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Sustainable Urban Transport and the Level of Road Noise – a Case Study of the City of Bydgoszcz

Abstract: Road transport in cities is one of the main sources of air and noise pollution, lowering the attractiveness of areas of sensitivity, influencing the quality of life and the ability to meet the basic needs of users. The reconstruction of the existing road network and introduction of a new, alternative type of transport can radically change the acoustic conditions occurring in a city. As a result of this, an assessment of the noise nuisance of a fragment of the city of Bydgoszcz – a city located in the northern part of Poland – which had undergone changes connected with transportation, was carried out in the work. The influence of a newly-built tram route “Bydgoszcz-Fordon” on the acoustic conditions occurring in its surroundings was assessed. The studies were carried out in two periods of time (2012 and 2019), corresponding to various spatial states of the terrain. The results confirm that the introduction of an alternative transport solution contributed to a decrease in the level of road traffic noise. This occurs as a result of improved road conditions on modernized road segments, the integration of transportation networks and a decrease in the share of individual road vehicle transport. It was also confirmed that a well-designed tram route can influence changes in transportation habits of users and have a positive effect on the attractiveness of residential areas. This is in line with the concept of sustainable urban transport.

Keywords: noise, tram system, spatial transformation, city, sustainable urban transport

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1. Introduction

A city, being a complicated and diverse spatial structure made up of many functional subsystems, fulfils various user services in the economic, social and environmental sense [1]. Undoubtedly, among the basic needs that have to be met in a city include the necessity of getting around. A city understood in such a way forms a center of mobility which, by optimizing flow, ought to meet the principle of sustainable development and spatial order [2]. Achieving the above is possible by improving public transport, encouraging the use of non-motorized means of transport, creating pedestrian zones and limiting the use of private vehicles, among others [3, 4]. As it is commonly known, mobility realized by means of road transport is the main source of air pollution as well as noise in the city [5]. These contaminants lower the attractiveness of areas of sensitivity, leading to the deterioration of the quality of life and the level in which the basic needs of users are met [6]. The above problem pertains, above all, to areas bordering roads with high traffic volume as well as those transformed in terms of transportation [7]. As claimed by Krajewska [8: pp. 10, 72–74], the spatial transformation process, inseparably connected with socio-economic development, causes the necessity of also locating functions posing a noise nuisance within a city, as a result of which increased noise levels occur in their surrounds. Studies carried out in residential areas confirmed that residents living in spaces which had not been changed for years get used to various nuisances. After some time, they cease to notice and assess the surroundings in which they live positively (the so-called “environmental pseudoadaptation” phenomenon) [9]. The emergence of a new transportation solution (road or rail), generating changes in the propagation of noise, influences the subjective perception of noise by the inhabitants, who feel its negative effects more strongly. Undoubtedly, any urban space ought to be ecologically acceptable [8], also when it comes to fulfilling acoustic standards. Achieving this requirement is possible by applying a concept of sustainable urban transport which, while fulfilling all the transportation needs declared by the users, at the same time does not threaten health in terms of noise [10, 11].

The concept of sustainable urban transport is promoted in the White Book of Transport, a publication with a rich 30-year history. The book distinguishes three paradigms of transport, i.e.: the shifting of, division, and effective use of resources [12]. The aim of the first of these is to limit individual vehicle transport through the use of public transport. The second pertains to economic growth and limiting transportation needs. In the third paradigm, which was not assumed until 2011, it was claimed that the development of a competitive form of transport ought to comply with the effective use of resources, among others by strengthening the role of rail transport, as one which is less harmful to the environment [13]. According to Sokołowicz and Przygodzki [14], sustainable transport is the organization of the urban transportation system in such a way which fulfills the transportation needs of users but at the same time does not pose a threat to human health and the environment. This con-

cept does not mean to promote one of the existing types of transport in the city but rather to achieve a type of optimization between all available types; an optimization which guarantees the realization of the basic postulates of the existence of a sustainable transportation system, based on the following actions [13]:

