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The primary aim of the journal and its mission are to spread information and guidance relevant both for authorities responsible for the effective land administration (local, regional and central), scientists and teachers.

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ANALYSIS OF SPATIAL DISTRIBUTION OF TOURISTIC ACCOMMODATION IN POLAND WITH THE KERNEL DENSITY ESTIMATION OF POI_S

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ABSTRACT

Motives: Using Points-of-Interest (POIs) data and GIS software, the spatial heterogeneity of different types of accommodation could cheap, easily and quick be analyzed.
Aim: The use of kernel density estimation (KDE) of Points-of-Interest data to shown spatial distribution of different types of accommodation in Poland.
Results: There is a close relationship between the type of accommodation and the type of tourist attraction.

Keywords: Accommodation, Tourism geography, Points-of-Interest, KDE.

INTRODUCTION

Tourism geography, as an element of socio-economic geography, approves the dualism of geographical space and economic space. According to Domański [2012], Lewandowska-Gwarda [2013], Włodarczyk [2014] the geographical space is split into anekumene (part of space not used economically and not inhabited by humans due to unfavorable natural conditions), subekumene (a part of space temporarily used economically and inhabited by human beings due to difficult natural conditions) and ekumene (a part of space continuously used economically and inhabited by humans due to favorable natural conditions). Perroux [1950] defined an economic space as an abstract space determined by the economic relationships that exist between economic elements. Tourism strongly connects geographical space with economic space, because this area of human activity is most dependent on natural conditions. According to Liszewski [1995], tourism space is a part of a geographical space understood as a space consisting of natural elements of the Earth's shell (natural environment), permanent effects of human activity in this environment (economic environment), as well as the human environment in the social sense. This kind of definition provides a detailed anthropocentric division of the geographical environment into natural, economic, and social [Zajadacz, 2014]. Thus, on the one hand the tourist space is based on the wealth of the natural environment (forests, rivers, lakes, mountains) and on the other hand tourist mobility requires economic activity in the field of tourist infrastructure and social acceptability for this type of purposes

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of human habitation. According to Włodarczyk [2014], tourism space is a part of the geographical space in which the phenomenon of tourism occurs. A necessary and sufficient condition to classify a part of the geographical space as a tourist space is tourist activity, regardless of its size and nature. The existence of tourism infrastructure (quality, quantity, specificity) is an additional condition that makes its delimitation possible. Comparison of geographical and touristic space are shown in Table 1.

The basic prerequisite for human tourist activity is adequate accommodation, which corresponds to the concentration of tourist attractions both typically natural and related to the history and culture of societies. According to Wojdacki [2014], accommodation is the foundation of tourism, allowing tourists to increase the length of their stay outside their place of residence (more than 1 day).

Different types of accommodation in Poland (hotels, hostels, motels, pensions, holiday resorts, and camping sites, more on this topic in the chapter Data Description) will be the subject of spatial analysis, in this work Gathering information on all establishments providing accommodation throughout the country, is a difficult and time-consuming task. There are no structured accommodation databases that show geographical coordinates along with facility information, in Poland. Based on the growing interest in the application of POIs (Point-of-Interest) data in geographical research [Yu & Ai, 2014, Jia, Khadka & Kim, 2018, Lu et al., 2020], we also believe that POIs points, as an accessible and simple additional spatial data source, have got an potential. Using POIs data and GIS software, the spatial heterogeneity of different types of accommodation could quick be analyzed. The aim of this paper is to verify the assumption that POIs can be a simple and easy-to-use source of spatial data to diagnose the spatial distribution of accommodation in a given region, country or continent. Additional aim, is to find is there a close relationship between the dominant type of accommodation and the dominant type of region's tourist attraction (anthropological or environmental). The research used the Kernel Density Estimation (KDE) through ArcGIS Pro.

Table 1. Comparison of geographical and tourism space

Sphere	Space in general terms – geographical space	Tourism space
Geosphere	Includes concentric layers of the earth, of diversified chemical composition and state, e.g. lithosphere, hydrosphere, atmosphere. A part of it is the biosphere, understood as space inhabited by living organism, including humans	Natural tourism assets and attractions which are the basis for the development of many tourism activities
Anthroposphere		
Technosphere	The sphere of human interference with nature, involving the introduction of technical means into the natural environment. A part of it is the infosphere, i.e. the whole of registered, processed and stored information	At base, it is formed due to tourism development and accessibility by transport. The elements of tourism infosphere are distribution and reservation systems, which may enter non-sociological relations with the elements of development or accessibility by transport
Sociosphere	The sphere of interpersonal relations, human psychosocial environment. These relations may be variously characterised (e.g. economic, political, cultural, etc.)	Describes the relational approach to tourism space and landscape. Similar to space in general, these relations may be variously characterised, but in most cases they concern the relations of people with other components of tourism space
Noosphere	The sphere of thought, human mental activity, usually without formal limits	Includes perceptual-mental and metaphorical approaches to tourism space (virtual space, spiritual space, etc.)

Source: Włodarczyk [2014].

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LITERATURE REVIEW

In geography, basic research aims to develop new theories and methods that help explain the processes through which the spatial dimensions of physical and human environments evolve. Applied research, on the other hand, uses existing geographical theory or techniques to understand and solve specific empirical problems [Hall & Page, 2009]. This paper presents the second dimension of geography, because the spatial heterogeneity of different types of accommodation by using POIs data and GIS, is analysed as an element of tourism geography.

Tourism contributes to the growth of regional economies, providing a source of income for both resident households and local firms [Carrascal Incera & Fernández, 2015]. Tourism sector is a spatial phenomenon that requires spatial data collection and processing [Boers & Cottrell, 2007], namely to identify features relationships and to analyse those relationships in a spatial context [Basu & Thibodeau, 1998]. Tourism is the mobility of society in geographical space, which is conditioned by the search for tourist attractions, both natural and anthropological. Tourism is the mobility of society in geographical space, which is conditioned by the search for tourist attractions, both natural and anthropological. The close relationship between tourism and the natural, social and economic conditions of an individual place (as a resting area) has brought these two research areas together in a single science discipline. According to Williams and Shaw [Williams & Shaw, 2015] tourism geography is a broad research area that studies the interactions between the space, place, and environmental dimensions of geography. According to Hall [2013] if tourism is subject to scientific research taking into account concepts from geography, it can be treated as a separate discipline, i.e. tourism geography. According to Wei [2012] tourism has strong geographical attributes and GIS (geographical information system) itself is information system offering services to geographical research and decision-making, which can play a role in tourism management. Research in the field of tourism geography can use a number of tools available in GIS software: GWR model [Jin, Xu & Huang, 2019, Lee, Jang & Kim, 2020, Tasyurek & Celik, 2020], Bayesian model [Wong, Song & Chon, 2006, Assaf, 2012, Assaf, Tsionas & Oh, 2018, Kulshrestha, Krishnaswamy & Sharma, 2020], K-means clustering [Arimond & Elfessi, 2001, Gao, Janowicz & Couclelis, 2017, Renjith, Sreekumar & Jathavedan, 2018], GIS based 3-D landscape visualization [Woolard & Colby, 2002, Cowell & Zeng, 2003, Yang, 2016] and KDE (kernel density estimation) [Yu & Ai, 2014, Zhu et al., 2017, Lee, Jang & Kim, 2020].

