the minimum average value of environmental noise in this zone was 54.5 dB (A), while the maximum value was 84.9 dB (A). For the equivalent noise level in this period, 75.7 dB (A) was obtained.

The second specific location records higher noise levels, which is explained by the fact that the road that passes next to the place where the measurements were made is a transit road to which most freight traffic is directed. As shown in table 5, in the period from 7 am - 8 am, the minimum and maximum value of environmental noise in this zone was 46 dB (A) and 88.1 dB (A), respectively. During the analyzed period, LAeq was 84.2 dB (A). Slightly higher values were recorded in the afternoon, where a value of 86.8 dB (A) was obtained for the equivalent noise level.

Table 4 Results of measurements of noise levels at SL1

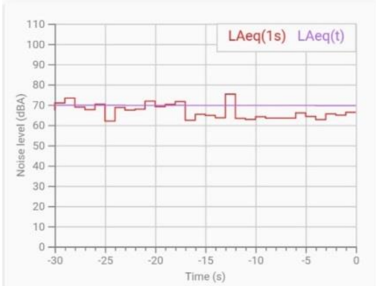
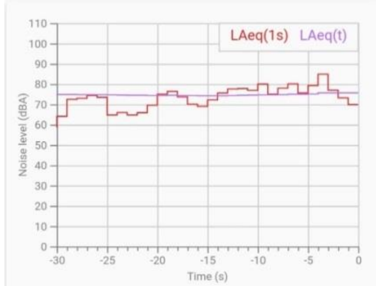
SL_1						
Time of measurement	**7 am – 8 am**			**3 pm – 4 pm**		
Noise level [dBA]	**LA_{min}**	**$LA_{eq(t)}$**	**LA_{max}**	**LA_{min}**	**$LA_{eq(t)}$**	**LA_{max}**
	46.9	**69.6**	**80.1**	**54.5**	**75.7**	**84.9**
Graphics						

Table 5 Results of measurements of noise levels at SL2

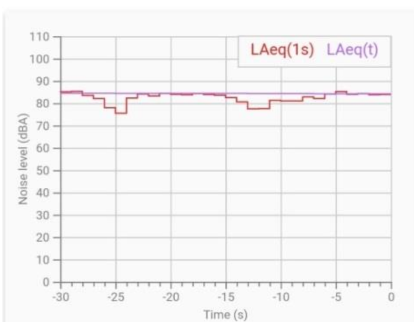
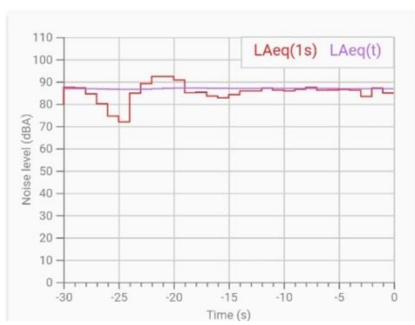
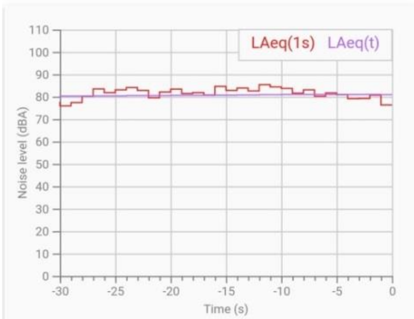
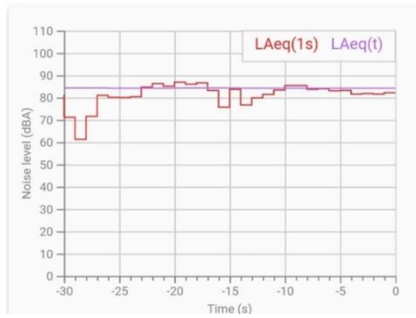
SL_2						
Time of measurement	**7 am – 8 am**			**3 pm – 4 pm**		
Noise level [dBA]	**LAmin**	**LAeq(t)**	**LAmax**	**LAmin**	**LAeq(t)**	**LAmax**
	46.0	**84.2**	**88.1**	**54.8**	**86.8**	**92.3**
Graphics						

Table 6 shows the results of noise monitoring at the third specified location. The equivalent noise levels used in the noise pollution simulation are 80.9 dB (A) for the morning peak's hours and 84.2 dB (A) for the afternoon peak's hours.