- ensuing an increase in the transportation sector and supporting mobility while, at the same time, achieving the aim of lowering the emission of contaminants by 60% (this also pertains to road traffic noise);
- better integration of the network, enabling a greater choice of the type of transport, including making it possible to choose alternative transportation solutions (rail and water) that, in an attractive manner, will offer high quality services;
- better accessibility of safe transportation systems, which, in a manner that is equal for the current and future generations, will contribute to the realization of transportation aims (principle of sustainable development);
- ensuring ecological urban transport and commute to work by implementing public transport on a greater scale;
- gradual elimination of conventionally-powered vehicles and replacement with ones which are electric- or hydrogen-powered, and hybrids, as well as creating better conditions for walking and cycling;
- limiting emissions as well as the amount of rainfall in the framework of the possibility of them being absorbed into the ground, at the same time using up renewable resources in amounts possible to recreate and non-renewable resources in amounts possible to be replaced with renewable substitutes, in order to minimize the occupation of land and limit noise emissions.

Analyzing the above, sustainable transport makes it possible for users to travel through space using various transportation systems, with actual price and time alternatives in the form of trams, bike or underground [14]. Moreover, according to Pojani and Stead [3], in a city that is balanced transport-wise, the modernization of already existing roads is a more advantageous solution than the construction of new segments, which often leads to chaos. Another important element of the discussed concept is limiting the emission of harmful substances, which migrate into the environment from roads, contributing to the degradation of living conditions in cities. These contaminants also include road traffic noise. Currently, nearly 16% of the European population is exposed to its negative effects [15]. In an effort to minimize the level of road traffic noise, various forms of noise protection, including investment-modernization spatial forms (so-called quiet surfaces, noise screens and noise tunnels) are applied. Their application, combined with a pro-ecological approach to spatial planning, makes it possible to maintain a proper acoustic climate which does not lead to exceeding the permissible levels. Undoubtedly included in the above stream of science are also actions taken in the scope of sustainable urban transport, which, according to Motowidlak [5], are an element of a long-term planning

concept, comprising an integrated action plan. This concept is therefore heading in the direction of achieving strategic aims placed in the strategy of sustainable development, which is multifacetedly directed towards maximizing the effectiveness of development in economic, social and environmental terms [16, 17].

The aim of the work was to carry out an assessment of the noise nuisance of a selected urban area which had been transformed in terms of transportation, accounting for short-term as well as long-term noise indicators². The above study will serve as the basis for the verification of the following research hypothesis: the implementation of a new tram line “Bydgoszcz-Fordon” led to a decrease in the level of road traffic noise in the area of the analyzed noise sensitive object.

The study was carried out in two time periods, representing various spatial states of the region, i.e.:

- STATE 1 – prior to the introduction of the transportation investment – April 2012,
- STATE 2 – after the implementation of the transportation investment – April 2019.

The aim of the work was realized based on the results of direct noise measurements, studies on road traffic volume, as well as the analysis of noise data of immision maps of road traffic and tram traffic noise derived from SNM resources of the city of Bydgoszcz, realized in two SNM mapping phases in Europe:

- STATE 1 – noise data derived from phase II of SNM mapping in Europe (data set for period 2012–2016) [18],
- STATE 2 – noise data derived from III phase of SNM mapping in Europe (data set for 2016–2021) [19].

Moreover, the work made use of onsite inspections and an analysis of the literature on the topic.

2. Studying the Influence of a Tramline on the Noise Conditions Present in the Surroundings of a Selected Noise Sensitive Object

An area located in the city of Bydgoszcz (Fordon District) in the Przylesie housing estate (Fig. 1) was chosen for the studies. Bydgoszcz is among the largest cities in northern Poland, with a population of over 360,000 inhabitants. The city is

2 Short-term noise indicator: L_{AeqD} – equivalent level of noise A for daytime house, from 6⁰⁰ to 22⁰⁰, and L_{AeqN} – equivalent level of noise A for the time of night, from 22⁰⁰ to 6⁰⁰. Long-term noise indicator: L_{DEN} – long-term average level of noise A expressed in decibels (dB) determined during all days and nights in a year, and L_N – long term average level of noise A expressed in decibels (dB) determined during all hours of the night in a year (from 22⁰⁰ to 6⁰⁰).