This research proposes a KDE model to investigate the spatial density of accommodation in Poland, with the use of Points-of-Interest. POIs can be obtained from many online sources, in which they are an integral part for example Twitter and Instagram (geo-positioned social media), OpenStreetMap and Google Maps (map applications), Airbnb, and Tripadvisor (applications for booking accommodation and positioning tourist attractions) [Milias & Psyllidis, 2021].

According to Lu et al. [2020] the Points-of-Interest are cartographically mapped in a geographical space and are uniquely associated with different aspects of human life. POIs in geographical information systems can greatly enhance the ability to describe the physical location of shopping facilities or even bus stops, for example [Gao, Janowicz & Couclelis, 2017]. There is currently a lot of interest in using points-of-interest in various studies [Gao, Janowicz & Couclelis, 2017, Lu et al., 2020, Milias & Psyllidis, 2021, Wu et al., 2021].

In this work, the spatial diversity of hotels, hostels, motels, pensions, holiday resorts, private, and camping sites were identified using the kernel density analysis method (KDE). The research results in a spatial visualization of the density for each of the accommodation types listed above. There are not many studies in the available literature that combine the use of spatial studies on accommodation types using points-of-interest as a spatial data source. Jeffrey [1985] conducted the research concerned with the identification and interpretation of spatial-temporal patterns of demand for hotel accommodation. The spatial-temporal patterns identified in that study would help with

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formulating an marketing and development policy for the hotel industry. In the research of Wall et al. [1985] the changing number and types of accommodation has been described and the spatial distribution of accommodation is analyzed using three methods of point pattern analysis and draw an attention to the significance of large cities as tourist destinations and to the importance of accommodation establishments as a component of the urban fabric. Voltes-Dort and Sanchez-Median [2020] presented a study about the drivers of Airbnb prices in Bristol using ordinary least squares (OLS) and geographically weighted regression (GWR) methods. The results also uncover statistically significant differences between the price determinants of apartments and house listings and reveal spatial patterns in the price effects. Similar studies were carried out by Suarez-Vega and Hernandez [2020] in terms of selecting prices determinants and including spatial effects in peer-to-peer accommodation. Spatial analysis of intensity in tourism accommodation has been conducted by Rodríguez Rangel et al. [2020] by using three different methods: quadrant counting, K-function, and kernel smoothing. The impact of various characteristics of geographical space on the location of tourist accommodation facilities has been assessed in the work of Navrátil et al. [2012] spatial indicators, nearest-neighbour analysis, kernel estimation of the probability density of occurrence, analyses of distances and location in selected environments were used. Applying the contour tree and location quotient index methods, based on the points of interest (POIs) data of the accommodation and catering industry in Beijing and on the identification of the spatial structure and cluster centre of the accommodation and catering industry, Han and Song [2020] investigated the distribution and agglomeration characteristics of the urban accommodation and catering industry from the perspective of industrial spatial differentiation.

MATERIALS AND METHODS

Study area

The spatial coverage of the research is limited to the borders of Poland, which is located in Eastern Europe. Poland has joined the European Union in 2004 and acceded to the Schengen Agreement in 2007. These two important events gave a positive impulse to the economic development of Poland and give a place to the increasing tourist movement. The area of Poland is about 313 thousand km² with about 38 million of inhabitants. The shape of the Polish territory is quite regular, in the north there is the Baltic Sea

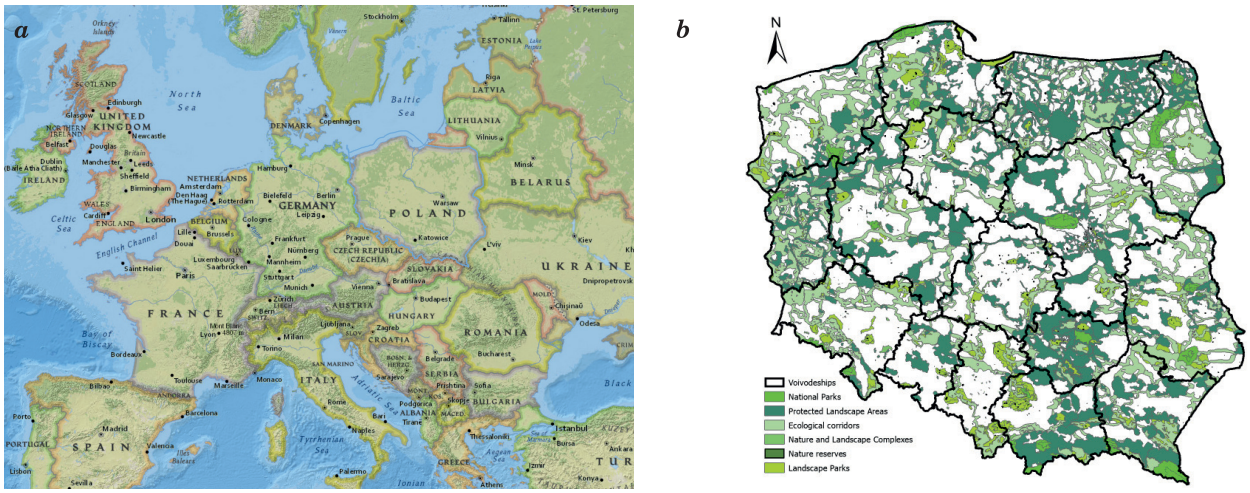

Fig. 1. Poland: (a) Location in Europe; (b) National and Landscape Parks, Protected Landscape areas, Nature reserves, Nature and Landscape Complexes, Ecological corridors

Source: own preparation.

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and in the south the mountains – the Sudetes and the Carpathians. The highest point is the Tatra peak Rysy 2499 m.a.s.l. The lowest point is located in Żuławy Wiślane – Raczki Elbląskie -1,8 m.a.s.l. Poland is a lowland country, descending in north-western direction. The area of forest land is almost 9.5 million hectares, in Poland. Figure 1 shows Poland's location in Europe and areas of National and Landscape Parks, Protected Landscape areas, Nature reserves, Nature and Landscape Complexes, Ecological corridors.

