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UTICAJ BUKE NA ZDRAVLJE. MERE ZA KONTROLU PREVELIKOG NIVOA BUKE U SAOBRAĆAJU

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IMPACT OF NOISE ON HEALTH. MEASURES TO CONTROL EXCESSIVE TRAFFIC NOISE LEVELS

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Sažetak

Brojna istraživanja su pokazala da zagađenje bukom ima negativne efekte na ljudsko zdravlje. U današnje vreme, buka u životnoj sredini je postala značajan problem u većini zemalja. Zagađenje bukom je širenje neželjenih zvukova u okolini. Buka je skoro uvek oko nas. Među faktorima životne sredine koji izazivaju zdravstvene posledice, buka u okruženju je na drugom mestu po značaju, odmah posle zagađenja vazduha. Zbog buke sa puteva, železnice i aerodroma, jedna od tri osobe iskusi uznemirenost tokom dana, a svaka peta ima poremećaj sna noću.
Fizički zdravstveni efekti zagađenja bukom mogu se javiti kao direktan ili indirektan rezultat izloženosti buci. U teškim slučajevima, glasni zvuci mogu direktno uzrokovati oštećenje sluha. Ova prekomerna buka ozbiljno šteti ljudskom zdravlju i ometa svakodnevne aktivnosti ljudi u školi, na poslu, kod kuće i u slobodnom vremenu. Hronična izloženost buci životne sredine takođe značajno utiče na fizičko i mentalno zdravlje.
Buka drumskog saobraćaja je najčešći izvor buke u životnoj sredini i najviše doprinosi ukupnim efektima buke na zdravlje. Ako se utvrdi da je smanjenje buke izvodljivo i odgovarajuće, jedna od najčešćih tehnika za redukciju buke su barijere za buku. Od nekoliko tehnologija koje su dostupne nadležnima za puteve, primena materijala koji smanjuju buku za izgradnju puteva, nije samo najisplativija, već se može primeniti u kratkom roku.
Ključne reči: buka, zdravlje, smetnja, saobraćaj

Abstract

Long-standing research has shown that noise pollution has harmful consequences on human health. Environmental noise is becoming a significant problem in most nations. The spread of undesired noises into the environment is known as noise pollution. We are virtually constantly surrounded by noise. Environmental noise causes an illness burden that is second only to the air pollution-related disease burden in terms of scale. Due to noise from roads, trains, and airports, one in three persons is annoyed during the day and one in five has sleep disturbances at night.
Noise exposure may have both a direct and an indirect impact on one's physical health. In extreme circumstances, loud noises might really harm your hearing. In addition to severely harming human health, this excessive noise prevents individuals from going about their everyday lives at home, at work, at school, and in their free time. Chronic exposure to environmental noise has a considerable negative impact on both physical and mental health.
The most common source of environmental noise and the main factor in the overall negative impact of noise on health is road traffic noise. The most popular technique for noise reduction, if noise mitigation is determined to be practical and appropriate, is the application of noise barriers. However, out of the several technologies available to road authorities, the application of noise-reducing pavements is not only the most cost-effective but also can be implemented on short notice.
Keywords: noise, health, annoyance, traffic

1 Introduction

Long-standing research has shown that noise pollution has harmful consequences on human health. Environmental noise is becoming a significant problem in most nations. Numerous surveys led to the conclusion that the main source of stress for city dwellers is noise from traffic. The quality of life in cities is significantly threatened by traffic noise, and non-urban regions are increasingly being engulfed by this pollution as well.

The roots of noise problems can be traced back thousands of years to ancient civilizations like the Roman empire (1). Julius Caesar himself is often said to have laid the foundation for many modern laws regarding the governing of noise pollution as early as 49 BC.

The spread of undesired noises into the environment is known as noise pollution. We are nearly constantly surrounded by noise, whether it is created naturally by things like birdsong or artificially by things like traffic. The health of people, however, can be significantly impacted by noise accumulation.

Environmental noise causes an illness burden in Europe that is second only to the air pollution-related disease burden in terms of scale. Due to noise from roads, trains, and airports, one in three persons is irritated during the day and one in five has sleep disturbances at night.