Table 6 Results of measurements of noise levels at SL3

SL$_3$						
Time of measure ment	7 am – 8 am			3 pm – 4 pm		
Noise level [dBA]	LAmin	LAeq(t)	LAmax	LAmin	LAeq(t)	LAmax
	41.6	80.9	85.8	54.0	84.2	89.2
Graphics						

In the graphics shown in previous tables, the measurement time is the independent variable, and it belongs on the x-axis (horizontal line) of the graph. At the same time, measured noise level is the dependent variable and it belongs on the y-axis (vertical line). Negative values in the x-axis are useful for viewing the monitoring history of results. The zero value corresponds to the instantaneous data at the moment of measuring, while negative values correspond to the results in the past. Positive values would represent the future, but that is impossible to predict. It can be seen that graphs show significant variations in the noise level in a sampling rate of 1 second – LAeq(1s). Some noisy occurrences on the roads such as car horns, car alarms, etc. cause that the noise indicator at the moment of averaging exceeds the equivalent mean noise values.

Comparing the results shown in Tables 4, 5 and 6 with the values defined by Regulation on noise indicators, limit values, noise indicators assessment methods, annoyance and harmful effects of environmental noise and which are shown in Table 2, it is concluded that in critical periods at the analyzed locations in Kragujevac, the noise level LAeq(t) is significantly higher than allowed. The maximum permissible noise level for analyzed locations is 65 dB (A) for day/evening while LAeq(t) for night is 55 dB (A). As the primary source of noise at the analyzed locations, traffic stands out. This can be proven by measured traffic load during peak hours.

6. SIMULATION OF ROAD TRAFFIC NOISE POLLUTION

The software used for simulation of road traffic noise pollution on the territory of the Kragujevac territory was QGIS 3.10.2. This software presents a free and open-source cross-platform desktop geographic information system application that supports viewing, editing, and analyzing geospatial data.

Simulation of road traffic noise pollution starts with the importation of the orthophoto map of Kragujevac in the appropriate coordinate system. In this case, the coordinate reference system is set on EPSG:3909 - MGI 1901 / Balkans zone 7 – Projected.

To model the environmental noise generated by road traffic in Kragujevac, two essential layers are created [18]:

– Buildings, and
– Roads.

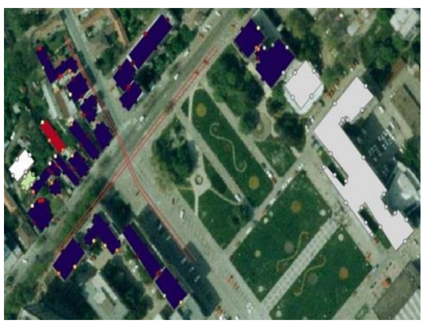
The first layer defined the buildings that were created as polygons. The buildings were drawn based on the already entered orthophoto map of the city of Kragujevac. The purpose of the building was not taken into account when drawing it. The roads are defined as the second layer. This layer represents the emission source of the traffic noise, and the type of the roads layer is a line type. When defining the second layer, it was necessary to define the traffic load for each direction using the attribute table.

Software QGIS has many plugins. One of them is opeNoise, which allows users to compute the noise level generated by point source or by road source at fixed receiver points and buildings used in this research. The first step in noise modeling is to make receiver points. These points are chosen automatically by software. Receiver points can bw created for each facade or equidistant receiver point along the facade. The facade is a layer created as a polygon, i.e., buildings. In this case, receiver points were determined on half of each building's facade in the vicinity of analyzed intersections.

