Original research paper

TRAFFIC NOISE ANALYSIS IN THE MAIN ROADS OF THE CITY OF SARAJEVO

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Abstract: *This research paper presents a comprehensive analysis of traffic noise levels along the main roads of the City of Sarajevo. Adopting a spatial, temporal, legal, and normative framework of the research, the study aims to establish the level and impact of traffic noise on the urban environment and the quality of life of residents.*

The methodology employed for traffic noise measurement involves a systematic approach, utilizing sound level meters placed strategically along key roadways to capture representative data. These measurements are conducted at various times of the day (day/night), to account for fluctuations in traffic.

The analysis of the measured noise values reveals significant variations in noise levels across different type of roads and times of day. By comparing the observed noise levels with established legal and normative standards, the research assesses the extent of compliance with regulatory frameworks and identifies areas of concern where noise mitigation measures may be necessary. Through the analysis, hotspots of excessive noise pollution are identified, pinpointing specific locations where intervention strategies could be implemented to reduce noise exposure for nearby residents.

The analysis also highlights significant risks to the environment, public health, biodiversity, urban quality of life, education, and the economy. These risks necessitate immediate and comprehensive mitigation strategies to protect both the natural ecosystem and the well-being of the city's residents.

In conclusion, this research underscores the importance of addressing traffic noise as a critical environmental and public health issue in urban areas like Sarajevo. The study provides valuable insights for policymakers and urban planners to develop effective noise management strategies and enhance the overall quality of urban living.

Keywords: *traffic noise analysis, noise pollution, human health, sustainable urban mobility, traffic noise risk*

1. INTRODUCTION

Noise pollution is a significant environmental and health issue in Europe, with the transportation sector being the primary contributor. The construction of transport

infrastructure, the increase in the number of vehicles, and the non-compliance with legal regulations have led to alarming levels of traffic noise.

According to the European Environment Agency (EEA), road traffic is the most dominant source of noise in most member countries, exposing millions of people to noise levels that exceed permissible limits. Data from the EEA indicates that around 125 million people are exposed to harmful traffic noise levels above 55 dB Lden, which can result in stress, sleep disorders, health problems, and even premature death (European Environment Agency, 2019).