Data Description

The main idea of this research is to use simple and quickly available data from POIs (Points-of-Interest) databases. The source of data used in this paper is POIs

Table 2. Description of variables

POIs Types	POIs Description
Hotel	Buildings with at least 10 rooms (single or double rooms). A range of facilities available to customers during their stay
Hostel	A cheap place of temporary accommodation of a standard differing from a hotel mainly in the number of beds in rooms, bunk beds and sharing some equipment and rooms (e.g., kitchens, bathroom)
Motel	Buildings with at least 10 rooms (single and double rooms) located by roads with parking lot
Pension	Rooms in dwellings and houses (excluding collective accommodation facilities) and adapted farm buildings owned by farmers, rented out for overnight stays for a fee
Holiday Resort	Buildings with at least 30 beds, suitable for customer self-service and providing a minimum range of services related to the stay of customers
Private	Furnished rooms and premises in apartments, houses and other dwellings or converted farm buildings belonging to natural or legal persons (excluding farmers) which are rented out to tourists for the night against payment, excluding collective accommodation facilities such as hotels, holiday and leisure centres, guest houses, hostels, and camping grounds
Camping Sites	Guarded sites, providing accommodation in tents, camper vans and caravans, preparing meals, parking cars, as well as providing services related to the stay of clients; these sites may additionally provide accommodation in tourist cabins or other permanent facilities

Source: Act [1997].

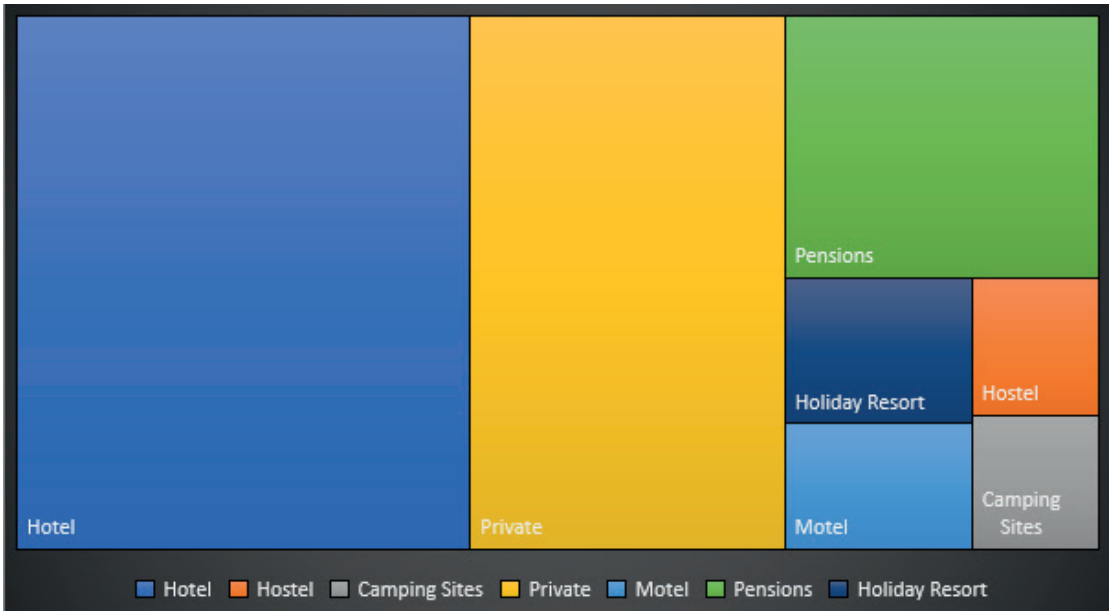

Fig. 2. The quantity of accommodation facility used in the study
Source: own preparation.

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database (www.poipoint.pl). Data was downloaded in February 2021. Data on 5743 accommodation facilities was collected. The scope of data is quite limited: type of accommodation and geographical coordinates. Table 2 shows the types of accommodation facilities with their description. Figure 2 shows the quantity of each accommodation facility.

Methods

The Kernel Density Estimation (KDE) through ArcGis Pro was used to analyze the spatial density of accommodation facilities in Poland. According to the *First Law of Geography* [Tobler, 1970], everything is related to everything else, but those which are near to each other are more related when compared to those that are further away. Thus, one can conclude that this method is based on this law, as explained in detail below.

The purpose of KDE is to generate a smooth density surface of point events over space by computing the event intensity as density estimation, and further to discover the spatial heterogeneity or inconsistency of the geographical process [Yu and Ai, 2014]. The density level is estimated using the so-called simple and kernel method. In the simple approach of the kernel density method, an area division into cells is created. Then, using the circular neighbourhood method, the density level is determined around each of the cells created. This is estimated by ratio of features number in relation to the size of the area. A smoother density surface is estimated by increasing the radius of the circular neighbourhood. This is the result of the circular neighbourhood covering more points [Läuter, 1988].

In the kernel approach of the kernel density method, during division, the area under examination has a number of cells defined by the investigator. In this method, a circular neighbourhood is estimated around each feature point and then a mathematical equation is applied that goes from 1 at the location of the feature point to 0 at the neighbourhood boundary [Anderson, 2009]. By using the kernel density method, an arbitrary spatial facility of analysis can be defined that is homogenous for the entire area, which makes the comparison and ultimately classification possible. According to Jia et al. [2018] by using the KDE method, any spatial object of analysis can be identified that is homogeneous for the whole area, which enables comparison and classification possible. Kernel Density Estimation (KDE) can be calculated using the formula at an (x,y) location to predict the density (ArcGis, 2021):

$$Density = \frac{1}{(radius)^2}\sum_{i=1}^{n}\left[\frac{3}{\pi}\cdot pop_i\left(1-\left(\frac{dist_i}{radius}\right)^2\right)^2\right] \quad (1)$$

where:

- i = 1, …, n are the input points. Only include points in the sum if they are within the radius distance of the (x, y) location;
- pop_i is the population field value of point i, which is an optional parameter;
- $dist_i$ is the distance between point i and the (x, y) location.

The calculated density in the next step is multiplied by the number of points or the sum of the population area, if such an area is given. This correction procedure makes the spatial integral equal to the number of points (or sum or population field) rather than always being equal to 1 [ArcGis, 2021]. An important part of the Kernel Density procedure is the choice of bandwidth, as this significantly affects the final results. The selection of the optimal bandwidth is influenced by the type of data and the specifics of the area under study. A large bandwidth leads to a smooth density pattern which makes it difficult to separate local hotspots, whereas, a small bandwidth leads to a sharp density pattern highlighting only individual hotspot locations [Shariat-Mohaymany et al., 2013, Jia, Khadka & Kim, 2018]. According to Anderson [2009] the KDE method, compared to clustering (K-means) or statistical hotspot methods, is more advantageous to use.

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RESULTS

In this research, using the kernel density analysis method (KDE) of POIs (hotel, hostel, motel, pension, holiday resorts, private and camping sites) was visualized, and its spatial density was determined. Points-of-interest of all types of accommodation in Poland are shown in Figure 3.