characterized by diverse spatial zoning. In the center, dense development abounds, whereas in the eastern and western part, scattered development with numerous areas of greenery can be found. The layout of the road network of the city is linear-concentrated. It is characterized by expansion into the eastern and western directions, as well as short distance from its northern to southern borders. The Fordon District is located in the eastern part of the city. It is the largest area of Bydgoszcz, lying in the Fordon Valley, the natural eastern border of which is formed by the Vistula River. The surface area of Fordon is close to 31 km², comprising 18% of the surface area of the entire city; it is inhabited by approx. 20% of the city's residents. Fordon comprises 16 housing estates, including the analyzed Przylesie estate. Przylesie is the part of so-called New Fordon (Nowy Fordon). The area is made up mostly of residential areas with multi-family development from the 1980's and incorporated into enclaves of accompanying greenery, formed from coniferous trees – volunteer pine. Commercial development of a basic nature is a complementary function of the area.

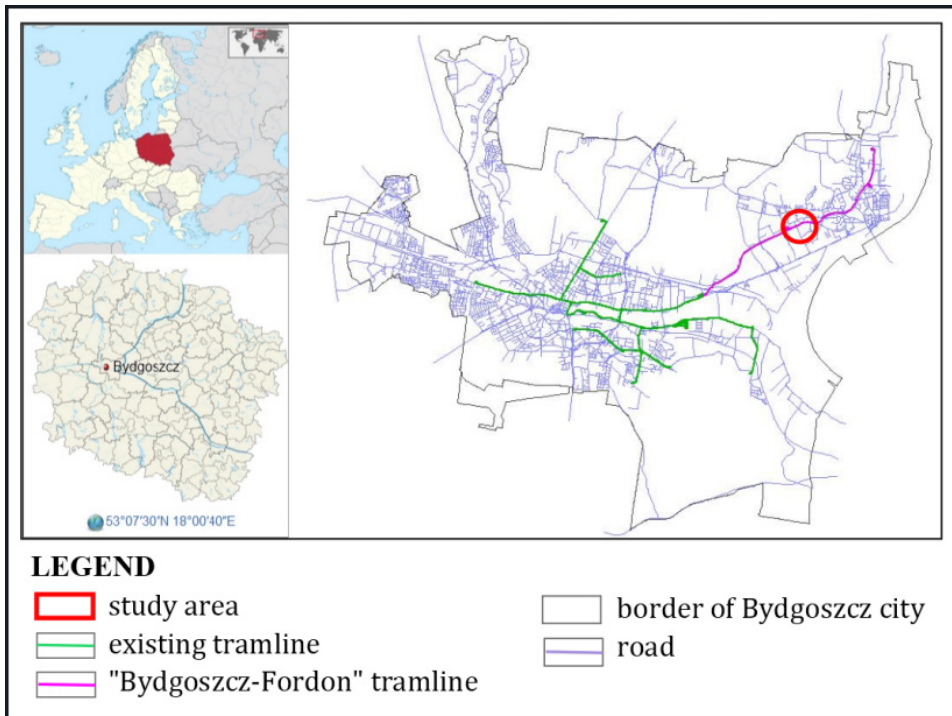


Fig. 1. Transportation layout of the city of Bydgoszcz with indicated "Bydgoszcz-Fordon" tramline

In 2013, in the area of Fordon, including the Przylesie estate, the construction of a tramline connecting the center of Bydgoszcz with the Fordon District (Bydgoszcz-Fordon route) along with the reconstruction of the existing road network

was commenced. The aim of the new transportation investment was to improve the standard of travelling and counteract the increase in individual vehicle transport, which falls in line with the concept of sustainable urban transport for the city of Bydgoszcz. The value of the investment, along with the tram rolling stock, comes close to 102 million euros (co-financed by European Union funding to the level of 59 million euros). The length of the entire route is nearly 10 km (Fig. 1). The new tramline was opened for use as of 16 January 2016 [20, 21]. Due to the aim of the work, studies were carried out in two time periods, corresponding to various spatial states, including:

- STATE 1 – prior to the implementation of the transportation investment – April 2012,
- STATE 2 – after implementation of the transportation investment – April 2019.

