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TRAFFIC NOISE AND ECOLOGICAL BALANCE: FROM TECHNICAL EMISSIONS TO ENVIRONMENTAL DAMAGE

Predrag Pravdić[1]
Zorana Milosavljević[2]
Darko Manjenčić[3]
Violeta Đorđević[4]

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Abstract: *This paper examines traffic noise as a significant environmental pollutant and its impact on human health, vehicle users, and the surrounding environment. It highlights that noise is one of the leading environmental risks, immediately after air pollution, with serious consequences for physical and mental well-being. The study analyzes the effects of long-term exposure to noise, including hearing loss, cardiovascular diseases, stress, sleep disturbances, and reduced cognitive abilities. Special attention is given to noise inside vehicles, which is often overlooked despite evidence that it frequently exceeds recommended safety limits. The paper explains the main sources of vehicle noise, including engine operation, tire-road interaction, aerodynamic effects, and structural vibrations. It also distinguishes between structural and airborne noise and their contribution to the overall acoustic environment in the vehicle cabin. The study reviews modern technological solutions for noise reduction, such as improved vehicle design, sound insulation materials, quieter tires, and active noise control systems. It also emphasizes the importance of regulatory measures and stricter standards for both external and in-vehicle noise. The findings suggest that reducing traffic noise requires a comprehensive approach that combines technical, environmental, and policy measures. Ultimately, effective noise management contributes to improved public health, enhanced traffic safety, and a higher quality of life in urban environments.*

1 Academy of professional studies Kruševac, Department of technical and technological studies in Kruševac, Serbia
2 Academy of professional studies Kruševac, Department of technical and technological studies in Kruševac, Serbia
3 Academy of professional studies Kruševac, Department of technical and technological studies in Kruševac, Serbia
4 Technical College of Vocational Studies Novi Sad, Serbia

SAOBRAĆAJNA BUKA I EKOLOŠKA RAVNOTEŽA: OD TEHNIČKIH EMISIJA DO ŠTETE PO ŽIVOTNU SREDINU

Ključne riječi: *saobraćajna buka, buka vozila, zagađenje bukom, zdravlje ljudi, izloženost buci, buka u vozilu, distribucija buke na autoputevima, akustički komfor, urbano planiranje, ublažavanje buke, kardiovaskularni efekti, tehnologije za kontrolu buke*

Sažetak: *Ovaj rad razmatra saobraćajnu buku kao značajan zagađivač životne sredine i njen uticaj na zdravlje ljudi, korisnike vozila i okolinu. Ističe se da buka predstavlja jedan od vodećih rizika iz životne sredine, odmah nakon zagađenja vazduha, sa ozbiljnim posljedicama po fizičko i mentalno zdravlje.*

U radu se analiziraju efekti dugotrajne izloženosti buci, uključujući gubitak sluha, kardiovaskularna oboljenja, stres, poremećaje spavanja i smanjenje kognitivnih sposobnosti. Posebna pažnja posvećena je buci unutar vozila, koja se često zanemaruje uprkos dokazima da nerijetko prelazi preporučene bezbjednosne granice.

U radu se objašnjavaju glavni izvori buke vozila, uključujući rad motora, interakciju pneumatika i kolovoza, aerodinamičke efekte i strukturne vibracije. Takođe se pravi razlika između strukturne buke i buke koja se prenosi vazduhom, kao i njihovog doprinosa ukupnom akustičkom okruženju u kabini vozila.

Analiziraju se savremena tehnološka rješenja za smanjenje buke, kao što su unaprijeđeni dizajn vozila, materijali za zvučnu izolaciju, tiši pneumatici i sistemi aktivne kontrole buke. Takođe se naglašava značaj regulatornih mjera i strožih standarda kako za spoljašnju buku tako i za buku unutar vozila.

Rezultati ukazuju na to da smanjenje saobraćajne buke zahtijeva sveobuhvatan pristup koji objedinjuje tehničke, ekološke i regulatorne mjere. U konačnom, efikasno upravljanje bukom doprinosi unapređenju javnog zdravlja, povećanju bezbjednosti saobraćaja i poboljšanju kvaliteta života u urbanim sredinama.

