LONG-TERM TRENDS IN ROAD TRAFFIC NOISE EXPOSURE AND ANNOYANCE IN A MODEL REGION

[a)] Lubica Argalasova,, Alexandra Filova, Katarina Hirosova, Martin Samohyl, Jana Babjakova, Jana Jurkovicova

[a)] Institute of Hygiene, Faculty of Medicine, Comenius University, Bratislava, Slovakia
lubica.argalasova@fmed.uniba.sk

Abstract: Environmental noise, particularly road traffic noise, has been considered one of the most widespread environmental pollutants. The primary aim of this study was a 30-year longitudinal investigation of road traffic noise annoyance trends in a model region - Bratislava's continuously monitored neighbourhoods, with data collected at 10-year intervals. Using validated methods to assess noise annoyance and psychosocial well-being, along with direct sound level measurements, the study analysed responses from 3 197 university students residing in exposed and control areas. Results showed a significant rise in traffic noise burden in exposed areas from 1989 to 1999 (L_{Aeq} = 67.5 dB), a slight decrease by 2019 (L_{Aeq} = 63.9 dB), and further reduction during lockdowns (L_{Aeq} = 62.5 dB). At the control site, noise levels significantly decreased from L_{Aeq} = 50.2 dB in 2019 to L_{Aeq} = 46 dB in 2020. Road traffic noise annoyance initially rose sharply, with ORMH values increasing from 2.56 to 6.01 over the first 10-year interval, gradually declining to ORMH 3.26 by 2023. Despite this trend, road traffic noise annoyance remains a concern, highlighting the need for preventive measures and healthier urban transport solutions.

Keywords: Environmental noise, Noise annoyance trends, Road traffic noise, University students, Bratislava region

1. INTRODUCTION

For a long time, the negative effects of noise on human health and development were underestimated. This could be because noise indirectly endangers human health, unlike other hazardous substances in the workplace or environment. However, noise is ubiquitous in daily life and can have both auditory and non-auditory health consequences [1-3].

Environmental noise was once referred to as the "forgotten pollutant," but it is now acknowledged as a problem for the environment and public health that must be resolved in contemporary society [1-4].

Road, rail, and air traffic, as well as construction sites, are significant sources of environmental noise exposure [2, 3, 5].

Excessive noise can annoy; however, research shows that it increases the risk of IHD and hypertension, as well as sleep disturbance, hearing impairment, tinnitus, and cognitive impairment, with growing evidence for other health effects such as adverse birth outcomes and mental health problems [1-5]. For many years, road traffic noise has been a major source of discomfort in Europe. The annoyance of road traffic noise has changed over time due to a variety of factors, including public awareness, transportation policies, urbanization, and technological improvements [4, 5].

According to the most recent data, the entire population exposed to average sound levels of 55 dB or more during the day, evening, and night is estimated to be 113 million for road traffic noise, 22 million for railway noise, 4 million for aircraft noise, and fewer than 1 million for industry noise [2, 3]. Similarly, road traffic is by far the biggest source of environmental noise during night-time, followed by railway, air, and industrial noise, respectively. These results indicate that at least 20 % of Europeans are exposed to long-term average day-evening-night noise levels of 55 dB or more and more than 15 % to night-time noise levels of 50 dB or more [2-4]. It is estimated that at least 18 million people are highly annoyed and 5 million are highly sleep disturbed by long-term exposure to noise from transport in the EU. In addition, it is estimated that long-term exposure to transport noise causes about 11 000 premature deaths and 40 000 new cases of ischaemic heart disease [2-4].

According to the World Health Organization (WHO), at least 1 million healthy life years (disability-adjusted life-years) are lost each year in high-income European countries (population of roughly 340 million people) due to ambient noise [4, 5]. Road traffic noise can contribute to the disease burden by impacting health in various ways, including sleep disturbance, cardiovascular effects, mental health impacts, and hearing damage [1-6].

In Slovakia, the rapid increase in traffic density associated with the country's economic transformation since 1989 has resulted in new environmental noise problems, particularly road traffic noise [7]. This study investigates long-term trends in noise annoyance within Bratislava using decade-long intervals (10, 20, and 30 years) incorporating the potential influence of COVID-19.