More than 100 million individuals in Europe were exposed to hazardous levels of environmental noise in 2020, according to a research from the European Environment Agency (2). Long-term exposure to environmental noise causes 12,000 premature deaths and 48,000 new instances of heart disease each year in Europe. In addition, 6.5 million individuals have chronic high sleep disturbance, and 22 million people experience chronic high annoyance.

Road traffic noise in particular is a public health problem in many urban areas. Noise is clearly a contributing factor in a large-scale health epidemic and therefore legislation is increasingly being introduced and adapted to combat noise pollution.

This paper presents a short overview of some physical and physiological aspects of noise and hearing and the various hazardous impacts that excessive noise can have on our health. Furthermore, some measures are described to reduce traffic noise.

2 Sound Versus Noise

2.1 What is Sound?

From a physics perspective, sound is small but fast change in air pressure that cycles around the air pressure that is all around us (3). The human hearing system is a marvel in converting these air pressure changes into a human response. It begins with a vibration of the eardrum because of the pressure changes.

According to physics, sound is the result of fast, small changes in air pressure that oscillate around the ambient air pressure (3). The technical ability of the human hearing system to translate these variations in air pressure into a neural response is quite amazing.

The *middle ear* functions to connect the sound waves from the external environment. First, because of the pressure fluctuations, the eardrum starts to vibrate (resonate). The auditory ossicles (malleus, incus, and stapes) play a key role in this function. The malleus connects to the tympanic membrane transferring auditory oscillations to the incus and then the stapes.

The stapes connects to the oval window allowing for mechanical energy to be transferred to the fluid-filled *inner ear*. It is often believed that the physics function of the three auditory ossicles is an amplification of the sound. However, this is not completely true since the amplification factor is about 3 (or 5 dB) which is significantly less than the hearing loss of 25 dB or more due to malfunctioning of the auditory ossicles.

The basilar membrane, which possesses tiny, sensitive nerve endings, receives vibrations from the inner ear and transforms them into what the auditory cortex interprets as sound (4).

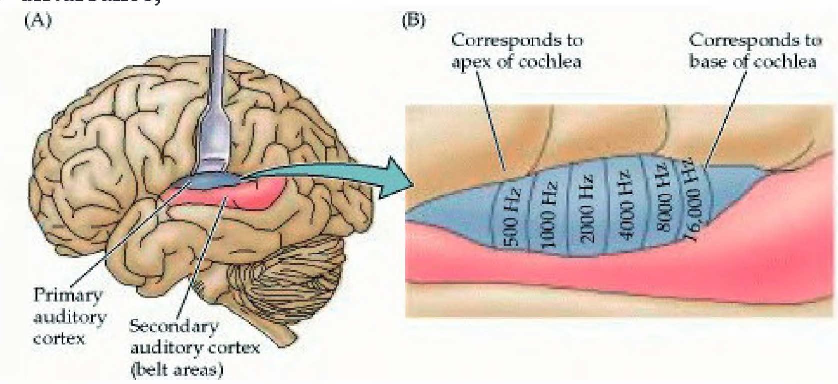

Figure1. The human auditory cortex.

Our hearing system can detect a broad range of pressure variations. Pascal (Pa) is the standard unit of pressure. Most young persons have a hearing threshold of 0.00002 Pa.

Most mammals have two ears. This enables them to use binaural hearing. Binaural hearing is essential for directional hearing but also for noise suppression (5).

2.1.1 Decibel

We can characterise our hearing as being non-linear. It sounds similar to hearing something change from 0.1 to 1 Pa (an increase of 0.9 Pa), or from 1 Pa to 10 Pa (an increase of 9 Pa). Furthermore, a sound at 2 Pa does not sound twice as loud as one at 1 Pa. Therefore, the sound pressure is transformed into sound pressure level as a measure of strength of sound. More specifically, the sound pressure in Pa is converted into decibels (dB), which closely corresponds to human experience.

