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The Influence of Traffic Noise on Apartment Prices on the Example of a European Urban Agglomeration

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Abstract: Traffic noise is one of the key determinants of apartment prices. The real estate market is highly sensitive to adverse environmental factors, which explains significant variations in apartment prices. The aim of this study was to identify the correlations between traffic noise levels and the prices of apartments traded on a local real estate market. The study analyzed three residential districts in the city of Olsztyn in north-eastern Poland. The database covered 5259 transactions concluded in 2005–2018. The collected data were standardized in terms of technical and functional parameters, and noise was the key factor differentiating the evaluated property. The relationships between the explained variable (apartment price) and the explanatory variable (traffic noise) were determined by linear correlation analysis. A negative correlation was noted, which confirms that a building's location relative to the road network and, consequently, the level of traffic noise, is one of the factors that play a role in the potential buyers' choice of property. The results of the study also indicate that the impact of traffic noise on the decisions made by real estate buyers continued to decrease in the analyzed period. Infrastructure projects in the city (construction of tramway lines and a ring road) have visibly reversed the previously observed trends and have decreased the strength of the above correlations in the evaluated residential districts. The values of the correlation coefficient were stabilized below the level noted in earlier stages of the analysis after the completion of the major infrastructure projects.

Keywords: environmental factors; traffic noise; city; acoustic map; apartment; real estate market; prices

1. Introduction and Research Objective

Landscape and its components are the objects of study in many branches of science. Landscapes are continuously transformed by the forces of nature and human activity [1]. However, this is not a correct interpretation because these terms have a much broader definition. As a visual phenomenon, a landscape is composed of many layers (landform, water bodies, vegetation, etc.), and it is the composition and perceptions of these layers that form a landscape. However, the individual layers do not constitute an integral landscape [2]. A landscape can also be experienced through the senses of hearing and smell, and according to some authors, a landscape can even be perceived through "touch" as part of multisensory integration [3,4]. In 1977, Schafer introduced the concept of "soundscape" which is used to complement visual perceptions of a landscape [5–8].

Soundscape components are often regarded as a significant inconvenience, in particular in urban settings where man-made sounds dominate. Most soundscape elements in the urban landscape are associated with noise that is caused by humans and has harmful consequences. Roads, airports and railways are the key sources of noxious noise that exerts a negative impact on human health and the quality of life [9,10]. Noise levels above 55 dB lead to a sense of discomfort, and noise levels higher than 65 dB pose a health threat by contributing to sleep disorders, irritation, apathy, concentration

problems, cognitive impairment, stress, mental disorders, as well as hearing and circulatory disorders. High levels of traffic noise increase social (disease, premature death) and economic costs (poor work performance, decision-making on the real estate market) [11–15]. Road noise is one of the greatest sources of discomfort [6] because road networks cover entire cities, including residential districts which are the key components of the urban fabric. For this reason, noise levels may directly influence apartment prices. Apartments situated far from noisy roads are in particularly high demand [16–22]. Due to growing levels of environmental awareness, real estate buyers are increasingly likely to search for quiet locations that support a relaxed lifestyle. Acoustic maps (noise sensitivity maps) are a tool that can support the decision-making process on the real estate market. Acoustic maps present the distribution of noise generated in city districts with different types of land use and functions.

The influence of noise on the housing market has been studied extensively in recent years. The relationship between rental prices and noise levels in Munich, Germany, was determined with the use of the hedonic price regression model. Rental prices decreased by 0.4% per dB (A) on average [23]. Theebe [24] analyzed housing prices in the Netherlands with the hedonic pricing method and estimated the Noise Sensitivity Depreciation Index (NSDI) at 0.3–0.5%. A study investigating single-family houses in Sweden with the use of the hedonic pricing approach demonstrated that loud properties sold with a discount of up to 30% compared to more quiet houses [25]. In research conducted in Poland, the NSDI ranged from 0.74% to 0.83% [20]. Similar correlations between housing prices and noise levels were reported by other authors [26–28]. The results of research exploring the significance of traffic noise have highly significant implications not only for property owners and tenants. They also indicate that the acoustic environment of large city dwellers needs to be improved. Excessive noise contributes to health problems such as sleep disorders, lower productivity, physiological stress, cardiovascular diseases, psychological disorders, and cognitive impairment in children [29,30].

The aim of this study was to analyze the relationships between traffic noise and apartment prices in residential districts on a local real estate market. The study evaluated apartments in three residential districts in Olsztyn, a city in north-eastern Poland. Olsztyn was an interesting object of study because the city's ring road was commissioned for use only recently, and one of the evaluated residential districts had been previously burdened by high levels of transit traffic. The methodology for developing acoustic maps and permissible noise levels in residential areas is presented in successive chapters of the article. The local real estate market was analyzed, and the results were used to generate a homogeneous set of input data concerning apartments. These data were used to analyze the correlations between the market price of apartments and traffic noise. The results of the study are discussed in the last chapter. The conducted analyses demonstrated that apartment prices are correlated with noise levels. This study is the first part of a comprehensive research project which will be continued in the future when all segments of the Olsztyn ring road have been put into operation. The study demonstrates that best practices in noise control can effectively decrease the harmful impact of traffic noise and improve the quality of life in urban areas.