Figure 3 shows all accommodation types used in the study based on available POIs data. Based on 5743 accommodation facilities gathered from POIs point data bases (with ArcGisPro), you can observe the spatial distribution of all types of accommodation. Already this stage of work it confirms that POIs database can be an alterative source of quick, cheap, and simple spatial data. However, such a simple and

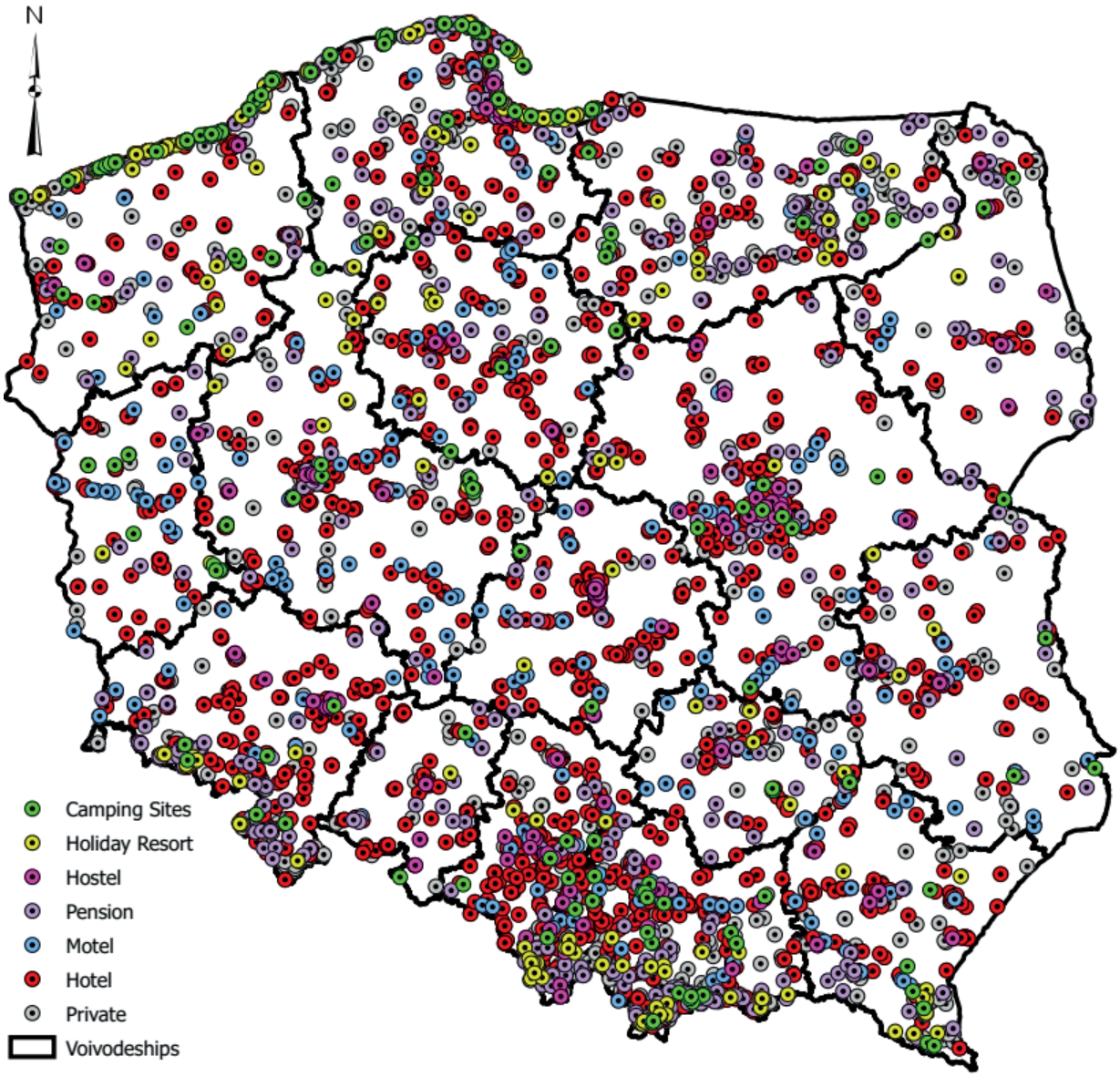

Fig. 3. Spatial diversity of all types of accommodation, based on point-of-interest, in Poland
Source: own preparation.

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effective (Fig. 3) type of spatial visualization of accommodation location has a large range of information in it. The highest density of accommodation facilities (all types) is in northern Poland (sea) and in southern Poland (mountains). Such a saturation of accommodation facilities is quite obvious and indicates tourism related to communing with nature. Further research using KDE will provide a more detailed explanation of this, for each type of accommodation individually. There is also a large concentration of accommodation facilities in the central part of Poland, near the capital Warsaw. Business and cultural tourism may be suspected here. The next stage of the research is the analysis of the spatial diversity of individual types of accommodation based on kernel density estimation (KDE), to model more accurate and smooth density all over the study area. Figure 4 shows the division of Poland into regions (a) and the KDE analysis for hotels. Figure 5 shows the kernel density estimations for hostels and models.

Figure 4a shows the area of Poland with administrative division of the country into voivodeships, to better organize the description of KDE results for various infrastructure accommodations. In the first stage, the kernel density estimation was carried out for hotels as the most numerous objects in the POIs database. The results of the kernel density analysis (Fig. 4a) show that the distribution of hotels in Poland is relatively uniform (in relation to other accommodation types). As a rule, overnight stays in hotels are related to business tourism or socio-cultural tourism (human culture). Therefore, in each of the voivodeships in Poland, we have a good hotel infrastructure. The highest kernel density of hotels has been estimated for Kraków (Małopolska – see Fig. 4a), Katowice (Śląskie), Warsaw (Mazowieckie) and the so-called Tricity (Pomorskie). This result is quite obvious because Warsaw, as the capital of Poland, is the first business tourism destination. Kraków in recent years has been a very attractive place for cultural and weekend tourism (entertainment). Katowice, as the capital of Silesia, (the energy center of Poland), is a business tourism destination. However, in the last decade the city has been changing its image towards a city of culture and art, which strengthens this area of tourism. Smaller density clusters are found near of Bydgoszcz (Kujawsko-Pomorskie) and Poznań (Wielkopolskie), it may be related to highway hubs in these voivodships.