2.2 What is Noise?

Noise is defined as objectionable sound. As such, what is noise to one person may not be so to another. The temporal and frequency characteristics of a certain sound, as well as the individual's notion of noise, all influence how people react to it.

Noise measurements and calculations are frequently presented after being filtered using a weighting technique to make this easier to understand. Weighting is performed to modify the levels at the various frequencies in accordance with how an average listener perceives them. There are four widely used weighting techniques to do this, with the A-weighting scheme being the most used in measures of noise, as shown in Figure 3. As humans are most sensitive in this range, frequencies between 1,000 and 4,000 Hz are given the most weight in this situation. Outside of this range, levels are attenuated (lowered).

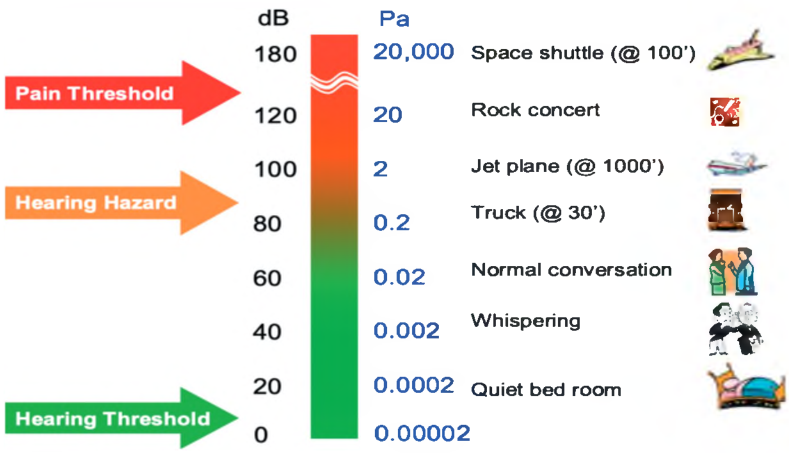

Figure 2. Some sound levels of familiar sources.

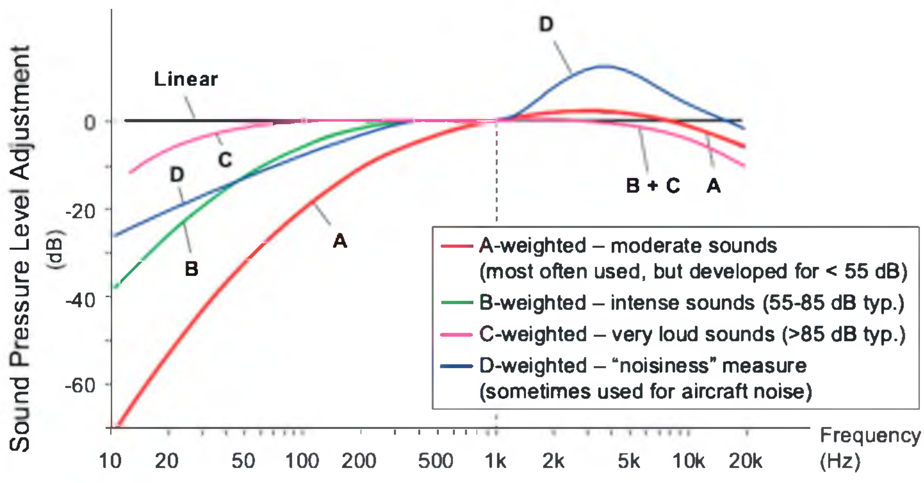

Figure 3. Weighting functions of sound spectra

3 Health Effects

The scientific community only recently understood that investigations of the health effects of long-term noise exposure should take a wider range of sound exposure aspects into account (6). These characteristics include its impulsivity, frequency distribution, and psychoacoustics factors, as well as its intensity change over time. Peak levels, maximum levels, and fluctuation may significantly affect how people perceive a nuisance, and it is well-known that people complain more about isolated high levels than they do about average exposure.

This may be even more crucial for sources other than those associated with traffic, such as noise from recreational activities or less-studied sound sources like ships or wind turbines. Due to the role of noise at the population level, problems in dose-effect correlations for irritability or sleep disturbance outcomes are typically the result of an erroneous measure.