2. Materials and Methods

2.1. Study Area

The study was performed in Olsztyn, the capital city of the Warmia and Mazury voivodeship in north-eastern Poland (Figure 1). Olsztyn has a population of 173,070 (as of 31 December 2017) [31]. The residents of the surrounding municipalities commute to work, school and retail outlets in Olsztyn, which contributes to traffic congestion in the city. The Olsztyn functional urban area with the surrounding municipalities has a combined population of nearly 300,000. The city is characterized by dense development, and many residential estates are located in the direct vicinity of major transport routes. Delayed construction of the Olsztyn ring road has significantly contributed to high levels of traffic noise in the city. Until 2019, transit traffic passed through the city, in close proximity to downtown Olsztyn and residential estates (both single-family homes and apartment buildings). Segments of the

Olsztyn ring road were commissioned for use in 2019, which created additional complications because traffic flow has changed, and some heavy duty vehicles continue to pass through the city via residential roads. The completion of the ring road project will improve traffic in the city and will reduce traffic noise in residential districts.

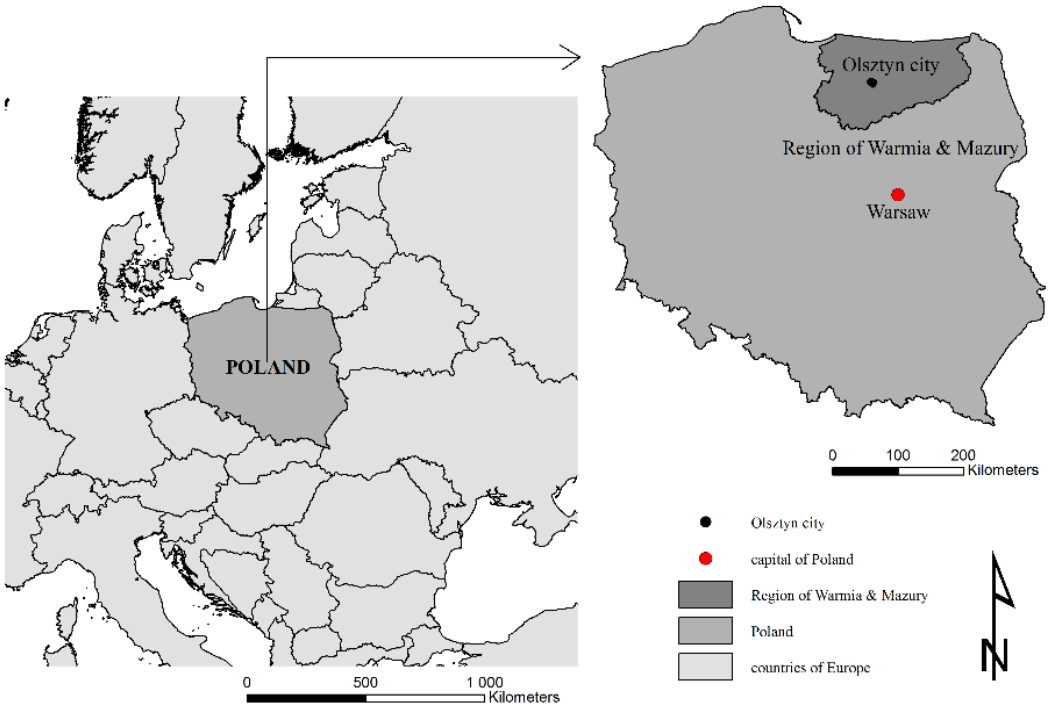


Figure 1. Location of Olsztyn on the map of Europe and Poland.

Olsztyn has 23 districts which constitute auxiliary territorial units of the Olsztyn municipality (Local Government Act of 1990). The study was conducted in three residential districts within the administrative boundaries of Olsztyn: Pojezierze, Jaroty and Nagórki (see Figure 2). The analyzed districts are composed mostly of apartment buildings. Nagórki is situated far from traffic routes, and residential activity is the main source of local noise. The district is intersected by local roads as well as municipal roads that are not a part of the national road network. In contrast, Jaroty is intersected by a regional road with high levels of traffic, including tramway traffic, as well as residential and local roads. This part of Olsztyn is exposed to high levels of traffic noise. Pojezierze is intersected by a major trunk road, and heavy-duty vehicles transiting Olsztyn in the direction of Poland's northern border pass in the direct vicinity of residential buildings. The remaining roads in Pojezierze are municipal and residential roads.