1. Introduction

According to data from the World Health Organization (WHO), noise is second only to air pollution in terms of its impact on human health. It is a significant cause not only of hearing impairment, but also of cardiovascular diseases, learning difficulties in children, and sleep disorders. However, the noise generated by traffic could be relatively easily reduced by as much as half by applying already existing technological solutions, provided that stricter regulations are introduced. In the period from 2015 to 2025, Transport & Environment (T&E) has been active at the level of the European Union and globally, advocating for stricter standards regarding the noise produced by cars, trucks and railway vehicles. In December 2011, the European Commission adopted a proposal for a new regulation with the aim of reducing the permitted noise levels for passenger and cargo vehicles, vans and buses, given that the standards have not been updated since 1996. Long-term and regular exposure to elevated noise levels can cause a number of negative health effects, including hearing loss, high blood pressure, heart disease and sleep disturbances. Although noise reduction measures have been implemented in many industries and transportation systems, relatively little attention has been paid to the noise inside the vehicles themselves. Research shows that noise levels in vehicles are often above the safe limit of 70 dB(A) for long-term exposure. Although this noise may not immediately cause acute health problems, millions

of people are chronically exposed to it during their daily commute. In addition to the above, it is important to point out that long-term exposure to noise in vehicles can lead to increased stress and reduced driver concentration. This can negatively affect traffic safety and increase the risk of accidents. Also, noise has a strong impact on the quality of life in urban areas, especially in densely populated areas. Reducing traffic noise would contribute to improving the mental health of the population. Modern technologies enable the development of quieter vehicles without significantly increasing production costs. In addition, the application of quieter tires and improved suspension systems can significantly contribute to reducing the overall noise level. Electric and hybrid vehicles are already showing positive effects in reducing noise in cities. Traffic infrastructure planning with emphasis on noise protection is an important step towards sustainable development. Raising public awareness of the harmful effects of noise can contribute to stronger support for stricter regulations. In the long term, reducing traffic noise brings multiple benefits for both human health and the environment.

2. Noise and vehicles

According to Arregi et al. (2024) and Münzel et al. (2024), regular and long-term exposure to elevated noise levels can lead to numerous negative consequences for human health, including hearing damage, increased blood pressure, ischemic heart disease, anxiety, and sleep disturbances. These effects do not appear suddenly, but develop gradually, often imperceptibly, which further increases their importance in terms of public health. As reported by Stansfeld et al. (2021), the maximum safe noise level for humans is 70 dB(A) during 24-hour exposure without harmful health consequences. It has been shown by Park et al. (2025) that noise levels of 85 dB(A) and higher can cause permanent hearing damage and even complete loss of hearing sensitivity. Noise-induced hearing loss is one of the most common occupational health problems. Based on the findings of Flanagan (2024), in the United States around 10 million people have already suffered irreversible hearing damage due to noise, while between 30 and 50 million people are exposed to potentially dangerous noise levels daily. The study by Kim et al. (2022) indicates that the US Environmental Protection Agency (EPA) defines a noise level of 75 dB(A) during an eight-hour exposure as a limit without significant risk to public health. When it comes to professional exposure, the permissible limit is 90 dB(A) for a maximum of eight hours of work per day. At the same time, the Occupational Safety and Health Administration (OSHA) mandates the mandatory use of hearing protection to reduce the noise level to a time-weighted average (TWA) of 85 dB(A) during an eight-hour shift by Bluhm et al. (2017). Although numerous noise control measures have been introduced in households, industry and traffic, the interior of a vehicle is rarely seen as a space that requires special protection of passengers and drivers from the harmful effects of noise. Therefore, the effects of vehicle noise on public health are often overlooked in traffic and transportation studies. From the point of view of the source, the noise in the vehicle can be divided into structural and airborne. Structural noise occurs as a result of vibrations at the points of support or attachment of individual components. These vibrations are transmitted through the vehicle structure and are then acoustically emitted into the cabin. Research conducted by Stankov (2022) suggests that such effects are related to structural resonance and cabin acoustic modes, with low fre-