In order for the noise conditions occurring in the area of the tramline “Bydgoszcz-Fordon” to be identified in detail, an area with a total surface area of 0.6971 ha, comprising a fragment of the Przylesie estate, was selected. It is located an area where Akademicka, Rupniewskiego and Kaliskiego streets intersect. The area is built-up with an object characterized by high noise sensitivity – a multi-family building which was opened for use in 1987, and built using large-panel construction. Its technical condition was determined as good. The analyzed building is located in the first line of development from Akademicka St. A noise screen measuring almost 400 m in length and 6 m in height, built by way of an environmental decision of 2012, is found between the street and the building (Fig. 2).



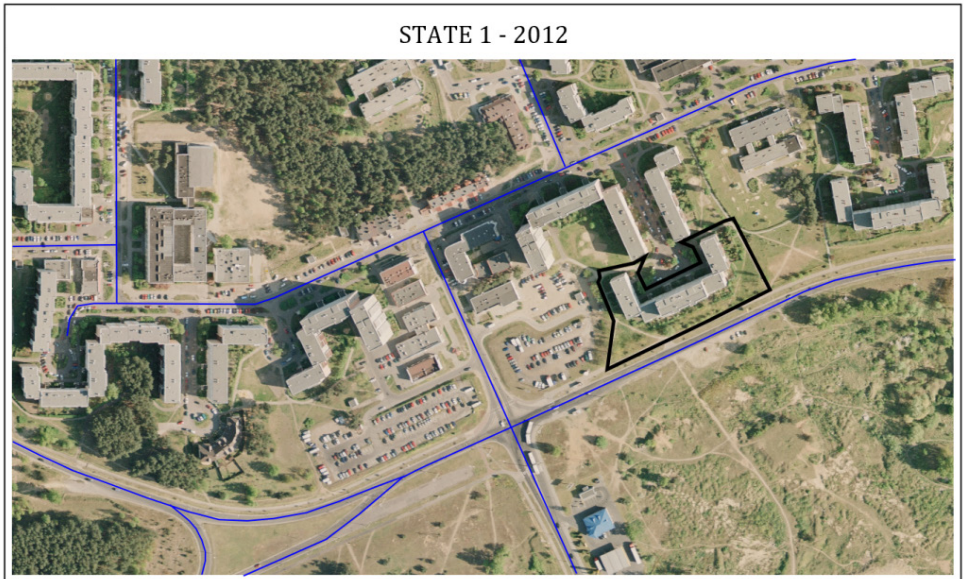
Fig. 2. The analysed objects of noise sensitivity – a multi-family building

2.1. Characteristics of the Transportation Network for Two Spatial States

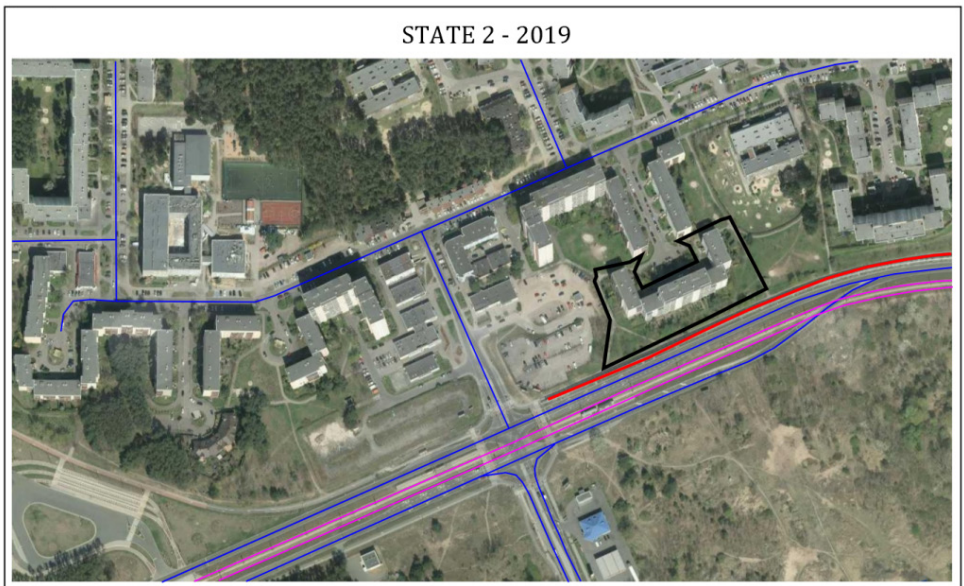
The transportation network of the analyzed terrain in 2012 (STATE 1) was merely a road system, co-created by one province road – Akademicka St. and two municipal roads – Rupniewskiego St. and Kaliskiego St. These are two-way asphalt roads with an average condition of road surface, for which a speed limit of up to 50 km/h applied. No traffic lights were noted at the crossroads of the streets, and the existing noise sensitive development is situated approx. 30 m away from them (Fig. 3a). After carrying out direct measurements of road traffic volume by means of a manual method on 16.04.2012 (Monday), it was stated that the greatest road vehicle traffic occurs on Akademicka St., which is one of the main roads connecting Fordon with the center of Bydgoszcz – average daily traffic volume (ADT), ADT = 9,647 vehicle/day, with the share of heavy goods vehicles being 9.88%. Individual transport had the largest share in the total traffic. The noted share of heavy goods vehicles results from the number of buses driving down Akademicka St., which are, at the same time, a component of city public transport. On the remaining sections of roads, heavy goods vehicle traffic was not noted; moreover, the average daily traffic volume is much lower than on Akademicka St. (Rupniewskiego St. – ADT = 3,744 vehicle/day, Berlinga St. – ADT = 2,791 vehicle/day). At the same time, Akademicka St. was considered to be a busy transportation route, where the volume and structure of traffic pose a noise nuisance to the analyzed residential area.