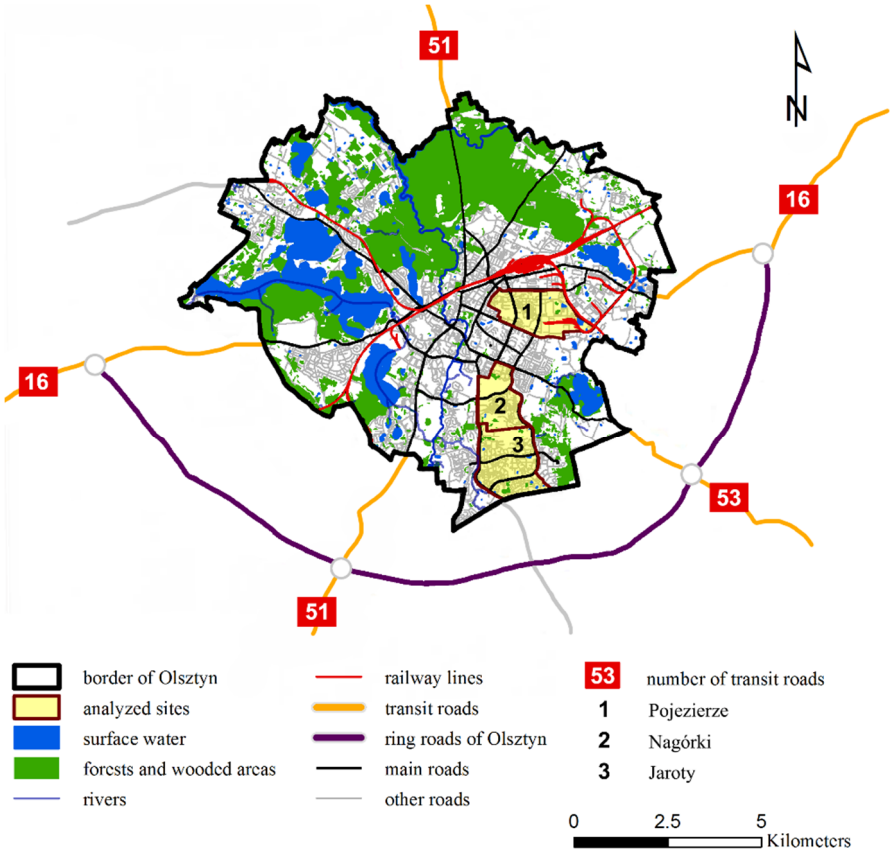


Figure 2. Location of the analyzed residential districts on the map of Olsztyn.

2.2. *Acoustic Map*

An acoustic map of Olsztyn was generated in line with to the provisions of Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (see Figure 3). In Poland, acoustic maps are developed and made available to the public pursuant to the provisions of the Environmental Protection Law of 27 April 2001 [32]. The long-term noise control policy for Poland relies on the following indicators [33]:

1. Long-term indicator of average noise level A (dB), determined in different times of the day (day, evening and night) on all days of the year–L_{DWN}. According to [33], L_{DWN} denotes the average long-term noise level A expressed in decibels (dB), which is calculated based on standard ISO 1996-2: 1987 on all days of the year (the calendar year for noise emissions and the average year for meteorological conditions) during the day (between 6 a.m. and 6 p.m.), evening (6 p.m. to 10 p.m.) and night (between 10 p.m. and 6 a.m.). This indicator describes general noise annoyance.
2. Long-term indicator of noise level A (dB)−determined on every night of the year−L_N. According to [33], L_N denotes the average long-term noise level A expressed in decibels (dB), which is calculated based on standard ISO 1996-2: 1987 on each night (between 10 p.m. and 6 a.m.) of the year (the calendar year for noise emissions and the average year for meteorological conditions). This indicator is used to describe sleep disturbances.

The maximum levels of environmental noise generated by roads and railway lines are presented in Table 1. Olsztyn has a population higher than 100,000. The analyzed residential districts are part of the inner city zone where maximum noise levels are set at 68 dB (L_{DWN}) and 59 dB (L_N) (Table 1).

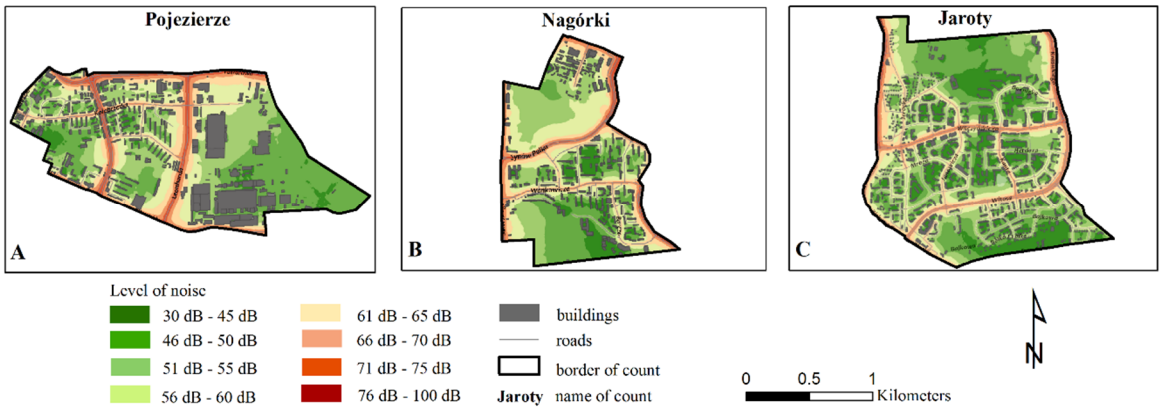


Figure 3. Acoustic map of the analyzed residential districts in Olsztyn ((**A**)–Nagórki, (**B**)–Jaroty, (**C**)–Pojezierze). Source: https://msipmo.olsztyn.eu/imap/?locale=pl&login=false&gpmap=gp15.