2. METHODS

At the Institute of Hygiene Faculty of Medicine Comenius University in Bratislava we have been dealing with the issue of environmental noise exposure and health risk assessment using the knowledge and methods of environmental epidemiology for several decades [7, 8].

This study analyses the trends in noise load over time for some population groups in the exposed and control areas in the Bratislava agglomeration (10, 20, and 30 years). Along with the general level of discomfort caused by various environmental noise sources, we also monitor disorder and interference with various daytime, evening, and nighttime activities. In the studies, we used risk quantification using a validated methodology of subjective assessment of "annoyance" and psychosocial well-being, as well as an objectification method by direct measurement of sound levels utilizing a sound analyser with a frequency analysis module.

The subjective evaluation of "annoyance" and psychosocial well-being, as well as the objectification of noise levels by direct measurement method utilizing a sound level analyser with a module for frequency analysis, were done using the validated methodology. Bivariate and stratified analyses have established the basis for statistical and epidemiological analyses.

The first monitored period was the period from 1989 to 1999. It was the most sensitive period when sharp political, social, and economic changes took place in the state with an impact on transport and its management.

2. 1. Exposure

For a long time, we have used the same standard measuring techniques to monitor equivalent noise levels (L_{Aeq}) at the exposed and control sites in Bratislava at various time intervals [7, 8].

During the regular working week in spring and autumn, two separate measurements were taken in both the exposed and control areas. During the day (6.00-12.00), afternoon (12.00-18.00), evening (18.00-22.00), and night (22.00-6.00), all measurements were taken following the applicable legislation. Each measurement was taken at a 15-minute interval. Measuring stations were placed two meters away from the building facades. The average equivalent noise levels ($L_{Aeq,24h}$) for exposed and control areas were calculated and compared.

Based on our measurements and strategic noise maps L_{DEN} (day-evening-night noise indicator), we determined the exposed location to be the place of a major university dormitory [9].

Throughout the day, this location is highly exposed to traffic noise from both road and rail traffic (trams). The control site is located in another university dormitory in a quiet pedestrian zone. The goal of these measurements and estimations was to reasonably categorize the subjects based on levels of noise exposure for epidemiological research.

2. 2. Subjective response – questionnaire

A validated noise annoyance questionnaire administered in person and modified over 10, 20, and 30 years was used to assess the subjective response [7, 8]. It included questions on noise annoyance from various sources, interference with various activities, and sleep disturbance, in addition to the demographic (age, gender, education, occupation, nationality) and behavioural (smoking, coffee, and alcohol consumption) and housing characteristics (building construction and type of residence). The questionnaire also included window orientation to quiet or noisy streets, flat location, and length of stay in a dormitory (at least four years in the same place).

For the years 1989 through 1999, we used a three-graded scale (Not at all annoys; Moderately annoys; Annoys) and for the years 2000 through 2022, we used a five-grade verbal scale (Not at all; Slightly; Moderately; Very; Extremely), developed and advised by experts from the ICBEN (The International Commission on the Biological Effects of Noise). However, for statistical purposes, the results had to be dichotomized (Not at all+Slightly; Moderately+Very+Extremely or trichotomized (Not at all+Slightly; Moderately, Very+Extremely). We also focused on the situation during the global COVID-19 pandemic. The questionnaire was administered in person, except the COVID-19 period. At that time the questionnaire was administered online using the Google Forms application [7, 8, 10].

2. 3. Samples

The study population consisted of medical students from Comenius University, forming a homogenous group of young, healthy individuals with similar ages, educational backgrounds, and lifestyles. The response rate was 90 %, and participation was limited to students living in Bratislava. Table 1 presents the number of respondents from both exposed and control areas across 10, 20, and 30-year intervals, as well as during the COVID-19 pandemic (2020–2021) and in 2022, following the pandemic. There were no significant differences between the exposed and control groups in terms of age, gender, education, health, or lifestyle; however, they varied in terms of residence location (quiet vs. noisy area), flat position, window orientation, satisfaction with their surroundings, and levels of noise annoyance.