Then, it is necessary to determine the noise level at receiver points generated by road sources (a line layer). For each road, the sound pressure level is calculated based on the data already mentioned (noise level, traffic load, road slope, type of terrain, etc.). The results are written in the attribute table of the receiver point layer and expressed in dB(A). If the level is not calculated or is less than zero, the value -99 is assigned [19]. In the last step, the noise levels are calculated for each receiver point to the corresponding building. The value assigned to the building is the maximum value among all the receiver points for that building.

Simulations were performed for different periods, more precisely for data from the morning hours and for data from the afternoon hours.

The simulation of road traffic noise pollution in Kragujevac at three specific locations is shown in Figure 8.

	7 am – 8 am	3 pm – 4 pm
SL1		

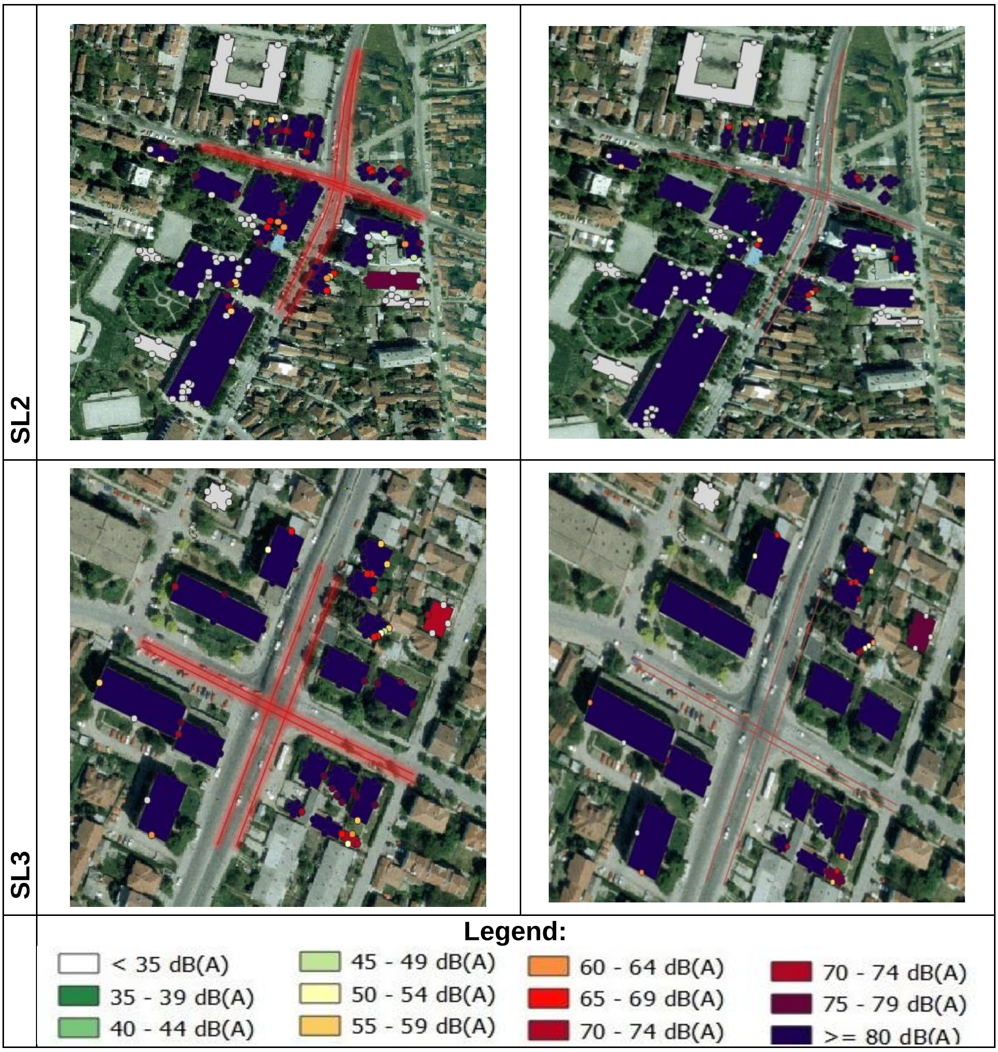


Figure 8 Simulation of road traffic noise pollution in Kragujevac at three specific locations

Buildings are marked with different colors depending on noise levels. According to the previous picture, it can be concluded that the highest noise level is noted at the points of the facades of buildings located at the intersection as well as the noise level of these buildings is at the highest level. Buildings that are at intersections are exposed to noise levels that are over 80 dB(A) during peak hours. This fact leads to the conclusion that analyzed locations are very polluted by the noise.