The transportation network in 2019 (STATE 2) is co-created by two transportation systems: an overbuilt road system and a newly created tram system. The new transportation investment pertained to, above all, the introduction of an alternative transportation system – a tram, but also accounted for the expansion of Akademicka St., which, in the analyzed internode segment, transformed from a two-way single lane road into a one-way, two-lane road with a good condition of the asphalt surface. The roads were divided by a belt of greenery as well as a tramway system. The analyzed crossroads also underwent reconstruction, with the addition of traffic lights and tram stops. The remaining streets did not undergo any changes in relation to their state as of 2012. In the area between Akademicka St. and the analyzed housing development, an acoustic screen was built. Its job was to limit the immission of road and rail traffic noise (Fig. 3b). After carrying out direct measurements of the road traffic volume using a manual method on 8.04.2019 (Monday), it was found that the heaviest road vehicle traffic takes place on Akademicka St., similarly to the situation observed in 2012, although the average daily traffic volume as well as the share of heavy goods vehicles in relation to the STATE 1 fell and is currently ADT = 7,993 vehicle/day, with the share of heavy goods vehicles amounting to 6.5%. A similar situation pertains to the remaining roads, on which nearly a 10% decrease in road vehicle traffic was noted as compared to that of 2012.

a)



b)



LEGEND





-  study area
-  road
-  "Bydgoszcz-Fordon" tramline
-  noise screen

Fig. 3. Transportation layout of the analysed area: a) STATE 1; b) STATE 2

2.2. Results for the Acoustic Conditions for the Two Spatial States

An assessment of the noise nuisance of the analyzed area was carried out for two groups of noise indicators. First, based on noise measurements, a study of short-term indicators – L_{AeqD} , L_{AeqN} was carried out. One test site – P01, located at a distance of 10 m from the edge of Akademicka St., was selected (Fig. 4). The studies were carried out in nine-time intervals, covering an entire 24-hour period. At each time interval, three 10-minute measurements (samples) at a constant height of 4 m were taken. Over the course of carrying out the measurement sample, the number of vehicles crossing a given road segment was counted, classifying them into light or heavy-goods vehicles. Light vehicles included passenger cars, whereas heavy duty vehicles with a weight of over 3.5 t (i.e. trucks, buses) were included in the heavy goods vehicle category. The study was carried out in accordance with the binding measurement method, using a sound level meter (STATE 1 – Mediator 2238, STATE 2 – Svan 971). The results of the studies for two spatial states are presented in Table 1. As can be seen, short-term levels of road traffic noise for STATE 1 are significantly higher than those for STATE 2. Prior to the introduction of the transportation investment, the permissible level of road traffic noise for short-term indicators³ was exceeded by 2 dB at daytime and nighttime. The introduction of the tram route (STATE 2) influenced the improvement in the noise conditions in the area of the analyzed residential building, which is well-illustrated by the decrease of 6dB in the road traffic noise level. At the same time, the permissible road traffic noise level was not found to have been exceeded.