Year	Exposed group (n/%)	Control group (n/%)	Total
1989	166/31	374/69	540
1999	374/44	483/56	857
2009	280/42	379/58	659
2019	87/31	195/69	282
2020-2021	78/37	132/63	210
2022-2023	199/37	340/63	539
Total	1 294/40	1 903/60	3 197

Tab. 1: Number of respondents during the years 1989 – 2023 (n = 3 197)

2. 4. Statistical analysis

To calculate community noise annoyance risks from various sources and the risks of interference with road traffic noise, bivariate and stratified analyses (presented as crude odds ratios, and Mantel-Haenszel weighted odds ratios) were applied. When the variables (Road traffic noise interference and annoyance) were trichotomized (Not at all+Slightly; Moderately, Very+Extremely), the Mantel-Haenszel weighted odds ratio was used in stratification analysis.

The risks were followed at time intervals of 10, 20, and 30 years and the time trends were assessed. Major analytical tools were Epi Info™, different versions during decades, the latest version EPI-INFO 7.2.5.21, and IBM SPSS Statistics 25.0 (International Business Machines Corp., New Orchard Road, Armonk, NY, USA).

3. RESULTS

Traffic noise in the exposed area steadily increased over 10, 15, and 20 years, exceeding the health risk zone of 60 dB (L_{Aeq}). The highest levels (67.5 dB L_{Aeq}) likely occurred between 1999 and 2009 [8]. (Fig 1).

There was a slight decrease after 2014 when the measured values fell to L_{Aeq} = 65.7 dB and in 2019 to L_{Aeq} = 63.9 dB [7]. In 2020, during lockdown due to the COVID-19 pandemic, they dropped to L_{Aeq} = 62.5 dB. However, they still reach higher values than allowed in residential areas and around school facilities. We observed a more significant decrease in environmental noise levels at the control site, where the noise level from L_{Aeq} = 58.7 dB in 1999 dropped to L_{Aeq} = 50.2 dB in 2019 and L_{Aeq} = 46 dB in 2020. The difference between the exposed and control locations was significant in each monitoring period ($p < 0.001$). In 2023, after the COVID-19 pandemic, the measured values increased in the exposed and the control locations by 1 dB (Fig. 1)

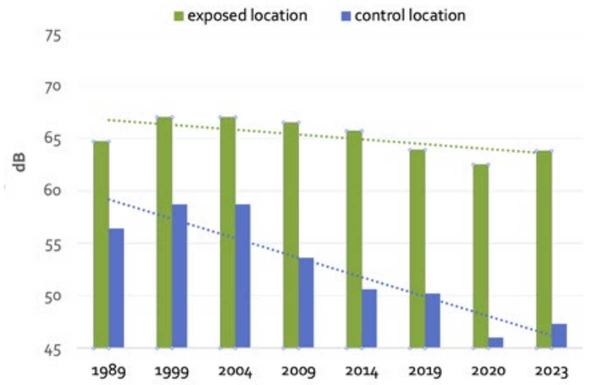

Fig. 1: The development of noise levels in the observed areas during 1989-2023

Road traffic noise emerged as the dominant source of annoyance in the exposed area, followed by noise from entertainment facilities. Residents reported a significant increase in road traffic noise annoyance over a decade (OR_{MH}: 2.56 in 1989 to 6.01 in 1999, 95 % CI [1.93-3.42, 4.97-7.95]. Annoyance from trams (OR_{MH}: 3.05, 95 % CI [1.93-4.82] in 2019) and neighbourhood noise (OR_{MH}: 2.81, 95 % CI [2.12-3.74] in 2023) also showed upward trends, with entertainment facilities reaching their peak annoyance level in 2023 (OR_{MH}: 4.31, 95 % CI [3.25-5.72]). Traffic noise annoyance risks showed a slight decrease between 2020-2021 (OR_{MH}: 4.37, 95 % CI [2.98—6.40] and 2023 (OR_{MH}: 3.26, 95 % CI [2.19—4.90], but remains a concern (Tab. 2).

4. DISCUSSION

In our study, during and after the COVID-19 pandemic, the risks of road traffic noise annoyance decreased. Noise levels in the exposed location dropped by 2 dB and in the control location by 5 dB and increased by 1 dB during the year 2023 after the pandemic. However, an important issue after the COVID-19 pandemic has been the noise from entertainment facilities and noise from neighbourhoods, which can be possibly related to the decrease in road traffic noise annoyance risk after the COVID-19 pandemic.