quencies below 500 Hz being dominant. Furthermore, Đerčan (2020) highlights that various vehicle components such as the engine, auxiliary systems, cooling fans, braking system, and exhaust system represent significant sources of structural noise. Airborne noise, on the other hand, refers to the sound that is transmitted directly through the air into the interior of the vehicle through gaps and impervious places, such as noise generated at the contact of tires and pavement, aerodynamic wind noise and the noise of other vehicles in the environment. Findings presented by Öhrström et al. (2016) show that this type of noise mainly occurs at frequencies above 800 Hz. Data from the European Environment Agency (2023) demonstrate that elevated noise levels at frequencies of 500, 1000, and 3000 Hz can significantly impair speech perception and communication ability. In addition, the same source (2023) emphasizes that in practical applications exchange rates of 3 dB(A), 4 dB(A), and 5 dB(A) are used, with the 3 dB(A) equal energy rule being the most reliable indicator of risk. The risk of hearing damage depends on the level of sound pressure, the frequency spectrum of the noise, its spatial and temporal distribution, the duration of exposure, as well as the individual sensitivity of the person. In addition, the risk to hearing is directly proportional to the amount of acoustic energy received by the ear. Long-term exposure to vehicle noise can lead to increased driver fatigue and reduced concentration. This can have a direct impact on traffic safety and increase the likelihood of traffic accidents. Noise also contributes to increased levels of stress and nervousness in passengers. Professional drivers who spend several hours in the vehicle every day are especially at risk. Contemporary trends in the automotive industry are increasingly directed towards reducing noise in the vehicle cabin. The use of advanced materials for sound insulation is one of the important solutions. Electric vehicles, although quieter in terms of the drive system, may have other sources of noise, such as tire noise. Therefore, a comprehensive approach to vehicle noise analysis and control is necessary. Reducing the noise in the vehicle does not only contribute to preserving health, but also to increasing the comfort and quality of the journey. In addition to the mentioned aspects, it is important to point out that noise in vehicles is often underestimated because it is considered an integral part of everyday traffic. However, continuous exposure to even moderate noise levels can have a cumulative effect on health. In the long term, this can lead to a decrease in the quality of life, especially for people who commute to work every day. Professional drivers of buses, trucks and taxis, who spend a large part of their working time in a noisy environment, are especially at risk. A higher frequency of cardiovascular diseases and sleep disorders was observed in these groups. Noise in the vehicle can also negatively affect the driver's psychological state, causing irritability and increased tension. Such a condition can reduce the ability to make quick and correct decisions in traffic. At the same time, increased noise levels can make communication between passengers and drivers difficult. This is particularly pronounced in public transport, where clear communication is of key importance for safety. Noise can also mask important sound signals from the environment, such as sirens or warning sounds from other vehicles. From a technical aspect, noise reduction requires optimization of the vehicle structure in the early stages of design. Improving aerodynamic characteristics can significantly reduce air noise at higher speeds. Also, proper balancing of rotating parts contributes to the reduction of vibrations and structural noise. Quality suspension systems can mitigate the transmission of vibrations from the roadway to the vehicle cabin. In addition, choosing the right tires has a big impact on the overall noise level. The development of new

materials with better sound-absorbing properties represents an important direction of further research. The application of multi-layer insulation panels can further improve the acoustic comfort in the vehicle. Active noise cancellation systems are becoming more common in modern cars. These systems use microphones and speakers to neutralize unwanted sounds in real time. Although they increase the complexity of the vehicle, their effectiveness has already been proven in practice. From the point of view of the legislation, there is an increasing need to introduce stricter standards related to the noise level in the interior of the vehicle. Existing regulations mostly focus on external vehicle noise, while cabin noise is often neglected. The introduction of clear limit values for in-vehicle noise could significantly improve the protection of users' health. Also, continuous measurement and monitoring of noise levels in real driving conditions would provide more reliable data. Based on such data, it is possible to develop more effective control measures. Reducing vehicle noise should be seen as part of a broader strategy of sustainable and safe traffic. The integration of technical, health and regulatory approaches enables long-term positive effects. This improves not only the health of individuals, but also the overall quality of urban life. Long-term investments in this area bring multiple social and economic benefits. Noise, as an invisible pollutant, requires the same attention as other forms of pollution.

