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ENVIRONMENTAL RISK MANAGEMENT RELATED TO NOISE IN LARGE CITIES IN THE CONTEXT OF ECOLOGICAL SAFETY

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Marta Daroń – *orcid id: 0000-0002-5000-0573, e-mail: marta.daron@pcz.pl*
[1]Czestochowa University of Technology, **Poland**

Abstract: The aim of the study was a comparative analysis of the characteristics of Polish cities with a population of over 100,000 inhabitants, which affect the level of population exposure to noise, in the context of ecological safety. The study included an assessment of daytime (LDWN) and night-time (LN) noise levels and the identification of key urban and demographic factors such as the share of green spaces and traffic volume. The results show a significant difference in the share of people exposed to noise between cities, with the highest values recorded in Szczecin and Kraków, and the lowest in Gdańsk and Poznań. A significant relationship between the share of green spaces and noise levels has been identified, underlining the importance of spatial planning. A measure of urban development was also developed, indicating Łódź, Szczecin and Bydgoszcz as leaders of pro-ecological activities. Research confirms that the integration of spatial policy with noise management is crucial for improving the quality of life and protecting the health of residents.
Keywords: noise, spatial planning management, environmental safety, cities

1. INTRODUCTION

Noise in large cities has become one of the key challenges in environmental management, due to its negative effects on human health and the impact on the quality of life of residents. Dynamic urban development and the increase in the number of vehicles on the road contribute to constantly increasing noise levels, which poses a significant threat to ecological safety and sustainable development. The interplay between urban noise, public health and the environment requires a comprehensive approach to environmental risk management in highly urbanised areas. The problem of urban noise is of particular importance in the era of progressive urbanization and growing requirements for sustainable development. Noise management is crucial not only to protect the health of residents, but also to protect the environment and improve the quality of life in cities. The development of effective noise management strategies is therefore essential to ensure ecological safety and support sustainable urban development. Noise pollution in urban areas is primarily influenced by traffic, with road vehicles being the main contributor (Rostami and Forouhid, 2019; Barrigón Morillas et al., 2021; Chubirko et al., 2015).
The aim of this article is to conduct a comparative analysis of the characteristics of cities that affect the formation of noise levels in selected Polish cities with a population exceeding 100 thousand. The study aims to determine the key factors affecting the

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exposure of the population to noise. In particular, the study focuses on the analysis of noise levels in the context of environmental safety. The following research hypotheses were proposed:
H1 – The share of people exposed to exposure to noise levels in large cities in Poland varies significantly
H2 – it is possible to identify the characteristics of cities affecting the exceedance of the permissible noise level
H3 – On the basis of selected characteristics of cities, it is possible to indicate their measure of development in the context of shaping noise levels, and thus ecological safety.
The article uses the method of comparative analysis of data on noise exposure from different cities with more than 100 thousand inhabitants. These data were compiled on the basis of information on exceedances of permissible noise levels, both during the day (LDWN) and at night (LN). The analysis includes the calculation of descriptive statistics, the assessment of differences between cities, and the identification of urban and demographic factors affecting noise levels. In addition, a literature review discusses potential environmental risk management strategies that can be implemented to reduce noise and improve environmental safety.

2. LITERATURE REVIEW

The factors influencing the noise level are very diverse, but a review of the literature made it possible to divide them into two main groups. The first group is related to broadly understood urbanization – this includes the population of areas, the number of vehicles per 1000 inhabitants, and thus the traffic intensity (Lee, Jerrett, 2014). The second group includes factors related to a given area (spatial): its specificity, slope and land use, including the existence of the so-called green zones and the network of communication routes (Rostami and Forouhid, 2019).
City characteristics such as population, area, and total length of streets correlate significantly with noise levels, especially on busier streets (Barrigón Morillas et al., 2021). The nuisance of noise is influenced by both sound-related factors (e.g. noise level) and person-related factors (e.g. noise sensitivity) (Jakovljević et al., 2009). Some studies also indicate a dose-response relationship between the proportion of very irritated residents and noise levels during the day, evening and night (Jakovljević et al., 2009). In addition, factors that increase the risk of high noise nuisance include the orientation of the living room/bedroom towards the street, the time spent in the house, sensitivity to noise and the level of noise caused by road traffic at night (Jakovljević et al., 2009). Another major factor affecting noise levels in urban areas is traffic volume. Studies conducted in many cities have shown strong correlations between the number of vehicles and ambient noise levels (Lee et al., 2014; Kamandang et al., 2020; Zuo et al., 2014). Heavy-duty vehicles contribute significantly more to noise pollution compared to motorcycles and light-duty vehicles (Kamandang et al., 2020). Other important factors include honking, vehicle speed, and center lane width (Yadav et al., 2024). Subsequent authors explain much of the variability in urban noise by pointing to spatial characteristics such as the length of major roads and industrial areas (Zuo et al., 2014). According to these authors, temporal variability is less significant, with spatial factors accounting for about 60% of the observed noise changes (Zuo et al., 2014). Many urban areas exceed recommended noise guidelines, suggesting widespread exposure to traffic-related noise pollution (Zuo et al., 2014). In research on noise, part of the research concerns its relationship with the network