Table 1. Maximum levels of environmental noise.

Land-Use Type	Maximum Noise Level (dB)	
	Roads and Railways	
	L_{DWN}	L_N
1a. Health spas 2a. Hospitals outside the urban core	50	45
1b. Residential estates comprising single-family homes 2b. Built-up areas where children and adolescents reside permanently or spend several hours each day 3b. Welfare homes 4b. Hospitals inside the urban core	64	59
1c. Residential estates comprising apartment buildings 2c. Farms 3c. Recreational areas 4c. Residential estates with services	68	59
1d. Inner city zones in cities with a population above 100,000	70	65

Source: own elaboration based on the Communication of the Minister of the Environment of 2014.

Indicator L_{DWN} was calculated with the use of the below formula based on the adopted method for generating an acoustic map of Olsztyn [34]:

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

where:

L_D—long-term indicator of average noise level A, expressed in decibels (dB), determined during the day throughout the year (from 6 a.m. to 6 p.m.),

L_W—long-term indicator of average noise level A, expressed in decibels (dB), determined during the evening throughout the year (from 6 p.m. to 10 p.m.),

L_N—long-term indicator of average noise level A, expressed in decibels (dB), determined during the night throughout the year (from 10 p.m. to 6 a.m.).

Indicator L_{DWN} was calculated based on long-term measurements of average noise levels. The measurements were conducted 4 m above ground along building facades most exposed to traffic noise. The noise intervals (in dB) are presented in the legend of the acoustic map of Olsztyn (Figure 3).

2.3. Research Methodology

The adopted research methodology reflects the research objective and the object of the study. It consists of several stages that account for the characteristic features of the real estate market, and the correlations between environmental factors and the decisions made by apartment buyers. The research was divided into stages due to the use of various databases containing information about environmental (acoustic maps), economic (register of prices) and spatial factors (cadaster).

The study was carried out in several stages. The type of the evaluated apartments and the time frame of the analysis were selected. The analysis covered apartments situated in Olsztyn's residential districts of Pojezierze, Nagórki and Jaroty that were traded on the local real estate market. The investigated apartments are characterized by similar technical standard, condition and usable floor area. They are located in buildings made of prefabricated elements, erected in 1960–1990. The evaluated apartments are managed by housing cooperatives. The study analyzed apartment transactions conducted in 2005–2018. The information about the apartments traded on the local real estate market was collected and used to develop a database of 5259 transactions (Nagórki—908, Jaroty—1885, Pojezierze—2466). The following types of data were acquired: date of transaction, price, location, year of construction, number of floors in the building, usable floor area, floor in the building. These data were obtained from the registers of apartment transactions kept by housing cooperatives. Noise levels in the analyzed apartments were determined based on the Olsztyn noise map.

The acquired data were verified and consolidated to produce a homogeneous sample. A histogram depicting usable floor area was developed in the first stage of the analysis. Apartments whose size was most characteristic of the evaluated residential district were selected for further analysis. A time trend analysis of the selected apartments was performed in the second stage of the study. The database of apartments in a given size category was narrowed down to 2008–2018.

In the third stage of the study, the Shapiro-Wilk test was used to eliminate transactions where the price per square meter considerably deviated from the average price in a given location [35]. The resulting database was composed of apartments that were traded in 2008–2018 and were characterized by similar floor area and similar prices per square meter. The studied objects differed mainly in terms of location relative to the road network and the associated levels of traffic noise. The correlations between apartment prices per square meter and noise levels during the entire period of the study and in each year of the analysis were analyzed.

3. Results

The data relating to the apartment market in the investigated area were collected and selected in the first stage of the research methodology described in Section 2.3. The aim of the study was to identify the correlations between noise and real estate prices in an urban area. Therefore, the highly diverse set of input data was homogenized to eliminate the influence of other factors that could affect the decisions of real estate market participants.

Histograms depicting the distribution of apartments in different size categories in each residential district were developed to create a homogeneous sample (Figure 4). In Jaroty and Pojezierze, the highest number of transactions involved apartments with a floor area of 30–40 m^2; therefore, the number of the analyzed transactions was narrowed down to 639 in Jaroty and 1170 in Pojezierze. In Nagórki, most of the traded apartments had an area of 60–70 m^2, and 337 transactions in this size category were analyzed.

The time trend analysis of selected transactions revealed that apartment prices were relatively similar in 2008 (Figure 5). Therefore, the number of transactions conducted in 2008–2018 was further reduced to 513 in Jaroty, 951 in Pojezierze, and 273 in Nagórki.