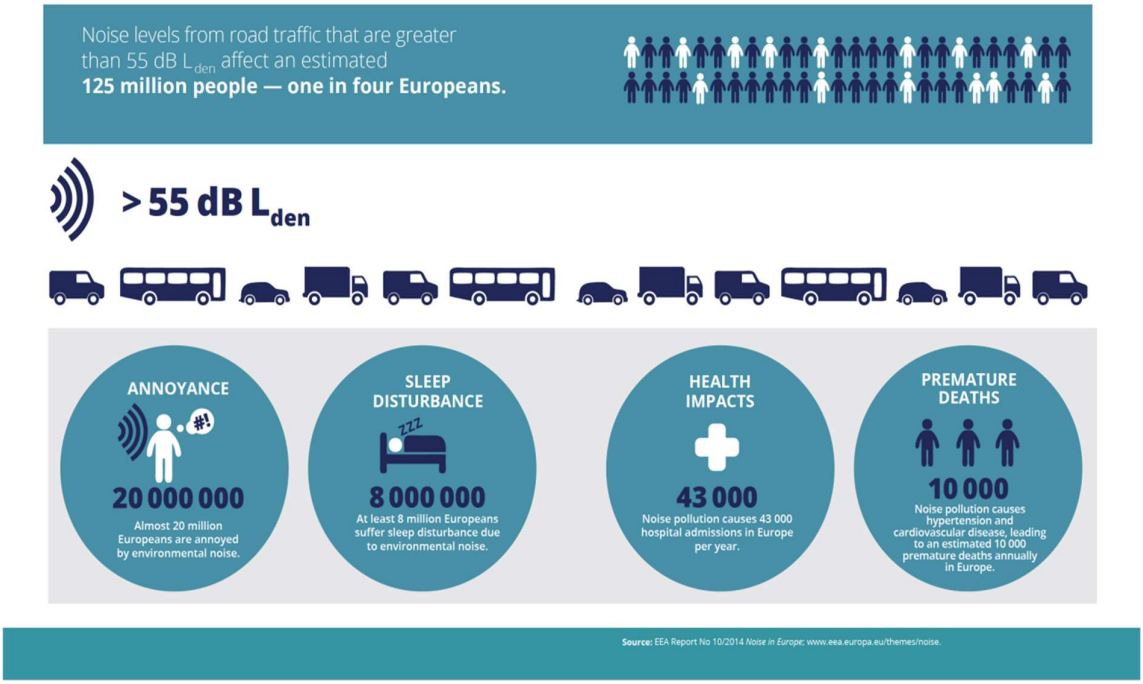

Figure 1: Traffic noise pollution in Europe (Infographic: Noise pollution in Europe, EEA)

This issue is not limited to Europe but is also present in countries like Bosnia and Herzegovina, where the increase in the number of vehicles over the past decade has further exacerbated the situation. With continuous traffic growth, a further increase in traffic noise and its harmful effects on the population is expected (Bosnia and Herzegovina car – motorcycle club, 2024).

According to the World Health Organization (WHO), noise from road traffic has detrimental effects on human health and is the second most harmful environmental stressor in Europe, just behind air pollution. Various studies indicate that noise can cause behavioral changes, such as increased aggression and social conflicts, and trigger stress reactions that affect physiological processes, obesity, and more. Noise can also negatively impact the central nervous system and the autonomic nervous system, reducing the ability to concentrate and pay attention, thereby decreasing work productivity (Singh and associates, 2018).

Additionally, noise can have harmful effects on various organ systems, including the cardiovascular, immune, and digestive systems, leading to functional impairments (Münzel and associates, 2014).

The impact of noise on quality of life can be understood through two main aspects: psychological and physical effects. Psychologically, noise can cause stress and sleep disturbances (Pirrera and associates, 2010), reduce concentration and productivity, and increase the risk of psychological issues such as high blood pressure and heart disease. Physically, noise can lead to elevated blood pressure and heart problems, with particularly vulnerable groups like children and the elderly facing higher risks (Lienhart and associates, 2018), (Babisch, 2014). Furthermore, long-term exposure to noise can result in hearing damage, which is a chronic effect that can greatly diminish one's quality of life (Babisch, 2002).
Additional research found out that children were more likely to display emotional problems if they were exposed to higher noise levels (Tiesler and associates, 2013).
According to the 2013 census, Sarajevo has a population of approximately 438,000 residents, with 290,000 registered in its four city municipalities. This growing population has driven a significant increase in the number of vehicles, resulting in unprecedented levels of noise pollution. The issue is further aggravated by the city's limited street capacity and inefficient land use planning, emphasizing the urgent need for a comprehensive analysis of traffic noise in Sarajevo.
The purpose of this study is to assess the traffic noise (equivalent sound pressure level, LA_{eq} (15 min)) and traffic flow in the main roads of Sarajevo.

2. MATERIAL AND METHODS

The study was conducted in the city of Sarajevo, the capital of Bosnia and Herzegovina. Noise measurement was conducted at 47 locations, representing a reference data set for analysis. The measurement locations are shown on the figure 2.