3. Distribution of vehicle noise levels on highways

In modern conditions, the majority of residents of the United States of America and the EU rely heavily on personal vehicles as their primary means of mobility. According to the Health Effects Institute (2022), the average daily commuting time is approximately 25.4 minutes. As noted by Basner et al. (2018), annual delays in traffic congestion range from about 42 hours in cities such as San Diego to up to 82 hours in Washington. Such data indicate that a significant part of the population spends a long period of time in vehicles every day, often in conditions of increased noise. Recent research shows that the noise level inside the vehicle is in many cases higher than the maximum safe noise level (MSNL), and that it largely depends on the speed of the vehicle. Research by Li et al. (2017) reveals that drivers in urban daily traffic conditions are exposed to noise levels between 71.10 and 72.59 dB(A). Moreover, Nieuwenhuijsen et al. (2018) report that highway noise levels can reach around 81 dB(A) on concrete pavements, while approximately 75 dB(A) is recorded on asphalt surfaces, particularly during nighttime conditions. Despite these findings, there is still a lack of research addressing vehicular noise exposure during workdays under daytime conditions, as well as assessing the health risks of such exposure to the wider population. For this reason, this research aims to analyze in detail the distribution of noise levels inside vehicles, assess the potential health risk for everyday passengers, and simplify the methods of assessing hazardous noise exposure on highways. In addition to the above, it is important to emphasize that driving conditions differ significantly depending on traffic density. During peak traffic periods, frequent acceleration and braking additionally contribute to an increase in the noise level in the cabin. Also, the condition of the road has a direct influence on the generation of noise, especially with older and damaged roads. The type of vehicle, its age and technical condition also play an important role in the formation of the overall noise level. Driving at higher speeds, characteristic of highways, leads to increased aerodynamic noise. At the same time, the tire's contact with the road becomes the

dominant source of sound. In the case of trucks, these effects are even more pronounced due to their greater mass and dimensions. Additional sources of noise can be ventilation and air conditioning systems, which are often turned on during long journeys. From a health perspective, long-term exposure to elevated noise levels, even if it does not exceed extreme values, can lead to chronic stress and fatigue. The driver may experience reduced concentration and an increased feeling of exhaustion. This has a direct impact on traffic safety and increases the risk of driving errors. In the long term, regular exposure to noise during daily commutes can contribute to the development of cardiovascular diseases. The results of such research can serve as a basis for the improvement of regulations related to permitted levels of noise in vehicles. Also, they can contribute to the development of more effective technical solutions to reduce noise in the cabin. The obtained data are also important for urban planners and traffic planners, because they enable better planning of road infrastructure. In this way, conditions can be created for a healthier and safer environment for all road users. In addition, differences in noise exposure between different groups of drivers need to be taken into account. Daily commuters who use highways twice a day are exposed to significantly higher accumulated noise levels than occasional drivers. Workers who travel long distances between their place of residence and work every day are particularly at risk. For them, the effects of noise can manifest themselves through chronic fatigue and reduced work efficiency. Also, the time of day has a significant influence on the distribution of the noise level in the vehicle. During morning and afternoon rush hours, noise is often uneven due to frequent speed changes. Night driving, although with a lower traffic density, can be accompanied by higher speeds and therefore increased aerodynamic noise. Weather conditions, such as rain or strong wind, additionally affect the noise intensity in the cabin. The psychological factor also plays a significant role in the perception of noise. Drivers under stress often experience noise more intensely than it objectively is. Long-term exposure to noise can lead to a decrease in tolerance to sound stimuli. This can result in increased irritability and nervousness while driving. From the aspect of research methodology, it is important to apply continuous noise measurements in real driving conditions. This results in more accurate data compared to laboratory measurements. Combining the measurements with speed and pavement type data allows for a more detailed analysis. Based on such data, reliable noise exposure assessment models can be developed. Understanding the distribution of in-vehicle noise levels on highways is an important step toward improving passenger health and safety. Such research contributes to a better understanding of the real conditions to which drivers are exposed. This opens up space for the development of targeted protection measures. In the long term, the results can have a significant impact on the improvement of transport policy.