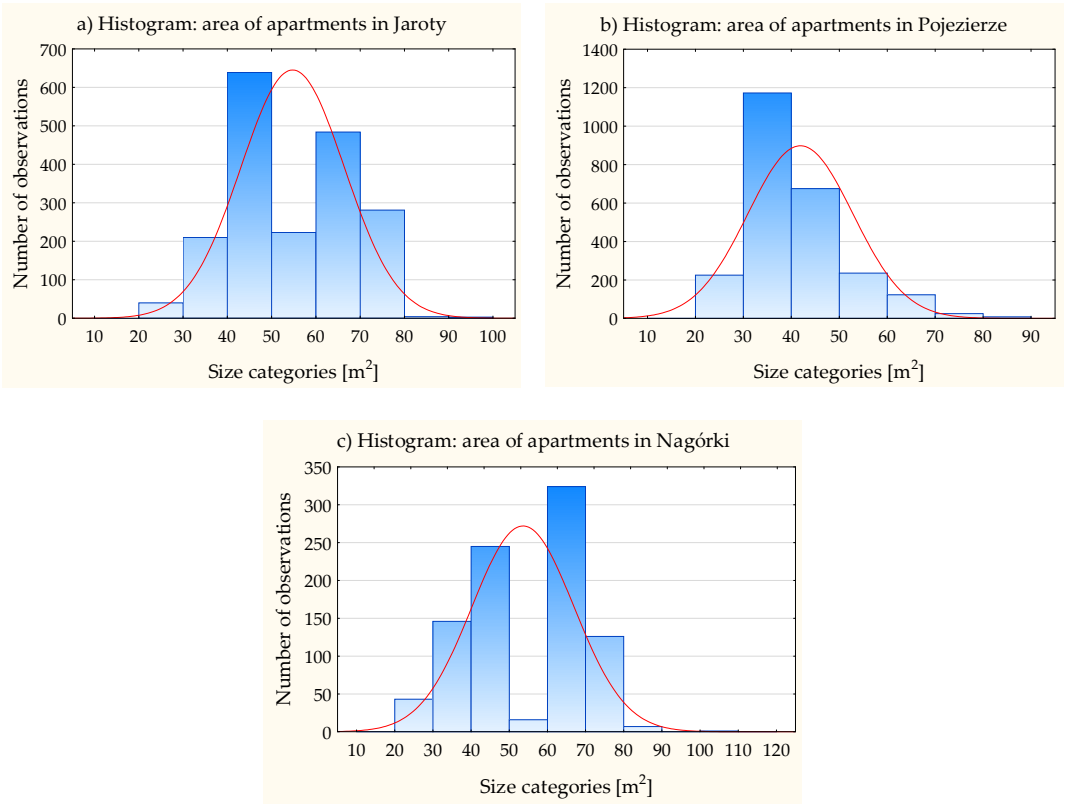


Figure 4. Distribution of differently sized apartments: (**a**) Jaroty, (**b**) Pojezierze, (**c**) Nagórki.

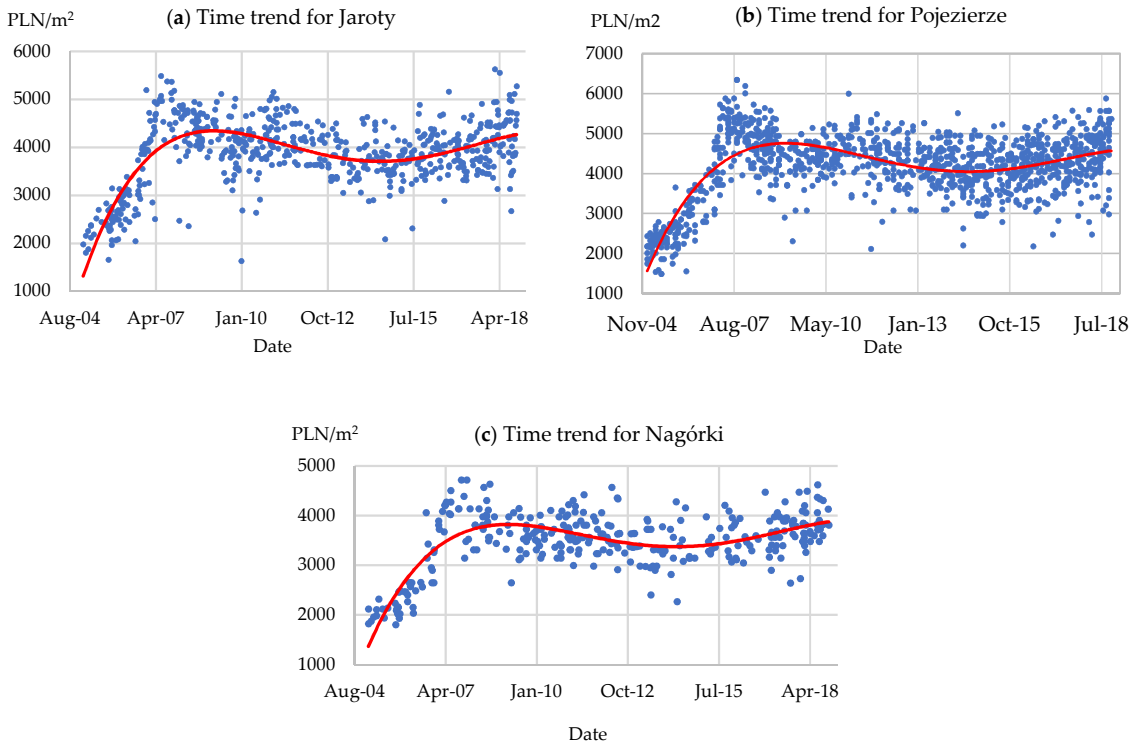


Figure 5. Time trend analysis: (**a**) Jaroty, (**b**) Pojezierze, (**c**) Nagórki.