3.1 Impact on Physical Health

Noise exposure may have both a direct and an indirect impact on one's physical health. In extreme circumstances, loud noises might really harm your hearing. In addition to gravely harming human health, this excessive noise prevents individuals from going about their everyday lives at home, at work, at school, and in their free time. Chronic exposure to ambient noise has a considerable negative impact on both physical and mental health. Environmental noise may result in sleep disorders, cardiovascular effect, cognitive effects, and hearing problems.

There is, however, surprisingly little evidence for additional impacts such immune system alterations and birth abnormalities.

3.2 Sleep Disorders

Sleep is crucial for maintaining health and for healing both physically and emotionally. A person must receive enough sleep that is uninterrupted to experience its restorative effects. Environmental noise is frequent contributor to sleep disruption. Figure 4 depicts the expected number of persons per 100,000 in the EEA nations who report having their sleep highly disturbed or highly irritated by noise from air, train, and road traffic (7).

The following two categories of sleep disturbances are widely known:

1. Immediate effects
2. Next-day effects

3.2.1 The Immediate Effects of Noise on Sleep

The body responds whenever there is a disturbance while asleep, especially noise that comes from a vehicle. Many body systems are impacted. For example, the heart beats more quickly, blood pressure increases, and blood vessel constriction occurs. Even after many years, the body never adjusts to nocturnal sounds. Thus, these reactions are repeated every night. However, the *sensation* of poor sleep might eventually go away.

A person may have trouble falling asleep, inability to stay asleep, or may wake up too early.

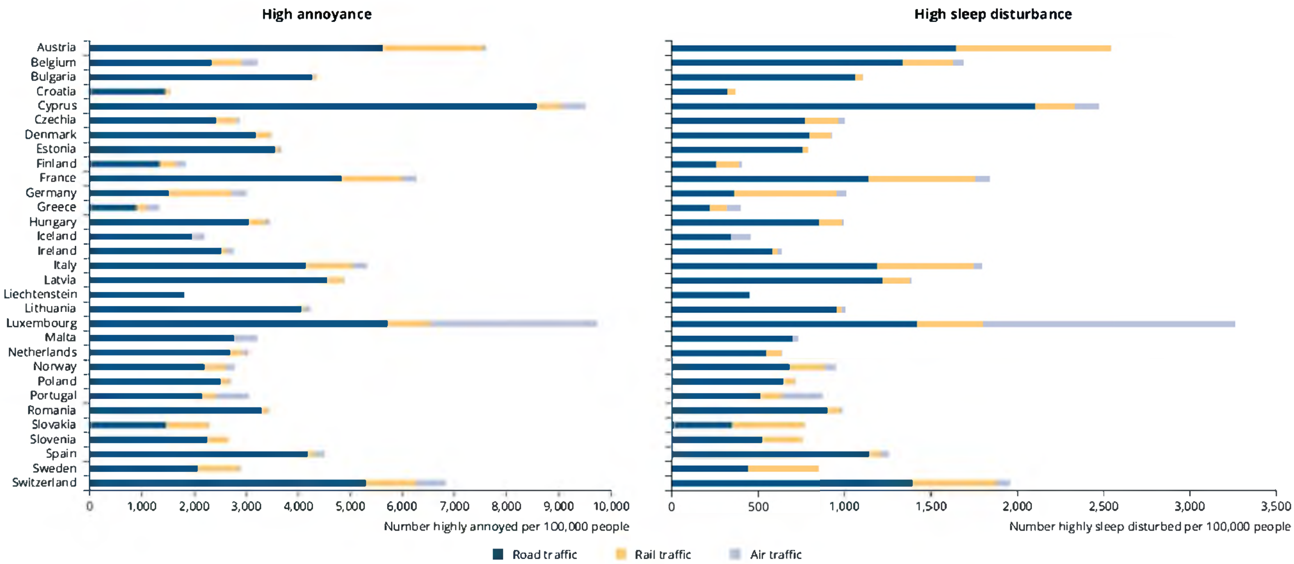

Figure 4. Estimated number of people annoyed and sleep highly disturbed by noise.