4. Sources and characteristics of noise produced by motor vehicles

The sources of noise produced by motor vehicles are numerous and interconnected. One of the main sources of noise is the drive motor of the vehicle, especially in vehicles with internal combustion. The combustion process in the cylinders creates impulse pressures that are transmitted to the engine structure and further into the environment. The operation of the engine's auxiliary systems, such as the alternator, water pump and compressor, also contributes to the overall noise level. The exhaust system plays a significant

role in the emission of noise, especially if it is not adequately damped. The air intake system can be an additional source of sound, especially at higher engine speeds. Engine vibrations are transmitted to the vehicle body via the mounts, creating structural noise. The braking system, especially during hard braking, can generate high levels of high-frequency noise. Friction between brake pads and discs often leads to screeching. The contact between tires and the road is one of the dominant sources of noise, especially at higher speeds. The characteristics of the tire, such as the tread pattern and the hardness of the compound, directly affect the intensity of the noise generated. The type and condition of the pavement structure has a great influence on the noise level, with concrete pavements generally producing more noise than asphalt pavements. Unevenness and road damage further increase the noise emission. Aerodynamic noise is caused by the flow of air around the vehicle body. This type of noise becomes more pronounced as the speed of movement increases. External elements of the vehicle, such as mirrors, mounts and antennas, can cause turbulent air flow and increase the noise level. The shape of the body and the quality of the joints play an important role in controlling aerodynamic noise. Interior noise in a vehicle is caused by a combination of external and internal sources. Insufficient sound insulation allows noise to penetrate more easily into the cabin. Chassis and suspension vibrations are transmitted to the passenger compartment and affect acoustic comfort. Older vehicles generally have a higher noise level due to worn components. Electric vehicles have a lower level of driving noise, but still produce noise due to the contact of the tires with the road. Due to the reduced overall noise level, other sources become more pronounced and easier to see. The characteristics of the traffic flow, such as density and driving mode, further influence the noise distribution. All the mentioned sources together determine the overall characteristics of noise produced by motor vehicles. In addition to the sources mentioned, it is important to point out that driving style significantly affects the level of noise produced by the vehicle. Sudden accelerations and frequent gear changes increase engine load and noise emissions. Driving at high revs leads to more pronounced operation of the engine and exhaust system. Also, inadequate vehicle maintenance can significantly increase the noise level. Damaged or worn parts of the exhaust system are often the cause of increased sound emission. Loose bodywork elements can cause additional vibrations and unpleasant sounds while driving. A faulty suspension system contributes to greater transmission of vibrations from the road to the vehicle. In the case of trucks, noise is often more pronounced due to greater mass and more powerful power units. Also, the vehicle load affects the noise intensity, because it increases the tire pressure on the road. Traffic conditions, such as ups and downs on the road, can further affect the noise level. Driving on an incline requires a greater load on the engine, which is reflected in increased noise emissions. In urban areas, frequent stops and starts of vehicles contribute to an increased overall noise level. Traffic lights and intersections represent points with pronounced noise. Environmental characteristics, such as built-up density, affect the reflection and propagation of sound. In urban canyons, noise can be amplified many times over due to bounce from objects. Green belts and protective barriers can partially mitigate the spread of noise. From that aspect, proper urban planning has an important role in traffic noise control. The development of modern technologies has enabled the application of various measures to reduce vehicle noise. The use of advanced vibration dampening materials reduces structural noise. Active noise control systems are increasingly used in modern vehicles. The introduction of stricter tech-