The dataset was reduced by selecting apartments within a given size category that were traded within the specified period of time. The number of transactions in each noise interval in the analyzed

districts was calculated for the reduced dataset (based on apartment size and the time trend analysis), and it is presented in Table 2.

Table 2. Number of transactions conducted in 2008–2018 in each noise interval.

District	Noise [dB]					
	30–45	**46–50**	**51–55**	**56–60**	**61–65**	**60–70**
Jaroty	52	119	221	107	14	0
Pojezierze	22	349	239	245	78	18
Nagórki	17	79	87	84	6	0

The transaction dataset was further reduced in accordance with the adopted research methodology. Transactions where the price per square meter considerably deviated from the average price of other transactions were eliminated with the use of the Shapiro-Wilk test (Figure 6). The dataset was reduced to 457 transactions in Jaroty, 800 transactions in Pojezierze, and 247 transactions in Nagórki.

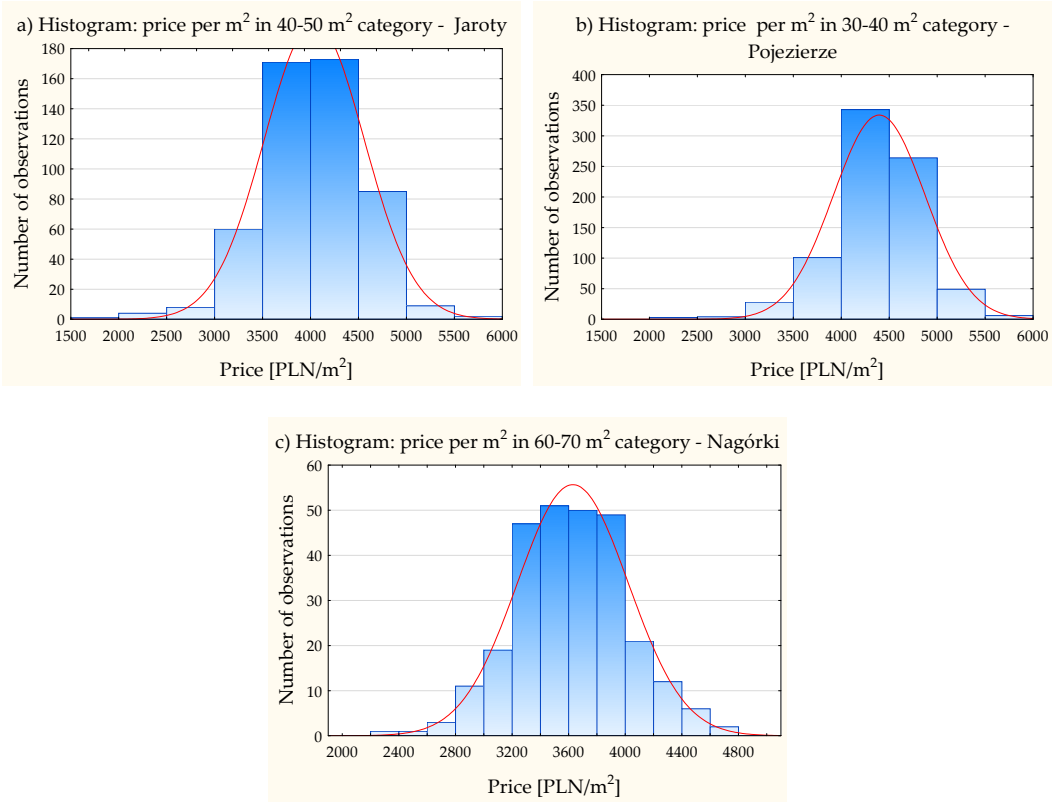


Figure 6. Distribution of prices per square meter in the analyzed residential districts: (**a**) Jaroty, (**b**) Pojezierze, (**c**) Nagórki.

The average prices in the analyzed residential districts ranged from 3500 to 4500 PLN/m^2. The results were expressed in Polish zloty (PLN). Apartment prices were not converted to other currencies (EUR or USD) because fluctuations in the average exchange rates increase the risk of error. The average exchange rate of PLN against EUR and USD quoted by the National Bank of Poland on the last day of the analyzed period (31 December 2018) was provided to increase the legibility of the results: EUR 1 = PLN 4.30, USD 1 = PLN 3.76 [36].

The correlations between apartment prices per square meter and noise levels were determined in the following stage of the analysis. The analysis involved a homogeneous dataset to eliminate

factors that influence real estate prices, excluding noise. The results were used to formulate general conclusions regarding all apartments traded in the evaluated districts, as well as apartments situated on the ground floor and higher floors (Table 3).