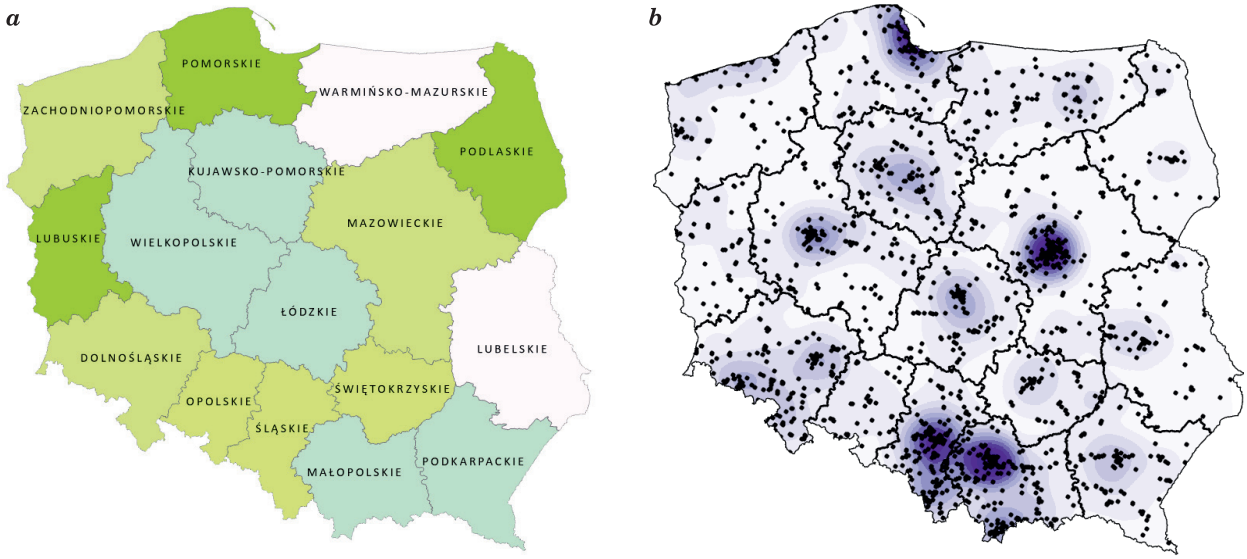

Fig. 4. Poland: (a) Administrative division of the country into provinces (voivodeships); (b) Kernel density analysis of POIs data: Hotel

Source: own preparation.

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The most impoverished eastern regions of Poland (Podlaskie, Lubelskie, Podkarpackie) have the lowest density of hotels, which is quite typical.

The spatial distribution of hostels and motels is quite similar to that of hotels in Poland (Fig. 5). Hostels are a cheap alternative to hotels (especially for foreign tourists), as they are usually well located in city centers. This feature, along with the low accommodation costs, provides an incentive for culture and entertainment tourism for youth. These assumptions are fulfilled in Warsaw, Kraków and Tricity, that's why KDE shows the highest density in these cities. In other parts of Poland you can see single hostels (Fig. 5b). Motels are usually located on the side of major highways, interstates, and ring roads and this kind of accommodation offers a convenient place to rest for travel. As you can clearly see, the kernel density of models, is less locationally clustered than hostels. KDE creates clustered states along the nation's major road infrastructure. An interesting result of the research is the large concentration of models in the Lubuskie voivodeship. This density is along the A2 highway, which leads to Berlin and all of Western Europe. The highest density is near the border with Germany and its cause is the lower cost of accommodation in Poland as a part of Eastern Europe. Figure 6 shows the kernel density estimations for private and pension accommodation.

Private accommodation (Fig. 6a) is a form of individual activity of apartment or house owners. The specificity of this market has a historical background from the time when Poland was a socialist country and its economy was centrally controlled (before 1989). Private accommodation was an acceptable form of additional income, during periods of seasonal tourist demand. Pension accommodation also have similar conditions (Fig. 6b). This has resulted in the high densities seen in Figures 6a and 6b at typical nature-based recreational tourism sites, namely the seaside and mountains. The whole part of northern Poland bordering the Baltic Sea shows a high level of concentrations, especially within 2–3 km from the sea. In the south of Poland, the typical tourist town of Zakopane is clearly visible. It is a base for mountain hiking and skiing in the winter. Another density is seen in the south-western part of Poland (Dolnośląskie) near the Sudety Mountains. The last high density is seen in the Warmińsko-Mazurskie province, which accumulates yachting tourism.

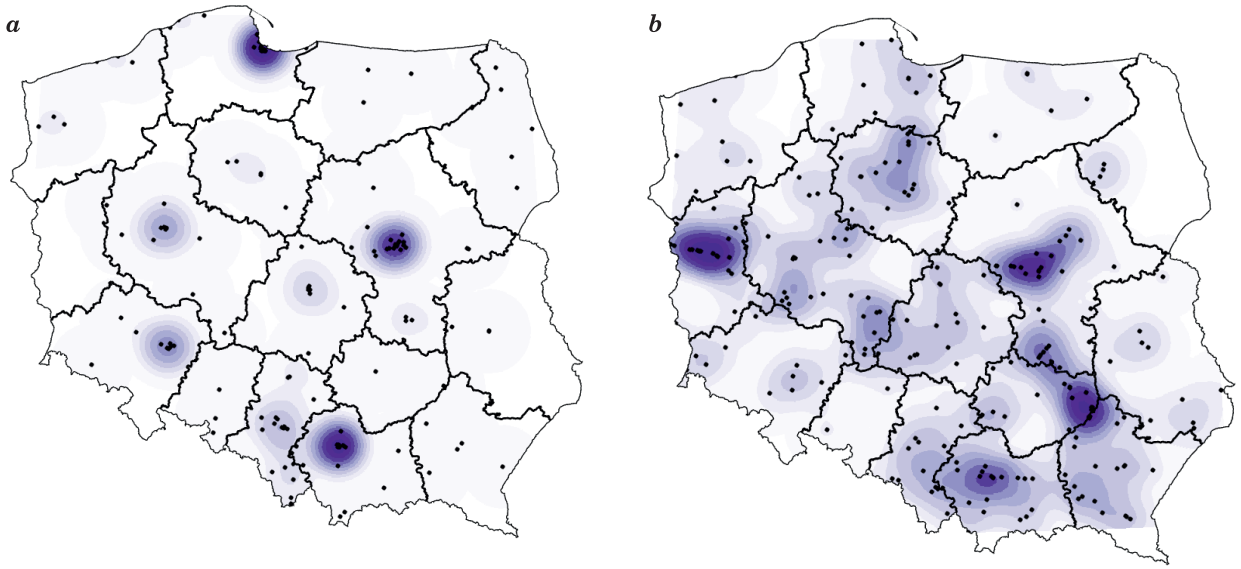

Fig. 5. Kernel density analysis of POIs data: (a) Hostel; (b) Motel
Source: own preparation.

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The colloquial name of this province, the Land of a Thousand Lakes, explains it. KDE results are significantly similar for both types of accommodation analyzed, namely, guesthouse and private. Figure 7 shows the kernel density estimations for holiday, resort, and camping sites.

The research visualized in Figure 7 shows that holiday resorts and camping sites have a very irregular spatial distribution. Due to its specific nature, this type of accommodation infrastructure is seasonal, focused on summer (in Poland from June to September). The highest concentrations of prices are therefore located in the entire coastal belt.