nical standards encourages manufacturers to further improvements. Reducing the noise of motor vehicles is an important step towards improving the quality of life and protecting the health of the population. Additionally, it is important to emphasize that the noise characteristics of motor vehicles change during their lifetime. As a vehicle ages, mechanical components wear and tear, resulting in increased vibration and higher noise levels. Bearings, gears and transmission elements are particularly sensitive, as they lose their optimal working characteristics over time. Improper lubrication or lack of lubricant further increases friction and noise emissions. Temperature conditions also affect material behavior and noise levels. At low temperatures, rubber and plastic elements harden, which can increase the transmission of vibrations. On the other hand, high temperatures can lead to changes in the elasticity of individual parts and the appearance of additional noises. These effects are particularly pronounced during long-term driving on highways. A significant source of noise can also be the power transmission system, especially the gearbox and differential. Misalignment of the gears or wear of the synchro leads to the appearance of a characteristic yaw. With automatic transmissions, additional noise can be generated by hydraulic systems. All these phenomena affect the overall acoustic signature of the vehicle. Recently, more and more attention has been paid to the difference between objectively measured noise and the subjective perception of the user. Certain sounds, although of lower intensity, can be extremely unpleasant due to their frequency or tonality. That is why psychoacoustic analyzes are applied in vehicle development. This approach enables a more precise adjustment of the acoustic comfort to the user's needs. From the aspect of safety, a certain level of noise also has a warning function. The sound of the engine and the movement of the vehicle allows other road users to react in time. With electric vehicles, due to reduced noise at low speeds, artificial sound signals have been introduced to increase pedestrian safety. These systems represent a compromise between reducing noise and maintaining traffic safety. Traffic noise cannot be considered in isolation, but as part of a wider acoustic environment. The interaction of multiple vehicles in the traffic flow leads to a cumulative effect of noise. In conditions of high traffic density, individual sources merge into continuous noise. This kind of ambient sound has a special effect on the inhabitants of urban areas. Traffic infrastructure planning can have a significant impact on reducing the negative effects of noise. The use of quieter asphalt mixtures reduces the noise of contact between the tires and the pavement. Placing sound barriers along roads contributes to the protection of the surrounding population. Also, speed limits have a direct effect on reducing aerodynamic noise. The development of intelligent transport systems enables the optimization of traffic flow and the reduction of unnecessary acceleration and braking. This indirectly reduces the noise emission. Educating drivers about environmentally friendly driving can have a positive effect on noise pollution. In this way, noise reduction becomes the joint responsibility of manufacturers, legislators and vehicle users.

5. The impact of traffic noise on human health and the quality of the environment

Traffic noise stands out as one of the most dominant forms of pollution in urban areas, arising as a direct consequence of the intensive movement of motor vehicles, trains and other means of transport. Its presence is not only an aesthetic problem or a violation of

comfort, but a serious risk factor that deeply affects the physical and psychological health of the population, as well as the stability of the ecosystems themselves. Chronic exposure to this pollution triggers a series of health problems, starting with serious sleep disorders and stress accumulation, all the way to the decline of cognitive functions, which is most clearly observed in children's development and learning. Studies unequivocally confirm that continuous noise directly contributes to the development of cardiovascular diseases, such as hypertension and heart attacks, while simultaneously disrupting mental stability by causing symptoms of anxiety and depression. In addition to the impact on humans, noise also drastically changes the natural environment because it disrupts communication between animals, reduces biodiversity and forces different species to change their behavior and migration paths. Studies by Emanuel (2020) and AIP Publishing (2023) indicate that the continuous presence of environmental noise in urban and suburban areas significantly reduces quality of life, making noise management a key component of modern urban planning. In order to suppress these negative effects, it is necessary to apply technical solutions such as sound barriers and silent asphalt surfaces, with stricter speed regulation and strengthening of public transport. In addition, a key role is played by the expansion of urban greenery and public education, which creates the basis for sustainable development and a healthier environment. Traffic noise represents one of the most widespread and significant forms of urban pollution in modern cities. According to Basner and McGuire (2018), traffic noise is generated by road vehicles, railways, subways, trams, aircraft, and other transport systems, with its intensity depending on traffic density, vehicle speed, vehicle type, and infrastructure characteristics. In urban areas with heavy traffic, noise is often constant, reaching levels that significantly affect the physical and mental health of the population. Chronic exposure to traffic noise leads to numerous negative health consequences. One of the first and most common effects is sleep disturbance. Constant noise disrupts deep sleep, shortens the duration of deep sleep stages and leads to frequent awakenings during the night. This directly affects fatigue, reduced concentration and lower work ability. In addition, long-term noise increases the level of stress and can cause changes in the hormonal system, especially in the secretion of cortisol, which contributes to the development of anxiety, depression and various psychosomatic disorders. Cardiovascular diseases are one of the most important consequences of long-term exposure to noise. Studies show that people who live in areas with heavy traffic have a higher risk of hypertension, myocardial infarction, stroke and other heart diseases. In addition, noise can negatively affect the immune system and increase susceptibility to infections. In children and adolescents, exposure to noise during development can lead to a decrease in cognitive abilities, problems with learning and concentration, as well as emotional disturbances. Apart from the physical consequences, traffic noise significantly affects the psychological state of people. It increases the feeling of frustration, nervousness and aggressiveness. Long-term exposure to noise can reduce social interaction as people avoid being outdoors, affecting the quality of life and social cohesion of the community. Traffic noise not only affects people, but also has wide-ranging environmental consequences. It disrupts natural ecosystems, disrupts animal communication and behavior, reduces biodiversity and can change migration patterns. Noise affects birds, mammals and other animals that depend on sound to navigate, hunt or warn of danger. Continuous noise can lead to displacement of animals from their natural habitats and reduction of populations. Also, noise has a negative effect