The assessment of the noise nuisance for long-term indicators: L_{DEN} , L_N was carried out based on data derived from SNMs of Bydgoszcz (SNM, 2012, 2019). Accounting for the structure and functional layout of the analyzed noise sensitive object, six checkpoints (P02–P07) were selected. Two of them, i.e. P02 and P03, were located 10 m from the road axis (Akademicka St.). Four subsequent ones, i.e. P04–P07, were situated 2 m from the elevation of the existing residential development (Fig. 4). Their aim was to assess the level of road traffic noise as well as to test the influence of road traffic noise on the acoustic conditions present in the area of the analyzed building. The location of checkpoints for tram noise is also presented in Figure 4. Detailed results of studies can be found in Table 2, where it can be seen that the permissible level of road traffic noise was only exceeded for STATE 1 at checkpoints: P02, P03, P05, P06 for the L_{DEN} indicator and at checkpoints: P02, P03 for the L_N indicator. Importantly, the level of road traffic noise at all checkpoints for STATE 2 (after implementation of the “Bydgoszcz-Fordon” tramline) did not exceed permissible values and decreased in relation to STATE 1. For points located near the road, an improvement in the noise conditions by 6 dB was noted.

³ In accordance with Polish law, the permissible noise level for road traffic noise for short-term indicators cannot exceed the following values: L_{AeqD} – 65 dB, L_{AeqN} – 56 dB.