Table 3. Analysis of correlations between apartment prices per square meter and noise levels in 2008–2018 for apartments situated on different floors in the building.

District	2008–2018		
	Price/Noise Correlation–All Apartments	**Price/Noise Correlation–Ground Floor Apartments**	**Price/Noise Correlation–Apartments on Higher Floors**
Jaroty	−0.21	−0.24	−0.20
Nagórki	−0.26	−0.34	−0.24
Pojezierze	−0.33	−0.38	−0.32

The results of the correlation analysis for each year of the studied period are presented in Table 4. The analysis covers the entire dataset (regardless of the apartments' location on different floors of the building). The trends observed in the analyzed period (2008–2018) were compared with those noted on the local real estate market (Figure 7).

Table 4. Analysis of correlations between apartment prices per square meter and noise levels in 2008 to 2018.

District	2008–2018										
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Jaroty	−0.30	−0.36	−0.17	−0.21	−0.25	−0.50	−0.35	−0.38	−0.17	0.17	−0.10
Nagórki	−0.32	−0.15	−0.10	−0.13	−0.38	−0.51	−0.40	−0.42	−0.18	−0.20	−0.15
Pojezierze	−0.28	−0.18	−0.40	−0.29	−0.27	−0.47	−0.42	−0.40	−0.25	−0.31	−0.27

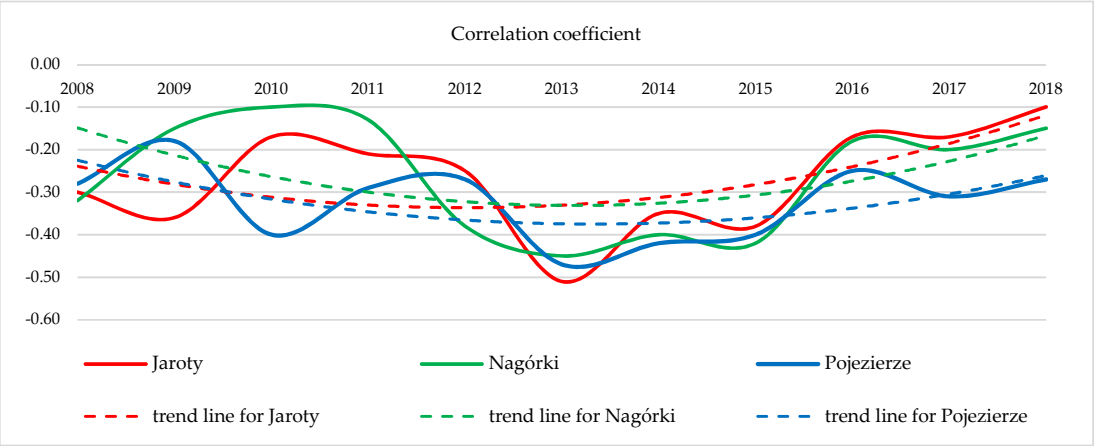


Figure 7. Trend lines for the correlations in each year of the analyzed period.

The correlations between apartment prices per square meter and noise levels in the analyzed period, determined based Table 4 data, are presented graphically in Figure 6.

4. Discussion

The results of the study have confirmed that a building's location relative to the road network affects property buyers' decisions. It should be noted that noise levels are not always directly

proportional to the distance between a building and the road network, but are also influenced by traffic intensity, natural and artificial noise barriers, landform and other factors. In simple terms, noise levels decrease with an increase in distance from the road, as illustrated by the acoustic map.

Apartment prices were negatively correlated with noise. The above was particularly visible in the residential district of Pojezierze, where the correlation coefficient was determined −0.33. The correlation coefficients were lower in the remaining districts, but they also confirm the influence of noise on apartment prices in Olsztyn. Pojezierze is situated most closely to the city center, and it is most exposed to traffic noise. This district is characterized by dense development, a dense road network, including transit and residential roads, a large number of multi-storey apartment buildings which increase population density, numerous public institutions, schools and retail outlets that generate high traffic. Jaroty and Nagórki have mostly residential functions (with lower population density) with services. These districts are enclosed by transit roads leading to the city center, which contributes to high levels of traffic noise during rush hours.

A comparison of the present results with the findings of previous studies conducted in Olsztyn [20,37,38] indicates that the impact of noise on property buyers' decisions has been gradually decreasing. The correlations between traffic noise and apartment prices were considerably higher in a study analyzing the same residential districts in 2013. The correlation coefficient reached −0.61 in the neighboring districts of Jaroty and Pieczewo (calculated jointly for both districts), −0.51 in Nagórki, and −0.41 in Pojezierze. The discrepancies between the previously noted values and the results of the current study can be attributed to different data processing methods. In the current study, the choice of apartments in each district was additionally narrowed down based on their size to produce a more homogeneous sample.