on the quality of the space where people live. Urban landscapes with a high level of noise become unpleasant to live in, reduce aesthetics and contribute to the psychological and physical exhaustion of the population. This has direct economic consequences because it reduces the attractiveness of locations for living and doing business. The main sources of traffic noise include vehicle engines, tire contact with the asphalt surface, braking and acceleration, rail traffic and aircraft flights. Also, road characteristics, vehicle speed, age and type of vehicle, quality of tires and asphalt surface significantly affect the generated noise. The biggest problem is represented by large urbanized areas with heavy traffic, where noise exceeds the permitted levels prescribed by environmental protection laws and standards. Clark and Paunović (2021) as well as Wrótny (2021) point out that reducing traffic noise has become a primary objective in urban planning and public health protection, requiring the implementation of effective and sustainable mitigation measures. The first step in the physical protection of the settlement is the construction of sound barriers along the busiest roads and railways in order to prevent the spread of sound waves towards the apartments. Along with the barriers, quiet asphalt coverings are increasingly being used, which are specially designed to absorb the noise created by the friction of the tires on the road. In addition to technical solutions, it is also crucial to regulate the speed of movement in densely populated areas, which directly reduces the intensity of noise produced by engines. The long-term strategy also implies a change in movement habits through the promotion of public transport, cycling and walking, which has the ultimate goal of significantly reducing the number of motor vehicles on the streets. An important natural ally in this fight is the careful planning of green areas and parks, which, in addition to their aesthetic role, function as effective natural sound absorbers. Finally, this entire process must be supported by continuous education of citizens about the harmfulness of noise and the ways in which everyone can contribute to reducing their own exposure to this pollutant. Traffic noise is emerging as one of the most serious challenges of modern urban life, considering that it deeply damages people's physical and mental health, disturbs sensitive natural processes and significantly degrades the general quality of everyday life. Therefore, its systematic management and strict control have become key factors for achieving sustainable development of cities and long-term preservation of population health. In order to successfully suppress these negative effects, an integral approach is necessary that harmoniously combines modern technical solutions, thoughtful spatial planning and continuous education of citizens. Such a comprehensive strategy can drastically reduce the harmful effects of noise pollution, thus directly contributing to the creation of a healthier and more humane living environment for all. Traffic noise is considered one of the key factors of urban pollution because it constantly increases with the growth of the number of motor vehicles. The noise level is measured in decibels, and most urban areas record average values above 65 dB during the day. Children exposed to constant noise in schools have poorer learning results and reduced attention. Exposure to noise at an early age can permanently affect hearing development and cognitive function. Noise in urban areas also affects the elderly, increasing the risk of depression and social isolation. Chronic noise can cause high blood pressure and increase the risk of heart disease. People who live in areas with heavy traffic are more likely to develop sleep problems and fatigue during the day. Continuous stress caused by noise can reduce immunity and increase susceptibility to infections. Long-term exposure to noise can contribute to the development of anxiety disorders in adults.