The German researchers analysed the effect of lockdown due to the COVID-19 pan-

Noise annoyance risks Year	Source of noise OR_{MH} (95 % CI)			
	Road traffic	Neighbourhood	Entertainment facilities	Railway
1989	2.56 (1.93-3.42)***	1.71 (1.29-2.27)***	1.51 (0.90-2.52)	0.56 (0.31-0.98)*
1999	6.01 (4.97-7.95)***	2.43 (1.99-3.03)***	3.90 (3.19-5.46)***	2.06 (1.58-2.71)**
2009	5.41 (4.28-7.25)***	2.48 (1.99-3.19)***	2.27 (1.76-2.98)***	1.41 (1.04-1.92)*
2019	5.41 (3.56-8.36)***	1.69 (1.16-2.47)**	3.45 (2.32-5.13)***	3.05 (1.93-4.82)***
2020-2021	4.37 (2.98-6.40)***	1.74 (1.24 - 2.44)**	2.89 (1.99-4.21)***	1.48 (0.99-2.21)*
2023	3.26 (2.19-4.90)***	2.81 (2.12-3.74)***	4.31 (3.25-5.72)***	2.88 (2.16-3.84)***

Tab. 2: The development of noise levels in the observed areas during 1989-2023

Legend: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ CI = confidence interval; OR_{MH} = Mantel-Haenszel weighted odds ratio.

demic on noise levels in the city of Bochum (365 000 inhabitants), similar to Bratislava, located in the densely populated and highly trafficked metropolitan Ruhr Area. They observed a significant reduction in levels in all territories, but the weakest decrease of 3.9 dB from 68.4 dB to 64.5 was found on the main street, compared to the strongest reduction in the formerly quite green urban area [11]. In the French study, a significant decrease in sound levels was observed at all the monitoring stations during lockdown. Reductions from 4 dB to 6 dB (L_{den}) were observed for monitoring stations with highly dominant road traffic noise. In addition to the effect noted in terms of sound levels, the structure of the city's soundscape has been significantly changed, and the order of sound sources reversed. Deliveries, stores, terraces, conversations, and other sounds associated with human activity which were before hidden by the predominance of transport noise and other sounds were gradually fading, making space for sounds that were already present but were still barely audible [12].

The study by Kumar et al., 2022 showed a noticeable increase in noise levels in the school site, in Guildford, UK, after the reopening of schools after COVID-19. It was likely that the elevated noise exposure was due to an increase in road vehicles after loosening the restrictions. As lockdown eased, noise levels increased by up to 3 dB throughout the week, suggesting the potential for greater noise disturbance at weekends than pre-pandemic [13].

In our long-time monitoring study, we observed the highest increase in road traffic noise annoyance during the years 1989 and 1999 which could be attributed to the period of political and socio-economic transformation and the changes in traffic management in our country. Then road traffic noise annoyance risks showed a decreasing trend up to 2020-2021 (OR_{MH}=4.37 (95 % CI=2.98–6.40) and (OR_{MH}=3.26 (95 % CI=2.19–4.90) in 2023. Despite a slightly declining trend, road traffic noise annoyance is an important issue. The experience generated by the pandemic offers data for the development of healthy urban transport and the necessity of applying preventive procedures to reduce traffic noise.

5. CONCLUSION

This 30-year study investigated the link between environmental noise and annoyance, focusing on a specific situation during the COVID-19 pandemic. The first decade revealed a substantial rise in road traffic noise annoyance, potentially due to the country's development and traffic management changes. While a slight decrease in traffic noise annoyance was observed recently, it remains a significant concern. Annoyance from entertainment facilities also increased. The experience and lessons from the pandemic can guide the development of sustainable urban transport and the implementation of noise reduction strategies. Our findings highlight the need for preventive measures to minimize environmental noise exposure in residential areas.

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Lubica Argalasova

Born in 1966 in Bratislava, she graduated with honors in General Medicine from the Faculty of Medicine, Comenius University in Bratislava in 1991. She specialized in Hygiene, Epidemiology, and Public Health and has been a full professor of Hygiene (Environmental Medicine) since 2019. Since 2022, she has served as the Head of the Institute of Hygiene at the Faculty of Medicine, Comenius University (FM CU) in Bratislava. In 2023, she became President of the Slovak Society of Hygienists within the Slovak Medical Association.