3.2.2 The Next-Day Effects of Noise

The impact of noise on sleep may be felt the following day. For instance, one may:

- Feel that they slept badly.
- Feel sleepy.
- Feel more tired.
- Feel the need to rest to make up for the lack of sleep or to fight fatigue.
- Feel less motivated.
- Feel less focused.
- Be less productive.
- Feel depressed.

Additionally, noises can influence the quantity of rapid eye movement sleep by lowering the depth and quality of sleep. A person's mood and capacity for concentration may be affected by this.

3.3 Cardiovascular Effects

Stress is a result of noise. It causes bodily responses, such as the release of chemicals like cortisol and adrenaline. After many years of noise exposure, these responses are what cause heart and circulatory problems to appear.

There is ample scientific proof that noise has negative (long-term) consequences, such as a higher risk of hypertension in adults who are often exposed to airplane and road traffic noise, as well as a higher risk of heart attack. Both systolic and diastolic blood pressure are significantly increased by environmental noise. Both acute and persistent effects (lag time > 30-60 min) are highly correlated with an increase of 5 dB(A), notably in females (8). As a result of traffic noise, those with prevalent chronic diseases have a somewhat increased chance of developing cardiac disorders than people without such conditions (9).

3.4 Cognitive Effects

The effects of noise on children, particularly cognitive impairments, and their reversibility, are a top priority research topic. In both developed and underdeveloped parts of the world, noise exposure is rising, especially in the general living environment. This suggests that noise exposure will continue to be a significant public health issue in the twenty-first century. Studies on noise-induced hearing loss in children are scarce, nevertheless.

Noise levels at home strongly correlate with school noise-levels from airplanes. Children who are exposed to airplane noise during the daytime at levels of 50 dB(A) or higher may have learning issues. Reading comprehension and mathematical reasoning are unaffected by road traffic noise, but reading speed and fundamental math skills are harmed. No task was affected negatively by irrelevant discourse (10). Male adolescents job performance is significantly impacted by noise (11).

Children can have hearing impacts from noise, but these effects are often cumulative and long-lasting (12). According to the current data, children are more susceptible to the cognitive consequences of noise than adults are to annoyance (13).

Children may find it difficult to study if there is unwanted or excessive noise at school or at home. They could have more trouble with concentration, communication and speech development, and cognitive performance. This could have an impact on a child's behaviour, interpersonal skills, and self-assurance.

Children from noisy classrooms and quiet homes had higher blood pressure than children from both peaceful surroundings, according to studies conducted in Serbia (14) on schoolchildren and young children. Children are especially susceptible to hearing loss brought on by noise (15). Children who are chronically exposed to noise for eight hours a day may develop irreversible hearing abnormalities, including the inability to detect specific frequencies.

There is no evidence to support the claim that elderly people are more sensitive to noise in terms of discomfort and disruption of sleep. There is no proof that adults over 60 react to ambient noise differently. However, it is possible that older people are more susceptible to cardiovascular problems, which may be a result of both air pollution and noise.

3.5 Hearing Problems

Hearing in people refers to the capacity of the auditory system to perceive sounds. The auditory system is active every single day. Ears are unprotected, as opposed to eyes, which have eyelids. As a result, ears are constantly awake, never at rest, and vulnerable to harm.

3.5.1 Hearing Loss

As mentioned before, hearing-loss risk and noise exposure are associated with one another. Hearing loss can result from actions like prolonged high-volume music listening and frequenting locations where audio is amplified. Young individuals who listen to music on portable audio players for more than an hour each day at a loud volume of 90 dB(A) or more are at risk of hearing impairment in the range of 5 to 10%.

When a person with hearing loss finds it difficult to communicate in everyday contexts, such as when there is background noise, it is seen to be a disability. Such a challenge has a big impact on how well the individual lives day to day. Due to the lack of binaural unmasking, it can already happen when just one ear is affected (5).