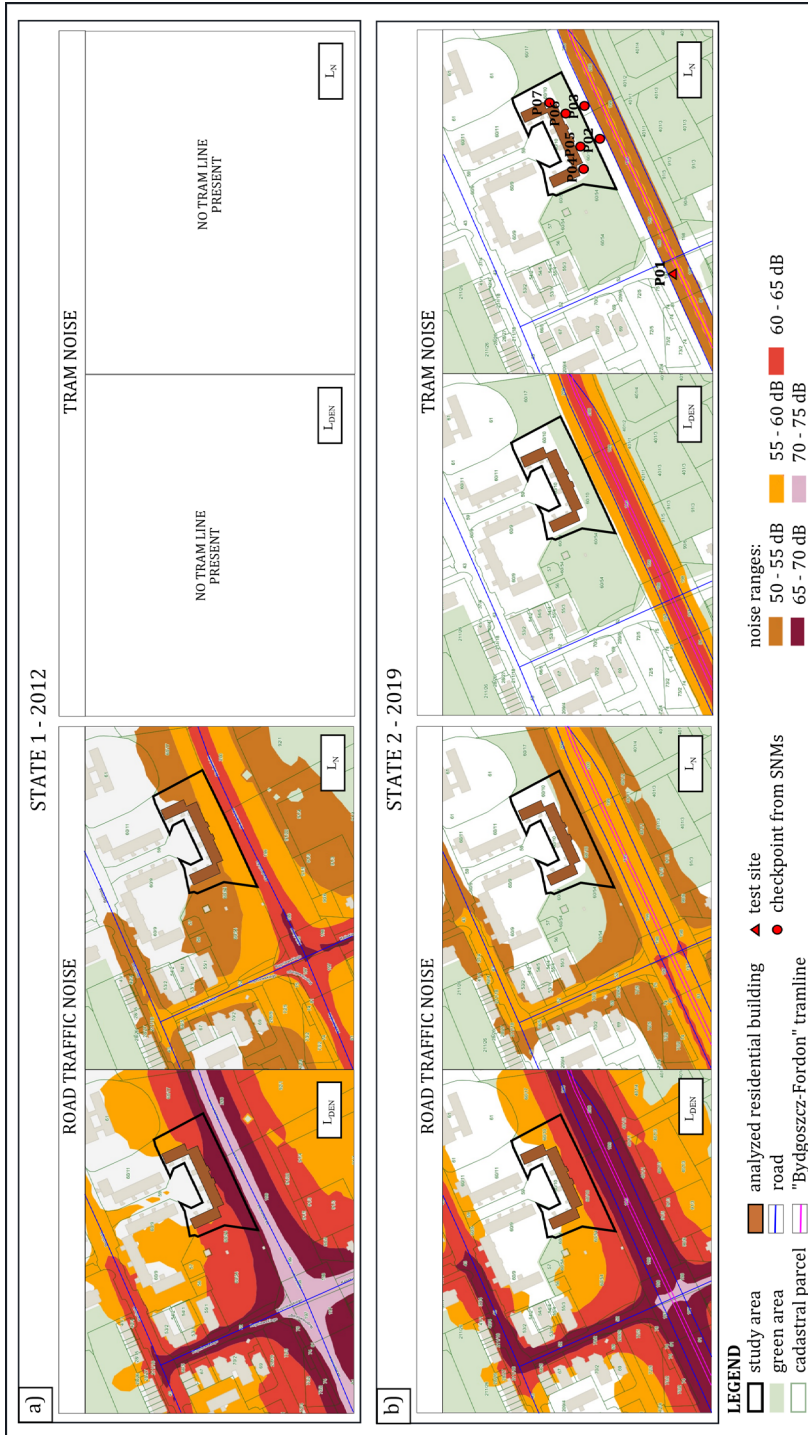


Fig. 4. Noise conditions occurring the area of the analysed residential building for the spatial states of the areas

The above difference results from decreasing road vehicle traffic on the discussed street (see pt. 1.2 – ADT for STATE 1 and STATE 2) and improving the road parameters, especially the condition of the road surface. For points located near the elevation of the building, a decrease in the level of road traffic noise by as much as 8 dB was noted. Such a large difference additionally results from the introduction of a noise screen in the area.

Table 1. Level of road traffic noise for various spatial states – short-term indicators (test site – P01)

Time interval	Time of day	STATE 1 (2012 year)		STATE 2 (2019 year)	
		L_{AeqT} [dB]	noise indicator [dB]	L_{AeqT} [dB]	noise indicator [dB]
06 ⁰⁰ –10 ⁰⁰	Day 6 ⁰⁰ –18 ⁰⁰	67.9	$L_{AeqD} = 67.06$	62.4	$L_{AeqD} = 61.73$
		67.5		62.5	
		67.6		62.7	
10 ⁰⁰ –14 ⁰⁰		67.0		61.9	
		67.5		62.0	
		67.9		61.2	
14 ⁰⁰ –16 ⁰⁰		69.0		61.8	
		67.9		62.5	
		68.8		63.1	
16 ⁰⁰ –18 ⁰⁰		67.1		62.8	
		67.3		62.1	
		68.3		63.2	
18 ⁰⁰ –20 ⁰⁰	Evening 18 ⁰⁰ –22 ⁰⁰	67.2	61.2		
		66.8	62.1		
		67.6	62.3		
20 ⁰⁰ –22 ⁰⁰		64.6	59.4		
		64.0	59.1		
		63.1	58.9		
22 ⁰⁰ –24 ⁰⁰	Night 22 ⁰⁰ –6 ⁰⁰	61.7	$L_{AeqN} = 57.91$	54.1	$L_{AeqN} = 50.27$
		60.4		53.2	
		61.1		52.9	
54.8		42.6			
24 ⁰⁰ –04 ⁰⁰		55.1		42.1	
		47.9		43.3	
		60.4		54.8	
04 ⁰⁰ –06 ⁰⁰		61.5		55.1	
		58.3		54.3	

Table 2. Level of road and tram traffic noise for various spatial states – long-term indicators (checkpoints P02–P07)

Checkpoint	Road traffic noise						Tram noise	
	L_{DEN} [dB]			L_N [dB]			L_{DEN} [dB]	L_N [dB]
	S1	S2	S1–S2	S1	S2	S1–S2		
P02	70.8	64.6	6.2	60.2	53.9	6.3	55.2	45.9
P03	71.3	65.3	6.0	60.5	54.4	6.1	55.1	46.3
P04	63.3	55.2	8.1	54.7	46.9	7.8	48.2	40.0
P05	68.6	60.8	7.8	57.8	50.1	7.7	52.3	43.8
P06	69.1	61.1	8.0	57.8	50.2	7.6	52.6	43.6
P07	62.9	54.8	8.1	53.9	45.9	8.0	47.9	39.7
Formal requirements	68			59			68	59

Key: S1 – STATE 1, S2 – STATE 2. Formal requirements determined for areas of multi-family residential development and collective dwellings in relation to road and rail traffic noise, in accordance with the Directive of the Minister of the Environment of 14 June 2007 on permissible noise levels in the environment (uniform text: Journal of Laws 2014 No. 0, item 112).