She is an expert in Preventive Medicine, a reviewer, and a member of the editorial boards of international peer-reviewed journals, including Noise and Health and the International Journal of Environmental Research and Public Health (IJERPH). Her scientific research focuses on both basic and applied studies, particularly in primary prevention and risk factors related to the living and working environment. Her work includes studying the health impacts of noise as a member of the international expert network ENNAH (European Network on Noise and Health) and Team 3 of ICBEN. She specializes in risk assessment methodologies for noise exposure in various environments (environmental and occupational) and across different population groups in multiple countries, investigating both auditory and non-auditory effects of environmental, occupational, and social noise (such as exposure to personal listening devices among adolescents and young adults).

She has published 421 publications, including 67 indexed in Scopus and Web of Science (WoS), four university textbooks, two university scripts, two scientific monographs, and one professional monograph. Her research has been cited 604 times, with 420 citations indexed in Scopus and WoS.

Alexandra Filová

(b. 1988, Liptovský Mikuláš, Slovakia) earned her master's degree in Environmental Planning and Management from the Faculty of Natural Sciences, Comenius University in Bratislava in 2012. She completed her PhD in Hygiene at the Faculty of Medicine, Comenius University in Bratislava in 2017. From 2017 to 2025, she has been a researcher at the Institute of Hygiene, Faculty of Medicine, Comenius University in Bratislava. She is the author and co-author of 113 scientific publications, focusing on public health, environmental noise and its impact on health, as well as radiation and health hazards.

Katarína Hirošová

She graduated in the field of Laboratory Investigation Methods in the Healthcare and got her PhD degree in the field of Hygiene. She has been working as a teacher and researcher at the Institute of Hygiene, Faculty of Medicine, Comenius University in Bratislava since 2010. She is mainly interested in the issues of environmental factors and their impact on health, environmental noise assessment, and the prevention of cardiovascular diseases. She is the author and co-author of numerous scientific publications and university textbooks.

Martin Samohyl

graduated in Public Health from Trnava University and has been working at the Institute of Hygiene, Faculty of Medicine, Comenius University since 2013. He began as an internal PhD student and later continued as an assistant professor. In 2018, he successfully defended his dissertation on „Nutrition of Selected Population Groups and Its Association with Cardiovascular Risk."His scientific research and teaching focus on public health, quality of life, nutrition, chronic disease prevention, hygiene in healthcare facilities, and radiation protection. He actively teaches 4th-year general medicine students and 5th-year dentistry students and is a successful supervisor of final theses for general medicine students. In the Web of Science (WoS) Core Collection database, he has 44 recorded scientific articles, along with six additional articles indexed in Scopus but not listed in WoS. Among these publications, he is the first or corresponding author in 29 cases. His research findings are regularly cited and contribute significantly to the advancement of hygiene as a discipline.

Jana Babjaková

(b. 1971, Trenčín) graduated in 1995 from the Faculty of Medicine, Comenius University in Bratislava with a degree in General Medicine. She specialized in Internal Medicine and completed PhD in Public Health in 2010. For the past 20 years, she has been dedicated to Environmental Medicine, focusing on the prevention of chronic non-communicable diseases. Since 2011, she has worked as an Assistant Professor at the Institute of Hygiene, Faculty of Medicine, Comenius University in Bratislava, where she teaches international medical students. She actively participates in scientific conferences and co-organizes the Living Conditions and Health conference. Additionally, she serves as the Scientific Secretary of the Slovak Society of Hygienists under the Slovak Medical Association. She is the author and co-author of numerous scientific publications, university textbooks, and monographs.

Jana Jurkovičová

She graduated with honours in General Medicine from the Faculty of Medicine, Comenius University in Bratislava. She has been working as a teacher and researcher at the Institute of Hygiene, Faculty of Medicine, Comenius University as a professor of Public Health (since 2016). Her scientific research focuses on nutrition, primary prevention, and the epidemiology of chronic diseases, as well as the auditory and non-auditory effects of noise on children and young people and environmental noise assessment. She is the author and co-author of numerous scientific publications, university textbooks, and monographs.