Accompanying the legal regulations in the Republic of Serbia, the noise on the facade of analyzed facilities should not exceed 65 dB (A). The analyzed buildings are classified as the most noise-endangered buildings due to their location along the city's busiest roads.

The comparison of measured and modeled data is performed. In that case, it can be concluded that there are certain deviations due to which this simulation cannot be officially proposed for noise assessment and planning.

Representative Figure 9 shows the building at the specific location 1 during the morning hours. It is noticed that the receiver points on one building have different noise levels. For example, on the shown building in Figure 9, there are a total of three receiver points where the noise level is higher than 80 dB(A), then one point where the noise level is 75 - 79 dB(A), one where the level is the noise of 65 - 69 dB(A) and one receiver points to which the software assigned a noise level of 50 - 54 dB(A). The simulation shows that the entire analyzed building is exposed to a noise level greater than 80 dB(A) because the noise assigned to the building is the maximum value among all the receiver points for that building.

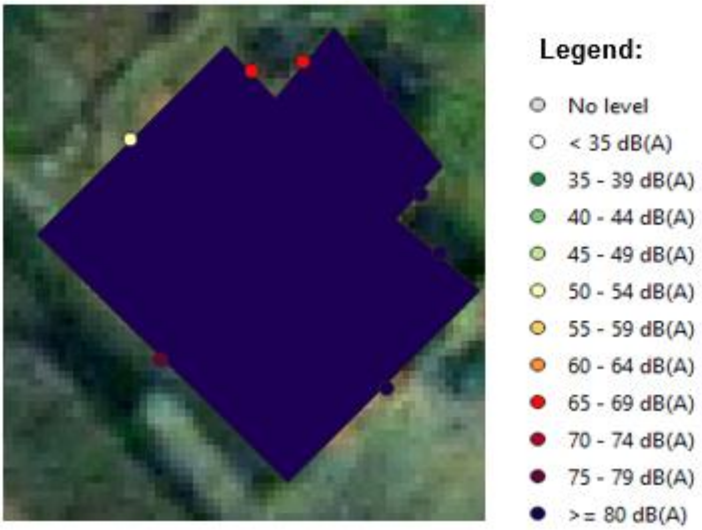


Figure 9 Representative building with receiver points

This type of simulation is sometimes not suitable because in this way it would be concluded that the inhabitants of a building are exposed to equal, maximum levels of traffic noise, which is not correct. In order to avoid these deviations and irregularities, it is recommended that in future research, noise measurements be performed in several different places at specific locations in order for the simulation to be valid.

Anyhow, people living in the buildings covered by this research are exposed to high noise levels. The population which lives at analyzed locations represents a vulnerable group which is affected by noise pollution. Simulated noise levels can have permanent and temporary consequences for public health. Noise-induced health disorders are an expression of a physiological response to stress, most of which are transient and short-lived (disorders of the cardiovascular, digestive and immune systems, decreased attention and memory, narrowed visual field), but which can become chronic (insomnia, high blood pressure, anxiety, depression). All of the above severely impairs the general health of individuals, quality of life, and social communication. To avoid the potential consequences for public health, it is necessary to undertake specific measures to reduce noise in the analyzed locations.

CONCLUSION

Road traffic noise pollution has been recognized as a new threat to the population in urban areas.

For the needs of simulation of noise pollution on the territory of the city of Kragujevac, noise monitoring in the environment was performed.