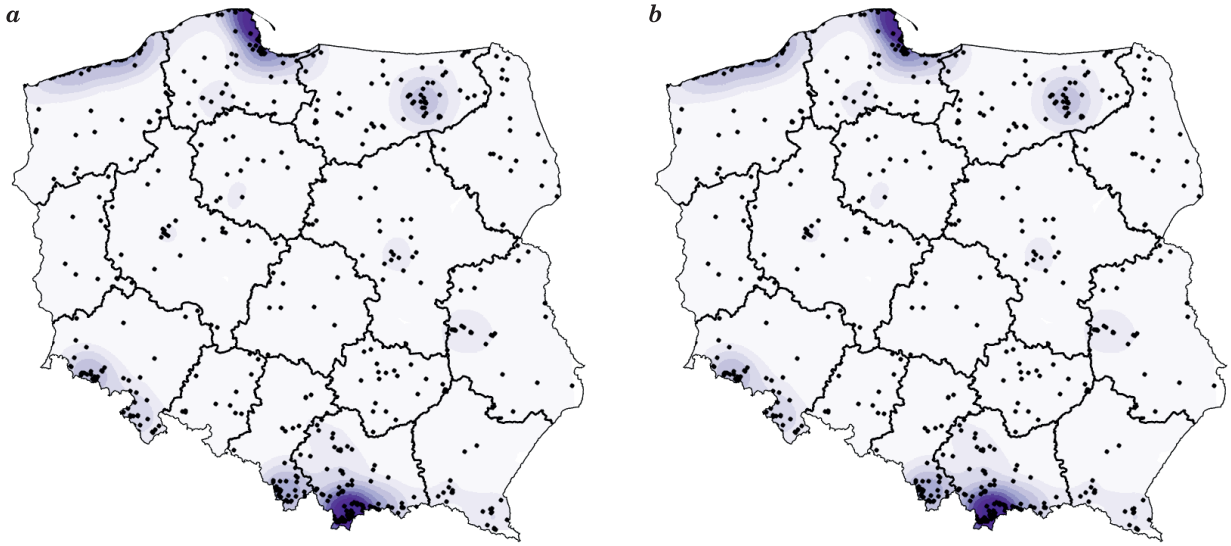

Fig. 6. Kernel density analysis of POIs data: (a) Private; (b) Pension
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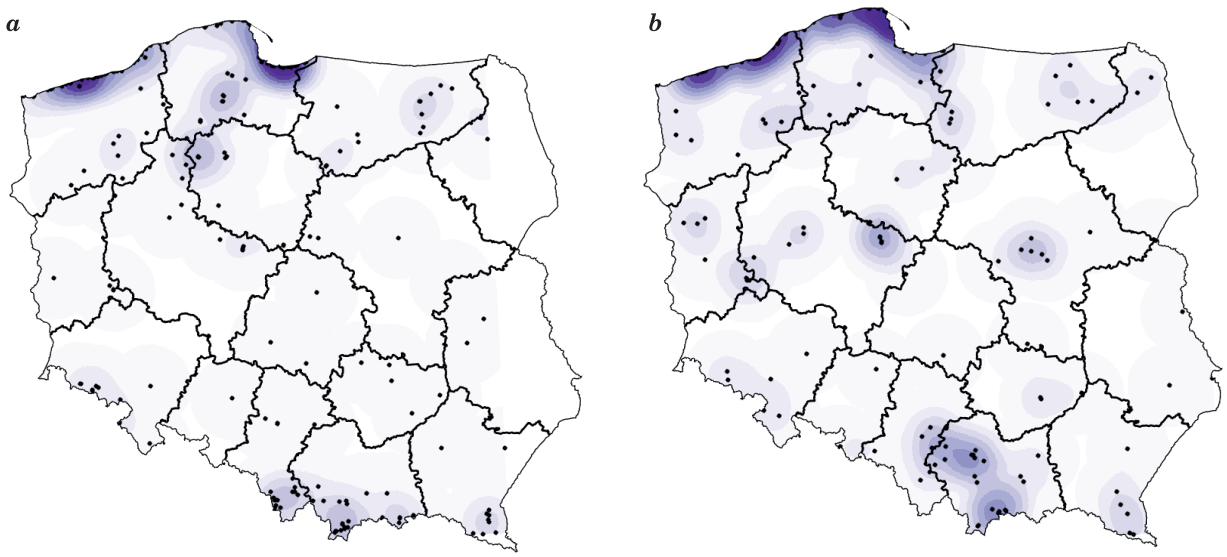

Fig. 7. Kernel density analysis of POIs data: (a) Holiday Resort; (b) Camping Site
Source: own preparation.

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CONCLUSIONS

Tourism, as an element of socio-economic geography, cannot exist without accommodation infrastructure. The intensification of accommodation in particular country areas is directly proportional to the tourist attractiveness of that place. Based on this research, it could be concluded that there is a close relationship between the type of accommodation and the type of tourist attraction. The research clearly shows that tourism focused on environmental attractions creates clusters of holiday resorts, guesthouses, private accommodation, and camping sites. Tourism focused on cultural and entertainment attractions, on the other hand, creates clusters of hotels and hostels. Motels, on the other hand, indicate places of car transit intensity in the road infrastructure.

The use of kernel density estimation (KDE) of points of interest data, allows us to quickly answer questions about the spatial distribution of different types of accommodation. This type of research procedure allows for clear and quick analyses whether you are researching a region, a country, a continent or the world. As a result, only on the basis of POIs and types of accommodation can we make conclusions about the type of dominant tourist attraction (natural environment or human cultural heritage). A great advantage of this procedure is the possibility of obtaining data from various sources, e.g., car navigation, which allow for the creation of spatial distribution of nights even without knowledge of the specificity of a given country.

Author contributions: author have given approval to the final version of the article. Authors contributed to this work as follows: M.B. developed the concept and designed the study, M.B. collected the data, M.B. analysed and interpreted the data, M.B. prepared draft of article, M.B. revised the article critically for important intellectual content.

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SAFETY PERCEPTIONS AT THE BEGINNING OF THE COVID-19 PANDEMIC IN POLAND

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ABSTRACT

Motives: The pandemic situation created unique opportunity to undertake research in the context of the changed living conditions of the population.
Aim: The main purpose is to assess broadly understood safety perceptions at the beginning of the COVID-19 pandemic in Poland. The key research tool used was a survey questionnaire (270 respondents), complemented by observations in Poznań (Poland) and photographic documentation. Hometown was chosen due to imposed restrictions on movement.
Results: The COVID-19 pandemic significantly changed people's life in many aspects and therefore affected perceived safety. Level of fear of the pandemic was varied and so was keeping up to date with information about the pandemic outcomes. Before the pandemic people felt safer in the analysed various places. Implication of the pandemic for everyday behaviour was significant, resulting e.g. in leaving home when it is absolutely necessary, working from home. Most of the imposed restrictions were rated positively.