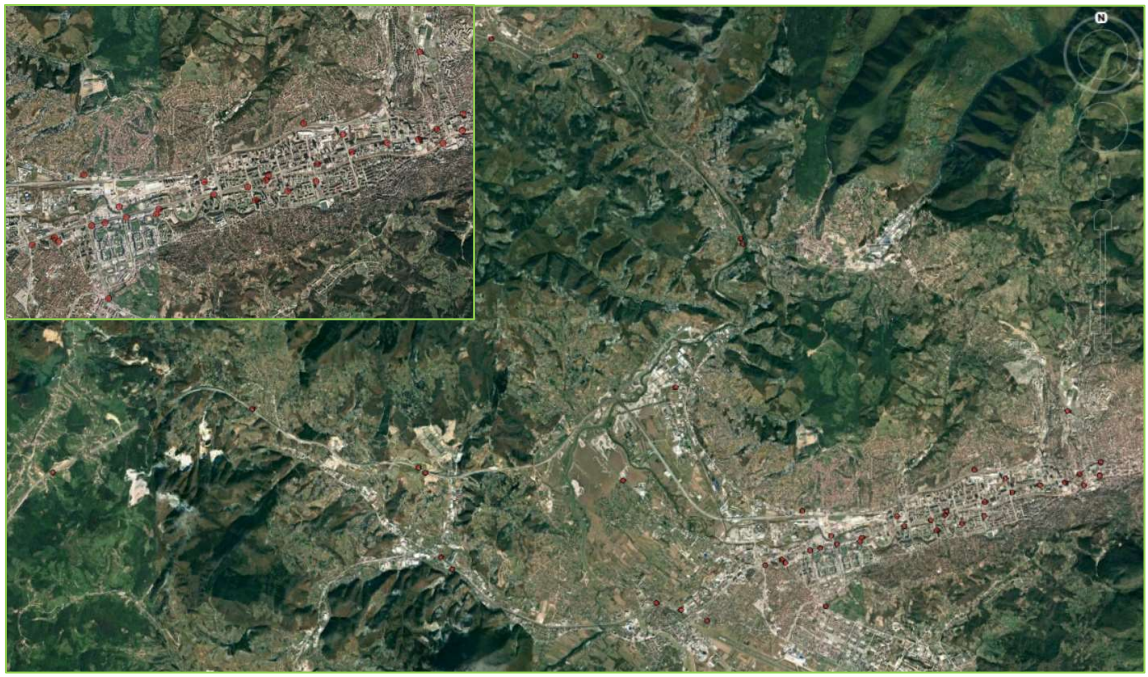

Figure 2: Map of traffic noise measurement locations for the selected study area (Author)

Traffic noise measurements were conducted in the months of May and June, during weekdays (Monday to Friday), for both daytime and nighttime regimes[1]. At each measurement point, the equivalent noise level was determined in fifteen-minute measurement intervals (Law on Noise Protection of the Sarajevo Canton, 2013), with certain extensions to ensure a representative number of samples. Research has shown that measuring noise during the passage of 70 vehicles guarantees a measurement error of less than 1 dB with a 75% level of confidence, while 170 vehicle passages guarantee a measurement error of less than 1 dB with a 90% level of confidence (Maruyama and associates, 2002).

The noise measurement device (Bruel&Kjaer type 2260 Investigator type 1, capable of real-time frequency analysis with 1/3 octave band and broadband and spectral statistical distribution) was positioned at a height of 1.2 meters above the ground surface, with the distance between the investigator and the device set at 1 meter. The device is placed at a distance of 10 meters from the central axis of the nearest traffic lane, and in case of proximity to objects, it is positioned at a distance of at least 3 meters from reflective surfaces.

3. RESULTS AND DISCUSSION

In this section, a comparison between the measured and estimated values of traffic noise levels will be conducted. The noise measurement with the Bruel&Kjaer 2260 Investigator instrument was carried out at 47 measurement points as shown in Table 1. A total of 82 measurements were conducted. To better understand the measured values, here is a brief explanation of the metrics LAeq and L10.

LAeq (Equivalent Continuous Sound Level) represents the average sound level over a specified period, expressed in decibels (dB), accounting for all fluctuations in noise. It provides a single value that reflects the total energy of the varying sound levels over time. Commonly used to describe overall noise exposure, such as the impact of traffic noise on communities. Gives a good indication of long-term noise levels and is a key metric for assessing environmental noise and compliance with regulations.

L10 (Percentile Noise Level) is the noise level exceeded for 10% of the measurement period. For instance, during a 1-hour monitoring period, L10 represents the noise level surpassed for 6 minutes (10% of the hour). It highlights higher noise levels caused by sporadic loud events, such as trucks or buses passing by. Often used to assess peak or "worst-case" noise levels in traffic noise studies. Helpful in understanding noise annoyance and specific loud occurrences within an area.