Noise levels were measured at three specific locations, more precisely at intersections formed by roads characterized by intensive road traffic. The measurement was performed for 10 minutes during peak hours of 7am - 8 am and 3 pm - 4 pm. In the same period, manual measurement of traffic load was performed.

The results of measuring noise levels in Kragujevac show that the levels of communal noise are high. In almost all measuring points, noise levels exceed the prescribed values for the areas of purpose - The city center, craftsman, commercial and administrative areas with housing, zones along highways, main roads and city traffic arteries which are 65 dB (A) for day/evening. The absolute highest noise was found at the measuring point of the specific location SL2, where the equivalent noise level reaches the value of 86.8 dB (A) in the afternoon. Using the results of field noise measurements and analysis of the traffic regime, i.e., traffic load at the observed locations, a simulation of noise pollution was performed. The simulation was performed in QGIS software using the opeNoise plugin. After the simulation, receiver points were determined on half of each building's facade located in the vicinity of the intersection, and the noise level was determined on the same. After that, a certain noise level was added to each building. The value assigned to the building is the maximum value among all the receiver points for that building.

Research like this shows the traffic noise modeling that reveals the areas where the environmental noise values are high enough to disturb different aspects of residents' lives in the analyzed city.

In order to improve the existing situation and minimize noise pollution in the city of Kragujevac, which was observed by modeling, it is considered that it is necessary to take specific measures. By reducing noise levels at sources altogether with methods to protect the urban population from noise exposure, practical actions can be done [20].

Measures that can be applied in order to reduce noise primarily are: control and change of traffic regime. This measure can be implemented through compliance with speed limits, improvement of pedestrian zones, the formation of so-called ecological traffic lights with notification for drivers - "Please turn off the engine", etc. There are also high-budget measures that would significantly reduce the current noise pollution in Kragujevac, such as the construction of a bypass for trucks, which will direct all freight traffic outside the central zones.

As the primary source of noise is road traffic, it is necessary to pay attention to the level of noise emissions emitted by each vehicle. Today, vehicles are manufactured in accordance with the standard that meets the maximum levels of noise emissions from vehicles. However, there is a problem with old vehicles that are still moving on the streets, and it is necessary to apply stricter restrictions in technical inspections of vehicles. Also, it is possible to introduce special taxes for noisier vehicles at the local level or to apply exclusion from the traffic of vehicles with excessive noise.

In addition to the above measures, it is possible to install protective sound barriers along congested roads and to implement zoning with the greening of settlements, which, in addition to improving the microclimate, also affects the protection of the population of Kragujevac from noise. In order to protect against noise, the residents of Kragujevac can install sound insulation on their buildings. Also, they can use personal protective equipment for reducing noise exposure, but that is not a long-term solution.

This kind of research represents the beginning and the base for further elaborating noise pollution mapping on the territory of the entire city of Kragujevac and the development of strategic noise maps.

The development of a strategic noise map in Kragujevac would greatly facilitate noise management at the local level. Namely, strategic noise maps contain data on the state of noise in the environment, such as the current, previous and estimated noise level in the environment expressed by noise indicators, places of exceeding the prescribed limit values, but also an estimate of the number of people and households, schools and hospitals in a specific area that are exposed to noise above the prescribed limit values, etc. The creation of a strategic noise map would significantly help and facilitate the further planning of traffic development in Kragujevac, which needs to be implemented as soon as possible because the current Traffic Development Strategy lasts until 2022.

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REFERENCES

[1] United Nations, Department of Economic and Social Affairs, Population Division: “World Population Prospects 2019 – Highlights”, (ST/ESA/SER.A/423), 2019, New York, SAD, 46, ISBN: 978-92-1-148316-1.

[2] United Nations, Department of Economic and Social Affairs, Population Division: “World Urbanization Prospects - The 2018 Revision”, (ST/ESA/SER.A/420), 2019, New York, SAD, 126, ISBN: 978-92-1-148319-2.