Keywords: COVID-19 pandemic, perception of safety, Poland.

INTRODUCTION

The unprecedented events taking place in Poland since the beginning of March 2020 as a result of COVID-19 have affected, to a lesser or greater extent, the daily lives of all of us[1]. The pandemic as well as the restrictions, bans and rules imposed to curb its spread prompt reflection on a number of aspects of our social and economic life. One of them is the broadly understood sense of safety, which is one of the basic human needs [Maslow, 1954]. United Nations Habitat [2012] points out two dimensions of safety: actual and perceived. First is based on the risk of becoming a victim, second refers to people's perception of in security in the context of fear and anxiety. This research concentrates on the second dimension. Perceived safety depends on a number of factors. First, it depends on individuals emotional responses to crime, such as worry or anxiety which may influence higher level of fear of crime. Second, safety can differ in various physical and social environments [Iqbal, 2017]. In the light of this safety is influenced by three kind of spaces: physical, mental, and social.

[1] COVID-19 was first detected in December 2019 in the Hubei province in Wuhan, China.

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Nowadays, a sense of safety should be analysed in a completely new context in the light of COVID-19. As this is not an ordinary situation, it has not yet been repeatedly studied in different contexts around the world. The biological threat with which we were faced is both new and global. An unusual situation requires unconventional measures. The regulations introduced in connection with the pandemic have significantly impacted on our social and economic life. Reduced traffic on the roads, reduced public transport services, people wearing facemasks and keeping social distance, queues in front of grocery stores, closed cultural and catering facilities as well as empty playgrounds and other public spaces have become a common sight during the pandemic.

LITERATURE REVIEW

There are many publications on the virus and pandemic. However, for obvious reasons, they focus on medical issues[2]. At the time of writing the paper, the author was not aware of any scientific publications exploring the perception of safety in Poland. There is a paper on spatial and functional dimensions of the COVID-19 epidemic in Poland [Krzysztofik et al., 2020], where basic data on the COVID-19 in the regional scale of Poland are presented.

There are some papers considering safety issues. Dryhurst et al. [2020] published a paper on risk perceptions of COVID-19 around the world. They assessed public risk perception of COVID-19 in ten countries: Australia, Germany, Italy, Japan, Mexico, South Korea, Spain, Sweden, United Kingdom, United States. The researchers included: risk perception, personal knowledge, social knowledge, direct experience, social amplification, prosociality, individualism worldview, trust in government, trust in science, trust in medical professionals, personal efficacy, collective efficacy, political ideology. Ling Wong and Jensen [2020] examined the interaction between: trust in government, risk perception and public compliance in Singapore in the beginning of 2020.

Some papers focus on the strategies controlling COVID-19 pandemic. Kouřil and Ferenčuhová [2020] focused on the Czech response to the COVID-19 pandemic, "smart" quarantine and "blanket" quarantine, nationwide preventive measures, which in fact can contribute the safety on inhabitants. Wolfe [2020] gives some insights into Switzerland's and Moisio [2020] into Finland's responses into pandemic.

Won Sonn and Kwang Lee [2020] presents the successful South Korean strategy based on smart city to control pandemic. Lee et al. [2020] analyze effectiveness of the South Korean government in taming COVID-19 without forced interruptions of inhabitants's daily lives. Mayer and Lewis [2020] give some insights into the COVID-19 global health emergency and present European (Germany, Italy, Sweden) and Asian (for instance: China, Hong Kong, Taiwan, South Korea, Singapore, Vietnam) various experiences.

Group of papers concerns the impact of the pandemic on the everyday life of society. Wolfe [2020] writes on the case of Switzerland, shows how pandemic interrupted daily life. Moisio [2020] explores the role of health care in Finland.

However, also publications on past pandemics, may serve as a certain theoretical background. Some researches on risk perception comes from previous pandemics: swine flu pandemic in 2009 [for instance Prati et al., 2011, Rudisill, 2013], the Ebola Outbreak [Prati & Pietrantoni, 2016, Fischhoff et al., 2018, Yang & Chu, 2018].

An example of such publications is the Routledge Handbook of Global Health Security edited by Rushton and Youde [2017]. McInnes [2017] discussed the many meanings of health security at national and international levels, pointing out that the link between security and health is not new, but it has most often been seen in very narrow terms relating to armed conflict. Diseases may affect military capacity and armed conflicts may affect health and health care. Interest in the problem grew at the end of the 20th

[2] They are published on a regular basis by the World Health Organization https://www.who.int/emergencies/diseases/novel-coronavirus-2019/global-research-on-novel-coronavirus-2019-ncov.

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century and beginning of the 21th century, when it was noticed 'that new global health risks had appeared as a result of emerging and re-emerging diseases, increased population mobility, spreading transnational crime, environmental change, and bioterrorism; and that these posed new security dangers' [Brundtland, 2003, CIA, 2000, WHO, 2007, Yuk-Ping and Thomas, 2010].

The fight against viruses is difficult for humans because with a lack of immunity this is more of a game played by the virus on its own terms [Caduff, 2005]. The foreword to the book by Feinberg et al. [2018] mentions two resolutions of the United Nations Security Council relating to the threat posed by the Ebola virus in Africa to international peace and security [Resolution 2177, 2014, Resolution 2178, 2014]. Indeed, safety in local communities depends on joint international efforts.

THE OBJECTIVE OF THE STUDY, METHODS AND DATA USED

The aim of the paper is to assess broadly understood safety perceptions at the beginning of the COVID-19 pandemic in Poland in the light of the regulations in place. The aim was accomplished by analysing people's (1) general fear of COVID-19, (2) keeping up to date with information on the pandemic and what implications it has, (3) perception of safety in selected urban places before and during the pandemic, (4) identification with selected statements concerning different aspects of life during the pandemic, (5) opinions on the restriction imposed. Two months of the COVID-19 pandemic were taken into account, starting from the end of March and finishing at the end of May. Results of the research and discussion of results are preceded by presentation of the COVID-19 situation in Poland and its impact on social and economic life in the light of available statistical data. It gives a background for further analyses.

The key research tool used in the study was a questionnaire. A survey questionnaire was conducted to check whether Poles keep up to date with information on the number of COVID-19 cases and deaths and to determine what implications it has. In addition, the research examined the respondents' perception of safety in selected urban spaces before and during the pandemic as well as their opinions on the restrictions, bans and rules imposed. The survey also examined which of the selected statements concerning different aspects of life in the current situation Poles identify with. The survey was carried out electronically between April 17th and 27th, 2020, using a Google form, on a sample of 270 respondents. Convenience sampling was used[3]. This type of sampling is not representative, but the aim of the research was to develop an initial understanding of safety perception in the new pandemic situation. The questionnaire was posted on the social media and it was possible to share it with other people interested in responding. At that time of many legal restrictions it was the way to gather information.