If the exposure is prolonged, the hearing loss worsens. Even after the exposure to noise has ended, negative consequences could still exist. In most cases, damage to the auditory nerve system or inner ear is irreversible.

The inner ear (cochlea; see Ch. 2.1) is particularly vulnerable to damage from loud noise. The cochlea's cells and membranes can be harmed by loud noise. Long-term exposure to high noise can overwork ear hair cells, which can lead to cell death (see Figure 5).

Irritability, exhaustion, and occasionally even clinical depression are side effects of tinnitus. In addition to noise, additional factors such as neurological impairment, ear infections, and nasal allergies can also contribute to tinnitus.

'Subjective' tinnitus is what we refer to when someone can typically only hear the tinnitus themselves. Surgery or medication are seldom effective treatments for this subjective tinnitus. However, the complaints can be diminished by changing the focus of the noises, for instance, to other sounds. Other people may occasionally be able to hear the tinnitus. In that situation, we use the term "objective" tinnitus.

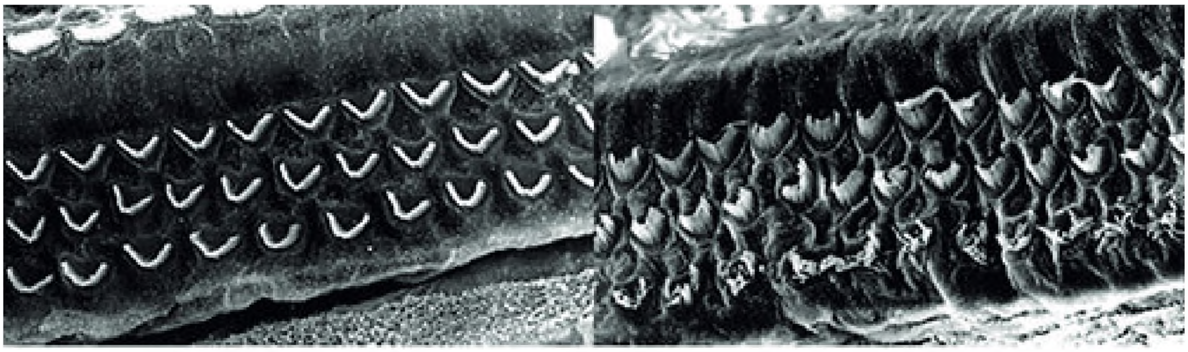

Figure 5. Normal and damaged hair cells in the cochlea.

3.5.2 Temporary Hearing Loss and Auditory Fatigue

Auditory fatigue is the temporary loss of hearing that occurs after being exposed to sound. Temporary threshold shift (TTS), a term used to describe the momentary displacement of the hearing threshold, is the outcome. If not enough recovery time is given before further sound exposure, the damage may become irreversible leading to a permanent threshold shift (PTS). The effects of temporary hearing loss are like those of permanent hearing loss, with the exception that temporary hearing loss can be reversed. A substantial amount of time—which can range from a few hours to a day—must be spent in a calm setting for one to recover from temporary hearing loss.

3.5.3 Tinnitus

Tinnitus frequently accompanies hearing loss brought on by noise. The sound of tinnitus is frequently characterized as ringing, although it can also be click, buzz, hiss, or roar. It may be low- or high-pitched, gentle, or loud, and appear to originate in one or both ears and even from the skull itself. It could make a constant sound or intermittent noises. These noises are heard by a person without being created by an outside source. Exposure to loud music or other sources of high noise might cause tinnitus. Tinnitus can also be brought on by loud or unexpected noises like an explosion or gunfire.

3.5.4 Hyperacusis

An extraordinary sensitivity to sounds is a defining feature of the hyperacusis condition. Even sounds that are often considered to be mildly loud or normal may induce discomfort or agony in those with hyperacusis. Hyperacusis and hearing loss are two distinct but related conditions. Tinnitus and hyperacusis are often paired. Noise-induced hearing loss is only one of the many variables that can contribute to hyperacusis.