In this study, we will focus primarily on LAeq values, as they provide a comprehensive measure of overall noise exposure and are most relevant for assessing long-term traffic noise impacts.

[1] According to the Law on Noise Protection of the Sarajevo Canton ("Official Gazette of the Sarajevo Canton", no. 1/96, 2/96, 3/96, 16/97, 14/00, 4/01, 28/04, and 6/13), the day lasts from 6 a.m. to 10 p.m., while the night is from 10 p.m. to 6 a.m.

Table 1. Measurement locations and measured values of traffic noise levels (Author)

No.	Road category (designation and measurement location)	Speed (km/h)	Measured noise (daytime)		Speed (km/h)	Measured noise (nighttime)	
	HIGHWAY	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
1.	**AC1 (Butile – Sarajevo west)**	110	72,2	76,3	-	-	-
2.	**AC2 (Sarajevo west – Lepenica)**	120	66,1	71,3	-	-	-
3.	**AC3 (Lepenica – Sarajevo west)**	120	68,7	73,5	-	-	-
4.	**AC4 (Sarajevo west – Butile)**	110	69,8	75,0	-	-	-
5.	**AC5 (Butile – Sarajevo north)**	120	69,5	72,8	120	66,4	70,7
6.	**AC6 (Sarajevo north – Podlugovi)**	125	71,4	75,9	130	68,7	74,0
7.	**AC7 (Podlugovi – Sarajevo north)**	125	73,4	77,4	130	69,8	74,7
8.	**AC8 (Sarajevo north – Butile)**	105	68,4	72,3	-	-	-
	EXPRESSWAY	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
9.	**BC1 (begining Sarajevo – Mostarsko cross.)**	70-80	72,2	76,0	80	67,9	71,2
10.	**BC2 (ending, near radar at the exit)**	60	72,6	75,1	60	68,2	71,5
11.	**BC3 (gas station PETROL)**	60-70	72,6	73,1	60	65,1	68,8
12.	**BC4 (exit near railway overpass)**	80	71,9	75,4	80-90	66,2	70,8
	MAJOR URBAN ARTERY	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
13.	**GAPR1 (In front of Obala high school)**	50-60	67,9	69,2	50-60	67,3	69,4
14.	**GAPR2 (In front of the BBI center building)**	50-55	68,0	71,1	50-55	69,7	73,3
15.	**GAPR3 (In front of the Center Health Center)**	50-60	70,7	73,9	50-60	69,7	73,3
16.	**GAPR4 (Marijin Dvor – In front of the SCC)**	50	70,4	71,5	50	68,0	69,1
17.	GAPR5 (In front of the war museum)	50-60	66,3	69,6	50-60	63,9	67,1
18.	GAPR6 (Faculty of Science and Mathematics)	60	70,7	74,0	60	68,3	71,5
19.	GAPR7 (In front of the Elektroprivreda building)	60	71,4	74,7	60	69,0	72,3
20.	GAPR8 (In front of the DZ „Omer Maslić“)	60-70	68,5	72,4	60-70	66,1	69,4
21.	**GAPR9 (Čengić Vila)**	60	69,3	72,8	60-70	69,2	71,9
22.	GAPR10 (Otoka)	60	68,3	72,3		65,9	69,1
23.	**GAPR11 (Nedžarići)**	60-70	67,0	69,8	60-70	67,3	71,0
24.	GAPR12 (Stup loop)	60	69,9	72,2	60	67,5	70,1
	MAJOR URBAN ROADS	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
25.	**GSPR1 (Koševo near the Zetra hall)**	40	65,1	68,4	50-60	65,2	70,1
26.	**GSPR2 (Skenderija)**	40-50	67,4	70,7	40-50	63,7	67,9
27.	**GSPR3 (Nedžarići – Dobrinja after the first roundabout)**	60	68,2	65,9	60	62,3	65,8
	SECONDARY URBAN ROADS	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
28.	**GSDR1 (Pofalići behind „Merkatora“)**	50	67,5	70,5	50-60	64,4	69,0
29.	**GSDR2 (Džemala Bijedića near ELPI)**	40	64,5	67,3	40-50	60,6	64,1
30.	**GSDR3 (street Safeta Zajke (in front of „GP Bosna“)**	50 (20-30)	64,7 65,0	68,0 68,7	50-60	63,2	66,78
31.	**GSDR4 (street Safeta Zajke – Remiza)**	radovi			40-50	59,4	63,0
	COLLECTOR STREETS	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
32.	**SU1 (Energoinvest – Pofalići)**	50-60	65,7	69,5	50-60	64,8	68,8
33.	**SU2 (Grbavica)**	40-50	63,8	66,9	40-50	58,1	62,2
34.	**SU3 (Hrasno)**	40-50	61,8	65,9	40	59,9	64,5
35.	**SU4 (Čengić Vila – BOSMAL)**	40-50	64,3	66,6	40-50	58,1	62,4
36.	**SU5 (RTV home)**	40-50	63,2	65,3	40-50	61,2	64,7
37.	**SU6 (Energoinvestov crane)**	40-50	63,1	67,3	40	62,2	66,5
38.	**SU7 (Stup – Retirement home)**	40-50	59,4	62,2	40-50	58,3	62,0
	SUBURBAN ROADS	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**
39.	**PC1 (Rajlovačka road)**	30-40	63,3	66,2	40-50	60,3	65,0
40.	**PC2 (Kasindolska road)**	40-50	60,6	64,1	50-60	62,7	67,2
41.	**PC3 (Doglodi)**	70-80	67,0	71,1	80	65,0	70,3
42.	**PC4 (Malešići)**	50-60	63,2	66,8	50	62,6	67,0
	INTERSECTIONS AND ROUNDABOUTS	**day**	**LAeq**	**L10**	**night**	**LAeq**	**L10**