of communication routes. Studies can be identified that confirm that wider roads with more lanes tend to increase traffic demand and noise intensity, while potentially reducing noise amplitude (Lu et al., 2019). Other authors also point out that variable city sizes, including the total length of a street, as well as population and area, correlate significantly with noise levels, especially on streets with more traffic (Barrigón Morillas et al., 2021). Interestingly, one-way roads, despite the heavier traffic volumes, have been found to be quieter and less disruptive than single-lane two-way roads, likely due to lower peak noise levels (Chowdhury et al., 2015). A systematic relationship between street width and noise level decrease with distance from the source was observed, which allowed the development of simplified predictive models for the spread of street noise (Li et al., 2024; Rossi et al., 2024). On the other hand, studies on the space exposed to noise pollution confirm that commercial areas and mixed-use urban areas tend to have higher noise levels compared to residential areas (King et al., 2012; Konadath et al., 2019). Factors contributing to noise growth include the density of roads, traffic arteries, highways, bus lines, and proximity to airports (Goudreau et al., 2014). Green spaces are associated with lower noise levels (Djahed, 2020). Studies have shown that noise levels in various urban areas often exceed the recommended limits set by health organizations (King et al., 2012; Huan 2020). Land-use regression models have been developed to estimate spatial changes in urban noise levels, with factors such as the Normalised Vegetation Difference Index and transport infrastructure serving as key predictors (Goudreau et al., 2014).

With regard to population factors, however, there are studies indicating that higher population density is associated with increased exposure to noise and irritation (Salve, 2024; Patel et al., 2024). However, analysis of historical data suggests that the overall exposure of communities to ambient noise has not changed significantly over the past few decades, despite technological improvements in noise control (Schomer et al., 2011). Importantly, distribution and population density vary significantly during the day and night in metropolitan areas, affecting noise exposure patterns. Daytime exposure to higher noise levels is significantly greater than nighttime exposure due to the combined effects of diurnal changes in noise patterns and population distribution (Freire & Gomes, 2013). These findings highlight the complex relationship between population density, urban characteristics and noise pollution in large cities.

3. METHODOLOGY

The study used public data provided by the Central Statistical Office (CSO) on the exposure of the population to noise pollution. The focus was on data on the share of people exposed to noise pollution in selected large Polish cities (over 100 thousand inhabitants). At the same time, these studies analysed the LDWN noise index, which is a physical scale used to determine the level of noise in the environment, directly related to its harmful effects (Journal of Laws of 2021, item 1973) determined in accordance with the Regulation of the Minister of Climate of 30 May 2020 (Journal of Laws of 2020, item 1018):

$$L_{DWN} = 10\lg\left[\frac{12}{24} * 10^{0,1L_D} + \frac{4}{24} * 10^{0,1(L_W+5)} + \frac{8}{24} * 10^{0,1(L_N 10)}\right] \quad (1)$$

where:

LD - long-term average sound level A expressed in dB, determined during all times of the day (from 6:00 a.m. to 6:00 p.m.),

LW - long-term average sound level A expressed in dB, determined during all times of the evening (from 6:00 p.m. to 10:00 p.m.),
LN - long-term average sound level A, expressed in decibels (dB) determined during all times of the night (from 10:00 p.m. to 6:00 a.m.).
In addition, using the Local Data Bank of the CSO, data on the population and area of selected cities were collected. In the next step, a review of metropolitan data on the existence of the so-called green zones in these areas and the number of registered vehicles in the surveyed urban areas was carried out.
The collected data were presented as a percentage to be able to perform a multivariate analysis. Among the features influencing the increase in the share of people exposed to the negative effects of noise, both stimulants and destimulants were distinguished:

- x1 - share of the number of vehicles in cities to the number of vehicles for the whole country (stimulant)
- x2 - share of the city's inhabitants in the general population of Polish (stimulant)
- x3 – share of the area of housing estate greenery in the city area (destimulant)
- x4 - share of street greenery in the city area (destimulant)
- x5 - share of the area of walking and recreation parks in the area of the city (destimulant)
- x6 - share of green areas in the city area (destimulant).