The cochlea is a loop-back mechanism that enhances the excitation patterns of the basilar membrane from a physics perspective. This enhancement makes it possible for us to understand speech. However, if a loopback component is damaged, the system becomes unstable and starts to oscillate which may result in tinnitus and/or hyperacusis.

4 World Health Organization

4.1 DALY

Disability-Adjusted Life Year is referred to as DALY. It is a metric used in epidemiology and public health to determine the total cost of sickness and damage to a community. Years of life lost (YLL) and years lived with disability (YLD) are combined to form the DALY.

Years of life lost (YLL) is a measurement of the number of years that could have been lived but were instead lost to early death. It accounts for the discrepancy between the age at which someone passes away and the average life expectancy. Years lived with disability (YLD) counts the number of years a person has had a health issue or handicap. It accounts for the severity and length of the illness or impairment.

The DALY offers a single statistic to evaluate the total health effect of a certain illness, condition, or accident by fusing YLL and YLD. It enables comparisons between various health issues and decision-makers in allocating resources and prioritizing solutions based on the burden of disease. To inform public health policies and treatments, the DALY is frequently employed in cost-effectiveness evaluations, health impact assessments, and disease burden studies. It offers a thorough assessment of a population's health state, considering both mortality and morbidity.

Table 1 shows statistics on the number of persons who are thought to be severely annoyed and highly sleep disturbed by road, rail, and aviation noise. Additionally, it provides data on the expected yearly incidence of IHD cases and premature deaths. The Burden of Disease (BoD) in DALYs is calculated using all the table's information.

Table 1. number of people estimated to be highly annoyed and highly sleep disturbed due to noise from road, railway and aircraft.

	Highly annoyed	Highly sleep disturbed	Ischaemic heart disease	Premature mortality	DALYs
Road traffic	14,400,000	3,700,000	33,600	8,900	300,000-700,000
Rail traffic	3,100,000	1,600,000	5,600	1,500	77,000-200,000
Air traffic	900,000	200,000	600	200	15,100-35,800

In the western portion of Europe, noise pollution from traffic contributes to the loss of at least one million healthy life years per year. The major burden of ambient noise is sleep disturbance and annoyance, which are mostly connected to traffic noise (13).

Due to the various noise-mapping methodologies used, it is challenging to compare the number of people per 100,000 who are severely irritated and severely sleep-disturbed by noise from road, rail, and air traffic. This is especially true in urban areas, where some nations map all streets while others only map the busiest streets. However, a significant section of the populace in most European nations has adverse health impacts because of noise. In contrast to train traffic, which is particularly significant at night in nations with extensive railway networks and contributes to sleep disruption, road traffic is the key factor in countries with high levels of discomfort due to noise.

4.2 END

For municipal governments, the Environmental Noise Directive (END) is the most crucial tool for calculating the levels of noise pollution (16). The Directive attempts to evaluate the impact of measures and has the potential to highlight the effects of substitute measures. The Directive encourages Member States to work to decrease the harmful consequences of environmental noise. According to the Environmental Noise Directive:

- Using standardized noise indicators, create strategic noise maps for all important highways, railroads, airports, and metropolitan areas.
- Calculate the number of persons exposed to particular transportation noise sources inside and outside of metropolitan regions, as well as at sizable industrial facilities inside of urban areas.
- Adopt action plans based on the findings of noise mapping to assist in preventing and reducing environmental noise, particularly in places where exposure levels have an impact on human health.
- To conserve the European soundscape, choose and preserve "quiet" regions.

In addition to irritation and sleep disruption, cardiovascular problems, and the cognitive impact on children (comprehensive reading impairment), health implications are also discussed (17). The real DALY calculations, which are limited to the number of persons who suffer negative effects from noise, are described using the example of sleep disturbance.

4.3 Vulnerable Groups

Environmental noise vulnerability has been understudied, underrepresented in research populations generally, and the evidence of differential impacts is still mostly anecdotal. Therefore, there are not many studies that provide explicit comparisons between the general population and the possibly sensitive groups and quantify these variations in terms of noise levels, which is in part why there are not many evident consequences.