43.	**R1 (Intersections Dom pensionera)**	50-60	66,1	69,3	40	63,7	66,9
44.	**R2 (Intersections Nedžarići)**	50-60	67,8	71,6	40	65,4	68,9
45.	**R3 (Intersections Alipašino)**	50-60	69,1	73,3	40	66,7	70,9
46.	**R4 (Intersections near RTV home)**	50-60	68,8	72,8	40	66,4	7,6
47.	**R5 (Intersections Čengić Vila)**	50-60	68,4	72,4	40	66,0	70,0

On the days when noise measurements were taken (Monday to Friday) during daytime periods, it was found that the noise near roadways (10 meters from the central axis of the nearest traffic lane) ranged from 59.4 dBA (collector street Stup – Retirement home) to 73.4 dBA (highway Podlugovi – Sarajevo North) in the measured 15-minute intervals. During nighttime periods, the results showed that traffic noise ranged from 58.1 dBA (collector street Grbavica and Hrasno) to 69.8 dBA (highway Podlugovi – Sarajevo North).

Table 2 presents traffic and noise data across roadway types, detailing the Average Annual Daily Traffic (AADT), vehicles per hour, truck percentages, speeds, and noise levels (Leq). Highways and expressways, with their distinct characteristics, correspond to the highest measured noise levels. The data underscores how traffic composition and road type influence noise levels, offering valuable insights for analyzing and modeling traffic noise in diverse environments.