The previous studies coincided with the construction of new tramway lines, which could also explain the high values of correlation coefficients. Public tenders for the construction of the Olsztyn ring road and access roads were also initiated at the time, which additionally exacerbated the residents' fears regarding high noise levels. However, these projects proved to be less arduous than expected. The observed trend was clearly reversed, and correlation coefficients decreased in all districts when the tramway project was launched in 2012 and completed in December 2015. Tramway lines generated less noise than anticipated, and even contributed to a reduction in traffic noise levels. The values of the correlation coefficient also decreased when the first segment of the Olsztyn ring road had been commissioned for use in 2018. The ring road decreased traffic in the evaluated districts and their direct vicinity, in particular in Jaroty and Nagórki. However, these infrastructure projects were completed only recently, and their impact on property buyers' decisions cannot be reliably determined at present due to a short data collection period. The influence of traffic noise on real estate prices will be continuously monitored in the coming years.

The trend lines presented in Figure 7 based on Table 4 data confirm that infrastructure development projects have improved acoustic comfort in Olsztyn. The values of correlation coefficients were stabilized at a low level after the completion of the major infrastructure projects in the city. These parameters ranged from −0.10 to −0.31 in 2017, and from −0.15 to −0.27 in 2018, which indicates that the influence of traffic noise on apartment prices has steadily decreased. Traffic noise exerted the greatest impact on apartment prices in Pojezierze, which could be attributed to the fact that this district was most burdened with the noise generated by transit traffic. Pojezierze was characterized by the highest values of the correlation coefficient during the entire study (Table 3), and annual values were stabilized above −0.25 in the last three years. In Jaroty and Nagórki, the values of the correlation coefficient have been decreasing steadily since 2015, which suggests that traffic noise is a less significant driver of apartment prices.

5. Conclusions

The impact of traffic networks and their components on real estate prices has been studied extensively by many authors, and the reported results confirm the present findings. Noise influences

the real estate market, in particular the apartment market [22,23,37–43]. Buyers search for apartments in quiet areas that are located far from major sources of noise. The results of this study validate other research findings, including those presented in the Introduction. Acoustic discomfort cannot be fully eliminated in urban areas, but noise levels vary in different locations and, consequently, influence property prices.

The results of this study indicate that Olsztyn's residents are aware of the harmful consequences of noise, but they recognize the local authorities' efforts to improve the traffic network and the benefits that follow from infrastructure development projects. The Olsztyn ring road has considerably decreased the volume of transit traffic crossing the city, in particular in the residential district of Pojezierze. An analysis of workday traffic in a major intersection along the administrative boundaries of Pojezierze revealed that daily traffic (50,000 vehicles) decreased by 3471 vehicles (approx. 7%). New tramway lines also contributed to a reduction in wheeled traffic, although to a smaller extent.

An opinion survey carried out by the Olsztyn City Office demonstrated that local inhabitants recognize the positive impact of reduced noise levels on apartment prices and the quality of life [44]. According to the respondents, the condition of Olsztyn's road network has been improving steadily. In 2019, 54% of the surveyed subjects were of the opinion that local roads and streets had been modernized, which led to improvements in acoustic comfort. A considerable improvement in road quality was recognized by only 27% respondents in 2012 and by 29% respondents in 2014. These results clearly indicate that infrastructure development projects have substantially reduced noise levels in the city. Only 2% of the respondents were of the opinion that noise poses a significant inconvenience in Olsztyn (15 factors were regarded as greater sources of residential discomfort, and only 8 factors were evaluated as less disturbing). Noise was recognized as a considerable problem in Olsztyn by 25% of the surveyed subjects.

The results of this study indicate that noise levels considerably affect apartment prices. The deployed research methodology supported the identification of the relationships between traffic noise and prices on the local real estate market based on the spatial distribution of noise sources and apartment prices. Large EU cities develop acoustic maps which are a highly valuable source of data for analytical purposes. The relevant data can be used to identify the threats associated with the development of traffic networks in urban areas. The results of research investigating the real estate market contribute valuable insights for the relevant analyses and support the formulation of guidelines for urban planning. They can be used to design and develop urban infrastructure projects that account for traffic noise as one of the factors that considerably detract from the quality of life in cities. Infrastructure projects should also be designed to protect the health of urban dwellers who are particularly exposed to acoustic discomfort. Noise analyses are a valuable tool for urban management which facilitate the identification of the relationships on local real estate markets and contribute to the reduction of the risks associated with high levels of traffic noise.

It should be noted that traffic noise is one of the environmental factors that can influence the decisions made by potential buyers of residential property. Other factors include the proximity of green areas, forests and water bodies, as well as air pollution and sunlight exposure. In the presented study, the former factors do not apply (absence of water bodies, scarce vegetation which is typical of residential estates built in the 1970s and the 1980s), whereas data on air pollution were not available. The influence of green areas was evaluated by [45] based on an analysis of housing prices and the results of a survey involving real estate agents, but the cited study examined a residential estate with different characteristics (a housing estate with a park).

The research findings and the measures undertaken by Olsztyn's authorities provide valuable guidelines for other cities in the process of reducing the harmful effects of traffic noise. The awareness of the threats posed by traffic noise and the availability of data on noise distribution in a city influence the attitudes and decisions of apartment buyers. Infrastructure projects that reduce noise nuisance play a key role in local policies that aim to eliminate threats. The presented analysis can be used in

research studies investigating the feasibility, scope and cost of infrastructure development projects that improve the quality of urban life in other countries.

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