Future epidemiological noise research will need to concentrate on vulnerable groups; some noise exposures may be worse for particular subgroups than for others, such as children, older people, and lower socioeconomic groups, according to a recent WHO guideline (13) on the burden of disease from environmental noise. Based on the facts currently available, it is not yet possible to set precise limit levels to protect vulnerable populations.

5 Focus on Traffic Noise

The most common source of ambient noise and the main factor in the overall negative impact of noise on health is road traffic noise. People who reside in metropolitan regions with more than 100,000 inhabitants are disproportionately strongly irritated and sleep-disturbed by traffic noise. In the western nations of the European Region, traffic-related noise accounts for more than 1 million healthy years of life lost each year to illness, disability, or early death.

5.1 Traffic Noise

Although the distinction between sound and noise was previously made very apparent, the sound produced by vehicles is typically referred to as traffic *noise*. It covers the combination of all potential noise sources on a vehicle and encompasses all sound that is experienced because of traffic moving along a road or street.

5.2 Noise Barriers

The most popular choice for noise reduction are noise barriers if it is determined that its application is practical and appropriate. These frequently take the shape of earthen berms and/or sound barriers. Since the barrier will lower noise if the line of sight between the source and the receiver is not disrupted, the height of the barrier is, therefore, very important. Since most of the sound is produced near to the ground, most barriers are very effective.

A noise barrier's efficiency depends strongly on its shape. For instance, there is often a 5 to 10 dB reduction in sound levels immediately behind a barrier. But at 100 to 150 m away from the barrier, it works less effectively. A so-called "shadow effect" may happen, which means that part of the traffic noise will "bend" due to diffraction around the top of the barrier. However, at this distance, neighbourhood background noise may start to become dominant since the traffic noise levels will be reduced by sound propagation (distance). It is obvious that if there are any breaches in a barrier, such as driveway access, it will lose some of its noise reducing effect.

5.3 Low noise Pavements

Low noise technology must be widely used due to how loud traffic is. The use of noise-reducing pavements is not only the most economically advantageous technology accessible to road authorities, but it can also be put into place quickly. These benefits have prompted the creation and use of several noise-reducing pavements. Due to ongoing research and optimization, noise-reducing pavements are among the most efficient ways to reduce traffic noise, and in the next years, significant advancements in both the overall reduction and the application range of the decreasing impact are to be expected.

One of the most important contributors to traffic noise comes from tire and road surface contact (18). The Acoustical Optimization Tool (AOT), a traffic noise prediction model, as well as the tire/road noise model play a significant role in assisting in the design and development of low-noise pavements or tires. A contractor can create or improve durable low-noise pavements using such a model.

A parameter model, based on mathematics from the Disturbing Theory in Quantum Physics, has been created with the goal of constructing the tire/road noise model, which must be precise, straightforward, and material-related (19). With the aid of this approach, many new mixes with a lifespan of more than 15 years have been created.

5.4 Situation in Serbia

The steady growth of traffic in Serbia due to the growth of the economy will lead to more nuisances in the form of noise. At present, the situation in Serbia and Belgrade already is very bad according to a preliminary study. This shall be even worse soon if no short-term measures are applied. The noise problem will create significant problems for human health and the environment. Among the most effective and efficient ways to reduce traffic noise, low-noise pavements and noise barriers (20).

As a result, Serbia will implement low-noise roads widely at affordable rates using local labour and resources. According to EU standards, Serbian environmental protection standards (Sl. G. RS br. 66/91, 83/92, 53/93, 67/93, 48/94, and 53/95), the Code book for Allowed Level of noise in Urban Environment (Sl. G. RS br. 54/92), ISO 2264, ISO 1996, and ISO 140, the negative environmental effects of developing infrastructure will thus be significantly reduced.

6 Conclusions

Numerous research clearly showed that noise can pose a serious threat to our health and well-being. Not only the hazardous effects can be very drastic, the scale at which these effects occur is also enormous. Noise pollution is a serious danger to public health. It is, therefore, important to pay much more attention to various forms of noise protection. This protection varies from small-scale measures (like headphone limiters) to large-scale measures (noise barriers near motorways).

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