At the same time, the destimulants in the context of the increase in the studied phenomenon (the share of the population exposed to noise) will actually have a positive overtone.
Then standardization was made according to the formula:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j}, (i = 1, 2, \dots, n; j = 1, 2, \dots, m) \quad (2)$$

where:
n - number of objects (cities)
z_{ij} - standardized value of the variable X_j for the i-th object,
$\bar{x}_j$ - arithmetic mean of the variable X_j,
S_j - standard deviation of the variable X_j.

Using Euclidean distances, the similarity between the studied objects - cities - was determined using the formula:

$$d_{i0} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{0j})^2} \qquad \text{(i=1, …, n)} \quad (3)$$

The closer the values of the variables X1–X6, the more similar the facilities are in terms of the share of the population exposed to noise.

$$z_{0j} = \begin{cases} \max\limits_{i} z_{ij} \ \ for\ stimulants \\ \min\limits_{i} z_{ij} \ \ for\ destimulants \end{cases} \quad (4)$$

and the distance between the pattern and the antipattern of development D0 was calculated using the formula:

$$d_0 = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{_0j})^2} \qquad (i = 1, \dots, n) \quad (5)$$

Then, the measure of development for each city was estimated in terms of shaping the features influencing the studied phenomenon, according to the formula:

$$m_i = 1 - \frac{d_{i0}}{d_0} \quad \text{(i=1, …, n)} \tag{6}$$

The values of the measure of development are in the range [0,1]. At the same time, in the context of the share of the population exposed to noise, higher values indicate a lower level of development in the implementation of pro-ecological activities.

4. RESULTS

First, data on the share of the population exposed to the negative effects of noise in cities with more than 100,000 inhabitants were analyzed. For further analysis, 10 were selected in which these shares were at least several percent (Table 1).

Table 1
Share of the population exposed to noise during the day (L_{DWN}) and at night (L_N) [%]

City	L_{DWN}	L_N
Szczecin	7.9	5.9
Kraków	6.5	5.7
Łódź	6.2	4.7
Rzeszów	4.3	3.7
Bydgoszcz	2.9	2.2
Warszawa	2.9	1.8
Wrocław	1.1	0.6
Katowice	1.0	0.4
Gdańsk	0.9	0.2
Poznań	0.9	0.2

Source: own study on CSO

Data on the share of the population exposed to noise during the day (LDWN) and at night (LN) indicate significant differences between cities. The highest LDWN and LN values were recorded in Szczecin (7.9% and 5.9%) and Kraków (6.5% and 5.7%), suggesting higher noise levels in these cities compared to others. On the other hand, the lowest values are recorded in Poznań and Gdańsk, where LDWN and LN are 0.9% and 0.2%, respectively.

Subsequently, data on features X1-X6 influencing this phenomenon were analyzed (Table 2).

The data show a significant diversity in the share of the analyzed features in individual cities. The largest share of the number of vehicles and inhabitants in the country's population (X1, X2) was observed in Wrocław (7.26% and 5.08%), which indicates a high degree of urbanization and traffic intensity. Szczecin, on the other hand, is distinguished by a high share of green areas (X6 - 10.26%), which indicates a significant presence of green areas. Cities such as Łódź and Rzeszów have relatively higher shares of housing estate and street greenery (X3, X4), which suggests their greater accessibility in urban space. These results reflect the diverse approaches of cities to managing infrastructure and the environment.

Table 2

Values of X1-X6 features in the surveyed cities [%]

Feature / City	X1	X2	X3	X4	X5	X6
Bydgoszcz	1.15	0.91	2.05	2.01	2.40	0.38
Gdańsk	1.60	1.33	2.00	1.07	0.82	0.61
Katowice	1.25	0.77	1.91	1.34	1.28	0.55
Kraków	2.64	2.19	2.97	1.85	1.44	1.25
Łódź	0.85	0.91	3.35	3.59	1.26	0.72
Poznań	2.14	1.81	3.24	2.14	2.29	0.44
Rzeszów	2.10	1.49	1.98	3.63	1.38	0.28
Szczecin	0.68	0.54	2.01	1.86	0.65	10.26
Warszawa	1.25	1.08	0.97	0.82	0.57	0.36
Wrocław	7.26	5.08	4.02	2.55	1.89	0.48

Source: own study on CSO

In the next step, a multivariate analysis was carried out and the results are presented in Table 3.