Source: own study based on the data from [18, 19]

3. Conclusions

Noise nuisance and the problem of road traffic noise can be observed, above all, in areas covered by investments in transportation. The reconstruction of an existing road network or introduction of a new, alternative type of transport (e.g. tram), can significantly change the noise conditions of a city. The study clearly confirmed the assumed research hypothesis: the implementation of the “Bydgoszcz-Fordon” tramline led to a decrease in the level of road traffic noise in the area of the analyzed noise sensitive object. The construction of a well-commuted tramline, facilitating a fast commute from the Przylesie District to the center of the city, as well as the proximity of the tram stop on Akademicka St. contributed to a change in the travelling habits of the inhabitants. Most of them gave up individual transport, replacing it with public transport – the tram. The study clearly indicates that the new transportation solution (tramline) does not pose a noise nuisance in the analyzed area. At none of the analyzed control checkpoints were standards for tram noise exceeded (Fig. 4). Moreover, introducing a new tram route contributed to the lowering of road traffic noise by 8 dB for long-term indicators, as well as 6 dB for short-term indicators. The above is the result of an improvement in the road conditions, integration of transportation networks, as well as the decrease in the share of individual road vehicle transport in traffic. At the same time, it was concluded that the assessment of the noise nuisance of the selected urban space subjected to transformation in terms of transportation, for both short-term and long-term indicators, proved to have a positive result.

The analyzed transportation investment fully realizes the tasks of sustainable urban transport, which, as a system, ought to ensure a diverse transportation offer that is well-adapted to the needs of different groups of users [22]. The studies carried out in the work confirmed the fact that well-designed space, including transportation infrastructure, guarantees proper acoustic conditions and influences the quality of life and attractiveness of residential areas.

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Zrównoważony transport miejski a poziom hałasu drogowego – studium przypadku miasta Bydgoszcz

Streszczenie: Transport drogowy w mieście jest głównym źródłem zanieczyszczeń powietrza oraz hałasu, który obniżając atrakcyjność terenów wrażliwości, wpływa na jakość życia i zaspokajanie podstawowych potrzeb użytkowników systemu transportowego. Przebudowa istniejącego układu drogowego lub wprowadzenie do przestrzeni nowego, alternatywnego rodzaju transportu może diametralnie zmienić warunki akustyczne panujące w mieście. Z tego względu w pracy przeprowadzono ocenę uciążliwości akustycznej zmienionej pod względem komunikacyjnym fragmentu Bydgoszczy – miasta w północnej części Polski. Zbadano wpływ nowo wybudowanej trasy tramwajowej „Bydgoszcz-Fordon” na warunki akustyczne panujące w jej sąsiedztwie. Badania przeprowadzono w dwóch okresach (2012 i 2019 rok), odpowiadających różnym stanom przestrzennym terenu. Wyniki potwierdzają, że wprowadzenie alternatywnego rozwiązania transportowego przyczyniło się do obniżenia poziomu hałasu drogowego. Powyższe jest wynikiem poprawy warunków jezdnych na zmodernizowanych odcinkach dróg, integracji sieci transportowych oraz zmniejszenia udziału w ruchu indywidualnego transportu samochodowego. Stwierdzono również, iż dobrze zaprojektowana trasa tramwajowa może się przyczynić do zmiany przyzwyczajeń transportowych użytkowników oraz wpłynąć korzystnie na atrakcyjność terenów mieszkaniowych, co wpisuje się w koncepcję zrównoważonego transportu miejskiego.

Słowa

kluczowe: hałas, system tramwajowy, przekształcenie przestrzeni, miasto, zrównoważony transport miejski