Table 2. Overview of data for different types and categories of roadways (Author)

Types and categories of roads **Number of measurements**	**Range AADT * [veh/day]**	**Range of vehicles per hour [veh/day]**	**Percentage of trucks [%]**	**Range of average speeds [km/h]**	**Range of the measured noise level Leq [dBA]**
HIGHWAY 16 measurements	7216-23868	424-1404	5,74-8,33	100-130	66,1-**73,4**
EXPRESSWAY 8 measurements	32893	756-1935	5,48	60-80	65,1-**72,6**
MAJOR URBAN ARTERY 24 measurements	26305-34592	1547-2035	2,03-10,62	50-70	65,9-71,4
MAJOR URBAN ROADS 6 measurements	19036-26394	1120-1553	2,56-3,43	40-60	65,1-68,2
SECONDARY URBAN ROADS 6 measurements	11167-14704	657-865	2,54-3,92	40-50	60,6 - 67,5
COLLECTOR STREETS 14 measurements	6244-16864	367-992	0,47-3,13	40-60	58,1-65,7
SUBURBAN ROADS 8 measurements	6618-7778	389-458	1,44-8,55	40-80	60,3-67,0

**Average Annual Daily Traffic*

Table 3 presents an overview of the highest permissible noise levels for specific land-use areas according to the Law on Noise Protection of the Sarajevo Canton ("Official Gazette of the Sarajevo Canton," no. 1/96, 2/96, 3/96, 16/97, 14/00, 4/01, 28/04, and 6/13).

Table 3. Highest permissible noise levels for specific areas (Law on Noise Protection of the Sarajevo Canton, 2013)

Zone	LAND USE	Highest permissible level (dBa)		
		Equivalent level L_{eq}		Peak level
		day	nigh	L1
I	Hospital and treatment	45	40	60
II	Tourist, recreational, recovery	50	40	65
III	Pure residential, educational and health institutions, public green and recreational areas	55	45	70
IV	Commercial, business, residential and residential along traffic corridors, warehouses without heavy transport	60	50	75
V	Business, administrative, commercial crafts, service (utility service)	65	60	80
VI	Industrial, storage, service, and traffic zones without housing	70	70	85
VII	Mixed-use zone (business, industrial, traffic, with housing)	60	60	50

Table 4. Comparison of measured and permissible noise levels according to Law on Noise Protection of the Sarajevo Canton (Author)

Zone	Land use	Permissible noise level L_{eq} [dBA]	Measurement location	Measured noise level *LAeq* [dBA]	Exceeding [dBA]
					day
III	Educational and health institutions	55	BC1 near JU "Sedma elementary school" Ilidža-Blažuj	72,2	**17,2**
			GAPR1 (In front of Obala high school)	67,9	**12,9**
			GAPR3 Health center Center	70,7	**15,7**
			GAPR6 (In front of the Faculty of Science and Mathematics)	70,7	**15,7**
			GAPR8 (In front of the DZ „Omer Maslić“)	68,5	**13,5**
III	Pure residential	55	PC1 (Rajlovačka road)	63,3	**8,3**
			PC2 (Kasindolska road)	60,6	**5,6**
			PC4 (Malešići)	63,2	**8,2**
IV	Commercial, business, residential	60	GAPR2 (In front of the building BBI center)	68,0	**8,0**
			GAPR4 (Marijin Dvor – In front of the SCC)	70,4	**10,4**
			GAPR7 (In front of the Elektroprivred building)	71,4	**11,4**
			GAPR11 (Nedžarići)	67,0	**7,0**
			GSPR2 (Skenderija)	67,4	**7,4**
			SU1 (Energoinvest – Pofalići)	65,7	**5,7**
VII	Mixed-use zone	60	GSPR1 (Koševo near the Zetra hall)	65,1	**5,1**
			GSDR2 (Džemala Bijedića near ELPI)	64,5	**4,5**
			SU2 (Grbavica)	63,8	**3,8**
			SU3 (Hrasno)	61,8	**1,8**
			SU4 (Čengić Vila – BOSMAL)	64,3	**4,3**

According to the current spatial plan of the Sarajevo Canton and the Law on Noise Protection, which sets the highest permissible noise levels for different land-use zones, it can be concluded from traffic noise measurements that the noise levels along roadways under normal traffic conditions often exceed the permissible limits. This is evident in some examples presented in Table 4. The exceeded noise levels range from the lowest value of 1.8 dBA (in the mixed-use zone) to the highest of 17.2 dBA (near a school).