Traffic noise disrupts normal life rhythms and reduces the quality of free time. Urban parks and green spaces can partly mitigate the negative effects of noise. Placing sound barriers along the roads significantly reduces the noise level in the surrounding residential areas. Modern asphalt materials with a low coefficient of friction contribute to lower noise emissions than tires. Speed regulation and the introduction of speed limit zones affect the reduction of traffic noise. The promotion of electric vehicles contributes to the reduction of noise levels in cities. Metro and tram systems with quieter technologies significantly reduce noise in urban areas. Urban planning that includes buffer zones between roads and residential buildings reduces the negative impact of noise. Continuous monitoring of the noise level enables identification of critical zones and planning of protection measures. Traffic noise also affects air quality because it reduces living comfort and limits outdoor time. Because of the noise, people use motor vehicles more often instead of walking, which increases the emission of exhaust gases. Noise disrupts animal communication in urban and suburban environments. Birds in noisy urban areas often change their nesting site and reduce reproductive success. Mammals reduce activity in noisy areas, which can lead to population declines. Traffic noise affects the acoustic landscape and the quality of recreational spaces. Prolonged exposure to noise can cause permanent stress-related changes in the brain. Sound pollutants disrupt the natural cycles and nighttime activity of animals. Noise can reduce the attractiveness of urban areas for tourism and business. Educating citizens about the consequences of noise and protection measures increases the effectiveness of preventive activities. Integrated noise reduction strategies combine technical solutions, urban planning and the promotion of sustainable transport. Sustainable management of traffic noise contributes to a better quality of life and preservation of the environment. In the modern world, vehicles are no longer viewed only through the prism of exhaust gases, but also as sources of specific, dangerous sound emissions that seriously damage the integrity of the environment. This noise, created by the operation of the engine and the friction of the tires on the ground, penetrates deep into the natural habitats, creating invisible barriers that interrupt the natural communication between animal species. When traffic noise becomes dominant in the ecosystem, it masks the vital sounds of nature, which directly threatens the predator's ability to hunt, as well as the prey's ability to detect danger in time. The environment is losing its biodiversity as many sensitive species are forced to migrate from areas under constant sound pressure. In addition to fauna, noise also degrades the very structure of human settlements, turning green oases and recreational zones into areas of high stress where nature can no longer perform its function of recovery and regeneration. Therefore, the recognition of vehicles as a source of dangerous sound emission is not only a matter of technical regulation, but a key step towards preserving the ecological balance and creating a sustainable coexistence between technological progress and the natural environment.

6. Discussion

Traffic noise is a significant form of pollution that directly affects human health and ecological balance. Its presence in urban and suburban environments is becoming more and more intense with the increase in the number of motor vehicles. Chronic exposure to noise causes sleep disturbances, increases stress and negatively affects people's cognitive

abilities. People who live in areas with heavy traffic have a higher risk of cardiovascular disease and mental disorders. Children and adolescents are particularly sensitive to the impact of noise, which can affect their development and school performance in the long term. The elderly are also at risk, as noise increases feelings of isolation and the risk of depression. From an environmental perspective, noise disrupts natural ecosystems and animal behavior. Birds and mammals change their migration patterns and nesting sites due to the presence of constant noise. Biodiversity is decreasing, and the ecological balance is being disturbed. Noise affects the quality of urban space and reduces the aesthetic and recreational value of the environment. Technical vehicle emissions, including noise, represent a combined environmental stressor. The continued presence of high noise levels can lead to permanent changes in the acoustic landscape. This phenomenon reduces the quality of life of residents and increases health risks. In cities with heavy traffic, noise often exceeds permitted environmental and legal standards. Noise reduction options include the use of quieter asphalt pavements and sound barriers. Speed regulation and control of traffic intensity contribute significantly to the reduction of noise emissions. The promotion of public transport and electric vehicles represents an effective strategy for environmental protection. Urban planning with buffer zones and greenery can mitigate the negative effects of noise. Citizen education increases awareness of the harmfulness of noise and encourages preventive measures. Continuous monitoring of the noise level enables the identification of critical zones and timely intervention. Reducing traffic noise contributes to the preservation of people's physical and mental health. At the same time, it contributes to the preservation of ecological balance and biodiversity in urban areas. An integral approach includes technical solutions, spatial planning and promotion of sustainable transport. Sustainable traffic noise management is a key segment of environmental protection. Traffic noise is not only a technical problem, but a serious environmental and social challenge. It is therefore necessary to plan and implement strategies that reduce noise emissions and protect people and nature.

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