[3] European Commission - Science for Environment Policy: “Future Brief: Noise abatement approaches”, Issue 17, 2017, University of the West of England, Bristol, 28, Doi: 10.2779/016648.

[4] Tobías, A., Recio, A., Díaz, J., & Linares, C.: “Health impact assessment of traffic noise in Madrid (Spain)”, Environmental Research, Vol. 137, 2015, pp. 136–140. Doi: 10.1016/j.envres.2014.12.011.

[5] World Health Organization Regional Office for Europe: “Environmental Noise Guidelines for the European Region“, 2018, Copenhagen, Denmark, ISBN: 978-92-890-5356-3.

[6] Murphy, E., & King, E.A.: “Environmental Noise Pollution”, 1st Edition, 2014, Elsevier, eBook ISBN: 978-01-2-411614-6.

[7] European Commission: “Future Noise Policy - European Commission Green Paper”, COM(96) 540 final, 1996, Brussels, Belgium.

[8] European Commission: “Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise”, Official Journal of the European Communities, OJ L 189, 2002, Brussels, Belgium.

[9] Kephalopoulos, S., Paviotti, M., Anfosso-Lédée, F.: “Common noise assessment methods in Europe (CNOSSOS-EU)”, EUR 25379 EN, Luxembourg: Publications Office of the European Union, 2012, pp. 180, Ispra, Italy.

[10] The Government of the Republic of Serbia: “Regulation on noise indicators, limit values, noise indicators assessment methods, annoyance and harmful effects of

environmental noise", Official Gazette of the Republic of Serbia, No 75/2010, 2010, Belgrade, Republic of Serbia.

[11] European Environment Agency: „Noise in Europe 2014", Luxembourg: Publications Office of the European Union, EEA Report No 10/2014, 2014, pp 68, Luxembourg, Doi: 10.2800/763331.

[12] Mihajlov, D.: "Multi-critetia optimization of the selection of the measurement strategy for the assessment of the long-term environmental noise indicators", PhD dissertation in Serbian language, 2016, Faculty of occupational safety, University of Niš, Niš, Republic of Serbia.

[13] Coalition 27: "Chapter 27 in Serbia: No-Progress Report", Young researchers of Serbia, 2018, Belgrade, Republic of Serbia.

[14] Statistical Office of the Republic of Serbia: "Municipalities and regions of the Republic of Serbia", Statistical Office of the Republic of Serbia, 2019, Belgrade, Republic of Serbia, ISSN 2466-3824.

[15] Local government - City of Kragujevac: "Traffic development strategy of the city of Kragujevac 2012-2022", in Serbian language, 2012, Kragujevac, Republic of Serbia.

[16] Institute for public health in Belgrade: "Route noise measurement on territories of the municipality of Obrenovac during November 2013", Unit for quality assurance, control and testing of environment, 2013, Belgrade, Republic of Serbia.

[17] Official Gazette of the Republic of Serbia: "Rulebook on Classification of Motor Vehicles and Trailers and on Specifications for Vehicles in Road Traffic", Official Gazette of RS no 40/2012, 102/2012, 19/2013, 41/2013, 102/2014, 41/2015, 78/2015, 111/2015, 14/2016, 108/2016, 7/2017 - revise, 63/2017, 45/2018, 70/2018, 95/2018, 104/2018 and 93/2019.

[18] Șorea, I., Stoleriu, C.C., Ursu, A.: "Road Traffic Noise Modeling. Case Study: Vaslui Town, North-Eastern Romania", Air and Water – Components of the Environment Conference Proceedings, 2019, Cluj-Napoca, Romania, pp. 375-384. Doi: 10.24193/AWC2019_37.

[19] QGIS - A Free and Open Source Geographic Information System, Internet address: „www.qgis.org", Date of Access: 10th July, 2020.

[20] Ivanović, L., Josifović, D., Ilić, A., Stojanović, B., Rakić, B.: "Noise as spects of life quality at urban areas", 8th International Quality Conference, 2014, 23 May, Kragujevac, Serbia, pp. 175-182.