4. RISKS ARISING FROM MEASUREMENT RESULTS

The analysis of traffic noise in Sarajevo highlights significant risks to the urban environment and public health. These risks are multifaceted, encompassing both direct and indirect effects on the city's population. Prolonged exposure to high levels of traffic noise has well-documented adverse health effects. In Sarajevo, where noise levels frequently exceed permissible limits, as shown in Table 4, residents are at heightened risk for various health issues. Studies have shown a strong correlation between chronic noise exposure and an increased risk of hypertension, ischemic heart disease, and stroke. The noise-induced stress response elevates blood pressure and disrupts cardiac function. Nighttime noise levels in Sarajevo often remain high, leading to sleep fragmentation and deprivation. Poor sleep quality can impair cognitive function, increase the risk of metabolic disorders, and reduce overall life expectancy. Additionally, noise pollution is associated with increased stress, anxiety, and depression. Persistent noise can exacerbate these conditions, reducing the overall quality of life and increasing the burden on mental health services.

Traffic noise also poses significant risks to the urban environment. Elevated noise levels can disrupt local wildlife, leading to changes in animal behavior and biodiversity loss. Noise pollution affects communication, mating, and feeding patterns of various species, which can destabilize urban ecosystems. Constant exposure to high noise levels diminishes the quality of urban life. It interferes with daily activities, reduces the usability of outdoor spaces, and detracts from the aesthetic and recreational value of urban areas.

Social implications of traffic noise include educational impact and community well-being. Schools and educational institutions located near noisy roads, such as those identified in Sarajevo, face challenges in maintaining a conducive learning environment. Noise disrupts classroom activities, impairs students' concentration, and affects academic performance. Noise pollution contributes to social conflicts and community stress. Areas with higher noise levels often experience reduced social cohesion and increased reports of nuisance and complaints.

The economic impact of traffic noise cannot be overlooked. Properties in high-noise areas often see reduced market values due to the undesirable living conditions. This can lead to economic disparities and affect the socio-economic fabric of neighborhoods. The health issues arising from noise pollution translate to higher healthcare costs. Increased incidence of cardiovascular and mental health conditions imposes a significant financial burden on both individuals and public health systems.

Addressing the risks associated with traffic noise in Sarajevo requires comprehensive strategies that encompass health, environmental, social, and economic dimensions.

Policymakers and urban planners must prioritize noise mitigation measures, enforce stricter noise regulations, and promote public awareness to mitigate these risks effectively. The adoption of a Green University Strategy can serve as a model for broader urban initiatives aimed at creating a healthier and more sustainable living environment.

5. CONCLUSIONS

Noise pollution in Sarajevo is not adequately recognized or addressed as an environmental issue. Scientific research shows that noise can pose significant health risks, disrupt communication, and decrease the productivity of residents, all of which affect the overall quality of life. Despite these findings, the problem remains overshadowed by other urban challenges.

This study highlights that traffic noise is a persistent issue on the roads of Sarajevo. Measurement results reveal that noise pollution levels in the urban area are high enough to adversely affect the health and productivity of the population, as indicated by the WHO outdoor environmental noise guidelines and the Law on Noise Protection of Sarajevo Canton. With the rapid pace of infrastructure development and the unplanned urbanization of land, the issue of traffic noise will likely reach critical levels soon, becoming an increasing concern for both the public and policymakers. This will inevitably lead to a significant decline in the quality of urban life.

Therefore, it is necessary to undertake protective measures related to planning, technical, legislative, and educational aspects to avoid the negative consequences of noise pollution on the environment. The primary objective should be to create action plans to lower noise levels in the City of Sarajevo, in line with Directive 2002/49 (European Comission, 2002) and the current legal framework. These plans aim to reduce environmental noise impacts on human health and consequently decrease the number of people affected by it. Addressing the risks associated with traffic noise in Sarajevo requires comprehensive strategies that encompass health, environmental, social, and economic dimensions. Policymakers and urban planners must prioritize noise mitigation measures, enforce stricter noise regulations, and promote public awareness to mitigate these risks effectively.

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