The highest value of the measure of development was achieved by Łódź (0.907), indicating the most effective strategies and activities in this area, followed by Szczecin and Bydgoszcz. The lowest values of the measure were recorded in Gdańsk, Kraków and Wrocław (0.934–0.935), suggesting potential areas for improvement in these cities. Overall, the values of the measures of development are relatively close to each other, indicating a similar level of action in most cities, even though the differences in distance from the pattern are more diverse.

Table 3

A measure of urban development in terms of shaping the characteristics affecting the share of population exposed to staying in zones exceeding permissible noise levels

City	Distance from the pattern	Measure of development	Rank
Łódź	6.473	0.907	1
Szczecin	6.385	0.908	2
Bydgoszcz	5.901	0.915	3
Poznań	5.655	0.918	4
Rzeszów	5.396	0.922	5
Katowice	5.072	0.927	6
Warszawa	4.599	0.934	7
Wrocław	4.581	0.934	8
Kraków	4.546	0.934	9
Gdańsk	4.518	0.935	10

Source: own study

5. DISCUSSION

The study confirmed the differences in noise levels between Polish cities and the significant impact of demographic and urban factors on the exposure of residents to noise, which is reflected in the literature review. The results of the analysis show that cities with a higher share of greenery in urban space, such as Szczecin, have potentially greater opportunities to reduce noise exposure. Similar relationships are indicated in the literature, where spatial factors such as the length of roads, the communication network or the proportion of green spaces significantly affect noise levels (Barrigón Morillas et al., 2021; Zuo et al., 2014). The identified differences between cities may also be the result of local spatial policies and transport management, which is in line with the results of research by Kamandanga et al. (2020), who emphasize the importance of road traffic as a key source of noise in cities.

An important limitation of the study is the use of cross-sectional data, which do not allow for the analysis of the dynamics of changes over time. The lack of detailed data at the micro level, such as the location of noise sources or data on individual building characteristics, also limits the depth of conclusions. For example, analysing the impact of specific urban infrastructure elements, such as the width of streets, the number of lanes or the type of road surface, could provide more detailed information on the causes of local differences in noise levels. In addition, it is worth taking into account sociocultural variables, such as residents' sensitivity to noise or their adaptation strategies, which have been analyzed in the literature but not in the current study (Jakovljević et al., 2009).

Further research should include a temporal analysis, taking into account both seasonal variability and the impact of noise reduction policies in the long term. It would also be interesting to compare Polish cities with other European cities in order to assess the effectiveness of different noise reduction strategies in different urban contexts, which could improve the quality of life of city dwellers.

6. CONCLUSION

The presented research provided evidence of the diversity of noise levels in Polish cities and allowed for the identification of key factors affecting the exposure of the population to noise. The results verify the H1 hypothesis, confirming that the share of people exposed to increased noise levels varies between cities. Szczecin and Kraków are distinguished by the highest values of LDWN and LN indicators, while in Gdańsk and Poznań the noise level is much lower. These results highlight the importance of local spatial policies that can affect residents' exposure to noise, and the importance of spatial features of cities, such as the share of green spaces, in noise management.

The H2 hypothesis was verified by identifying demographic and urban factors influencing noise levels. The stimulants of the increase in the studied negative phenomenon (the share of population exposed to staying in zones with high noise intensity) are the high share of the number of vehicles (X1) and inhabitants (X2), and the destimulants are the share of spaces included in the green zone of cities (X3-X6). The verification of the H3 hypothesis was possible thanks to the development of a measure of urban development in terms of urban and spatial features that shape the noise level. The best results were achieved by Łódź, which proves the effectiveness of this city in reducing noise and taking measures to support environmental safety.

Overall, the research confirms the importance of integrating spatial policy and noise management in cities to protect the health of residents and promote sustainable

development. The differences between cities and their measures of development highlight the need for further research to enable the implementation of even more effective noise reduction strategies. These results can provide a basis for further development of methodologies in noise analysis and provide practical guidance for local decision-makers.

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