The majority of the respondents were women (66.2%). The age structure of the respondents was as follows: under 18 – 2.2%, 18–24 – 24.2%, 25–34 – 24.2%, 35–44 – 27.1%, 45–54 – 14.1%, 55–64 – 5.6%, 65 and over – 2.6%. As regards the professional status of the respondents, 3.3% of them were school pupils, 24.2% were students, 75.8% were professionally active, 3.7% were unemployed, 3.0% were retired and 1.1% were retired on ill health grounds[4]. As regards the place of residence of the respondents, the largest proportion of the respondents lived in cities of over 500,000 inhabitants – 48.3%. Of the remaining respondents, 10.8% lived in cities of between 100,000 and 500,000 inhabitants, 12.3% lived in cities of between 20,000 and 100,000 inhabitants, 10.4% lived in towns of up to 20,000 inhabitants and 18.2% lived in rural areas. The respondents were also asked about whether the financial situation of their households had changed. The financial situation of a vast majority of the respondents (67.3%) had not changed. The financial situation of 24.2% of the respondents had deteriorated and the financial situation of 4.2% of the respondents had deteriorated significantly.

[3] Information about convenience sampling method: https://www.scribbr.com/methodology/sampling-methods/.

[4] The respondents could give more than one answer.

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According to 2.6% of the respondents, their financial situation had improved. The remaining respondents (1.7%) gave their own answers to the question (e.g. it will probably deteriorate in the near future, I had to give up my lease on my apartment and move back to an area with worse access to public services, which makes getting around the area and travelling from the area uncomfortable during the pandemic).

For the other complemented methods (namely observations and photographic documentation) the research area was the city of Poznań. It is located in western Poland and is the capital of Wielkopolska region. It covers an area of 261.9 km^2 and is inhabited by almost 540,000 people (population density is 2,042 pop./km^2. Poznań is author's hometown, was chosen due to imposed restrictions on movement at the time of the research. It was the only possible and eligible area, especially for observations and collection of photographic documentation. It is difficult to assess how the choice of research area affected the obtained results.

The survey questionnaire was complemented with the author's observations on: March 29th 2020 (Sunday), April 17th 2020 (Friday), April 24th 2020 (Friday), May 31st 2020 (Sunday). The photographic documentation was collected during observations. It allowed to observe people's behaviour in various spaces (recreational areas, shops, streets etc.) during the pandemic.

Study uses also data on mobility, social and economic life as a background for analyses (presented in the part 'General information on COVID-19 in Poland and its impact on social and economic life'). Google publishes COVID-19 Community Mobility Reports [https://www.google.com/covid19/mobility/] every week. It is to help people and public health officials understand responses to social distancing guidance related to COVID-19. The data shows how visits to places (concerning the following groups of places: retail and recreation, grocery and pharmacy, parks, transit stations, workplaces and residential) are changing in the geographic region. The reports are based on anonymised location data provided by, for example, Google Maps. In this study data referring to Poland were used. Relevant data regarding social and economic life used in this study were published by the Statistics Poland. They concerned the consumer prosperity and the boom in manufacturing, construction, trade and services at the early stage of pandemic.

GENERAL INFORMATION ON COVID-19 IN POLAND AND ITS IMPACT ON SOCIAL AND ECONOMIC LIFE

The first COVID-19 case in Poland was announced by the Minister of Health, Łukasz Szumowski, at a press conference on March 4th, 2020 [The First Case of Coronavirus in Poland, 2020]. On March 11th, 2020, the World Health Organization declared the outbreak of the virus a pandemic, confirming the global nature of the phenomenon.

As of the date when the survey questionnaire began (April 17th, 2020) 8,379 infections, 332 deaths and 866 recoveries had been confirmed in Poland. As of the date when the survey was completed (April 27th, 2020), 11,902 infections, 562 deaths and 2,466 recoveries had been recorded. At the end of May 2020, Poland had 23,786 infections, 1,064 deaths and 11,271 recoveries[5].

The government has gradually been introducing regulations aimed at curbing the pandemic. The regulations imposed related to, and quite significantly interfered with, different aspects of life, affecting the movement of people. Those regulations included for instance: restrictions on the organisation of mass events and gatherings, closure of educational settings and universities (and the introduction of online classes), ban on the use of green spaces, closure of shopping centres and such service businesses as hair salons, beauty parlours, etc., limits on customer numbers in shops and special shopping hours for the elderly. The restrictions have been changing[6].

[5] The current data is available here: https://coronavirus.arik.io/.

[6] The full information is available on the government's website at: https://www.gov.pl/web/coronavirus.

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On April 16th 2020, the Chancellery of the Prime Minister published a phased plan to lift the restrictions relating to coronavirus. At first, only the date when the first phase would begin (April 20th, 2020) was announced (Website of the Republic of Poland, 2020). As regards economic activity, new rules in trade and services were introduced, namely a limit of four people per till in stores of up to 100 sq. metres and a limit of one person per 15 sq. metres in stores of more than 100 sq. metres. As regards social life, Poles were permitted to use public spaces for recreational purposes (subject to social distancing and wearing a face covering) and access forests and parks (except for playgrounds), the limit on the number of people allowed in places of religious worship was increased to one person per 15 sq. metres and children aged over 13 were allowed to be in public places unaccompanied by an adult. The next phase of the reopening of the economy began on May 4th, 2020: hotels and other accommodation venues, shopping centres and some cultural venues (libraries, museums, art galleries) were permitted to reopen and rehabilitation services resumed. On May 6th, 2020, nurseries and kindergartens were reopened. The third phase began on May 18th, 2020: outdoor sport facilities (stadiums, pitches, ski jumps, tracks, 'Orlik' football fields) and open-air cinemas were permitted to open, work on film sets resumed and Poles were once again allowed to make photograph and audio-visual recordings in cultural venues, one-to-one classes at art universities resumed, limits on passenger numbers on public transport were changed (eased) and catering facilities, hair salons and beauty parlours were allowed to reopen (subject to strict sanitary rules). The fourth phase began on May 30th, 2020. First of all, Poles were permitted not to wear masks in open public spaces, subject to social distancing rules. The limit on the number of people allowed in a catering facility at any one time was lifted and gatherings of up to 150 people in open public spaces were allowed. A week later, gyms, play rooms, swimming pools, amusement parks and fitness clubs were permitted to reopen. Limits on the number of people allowed in a place of religious worship, shop, market and a post office were lifted. Moreover, Poles were allowed to organise wedding receptions and other family celebrations for up to 150 people.

Decisions to lift other restrictions will be taken by the Prime Minister following a recommendation from the Minister of Health based on an analysis of the increase in the number of COVID-19 cases, health care capacity and implementation of sanitary guidelines by the entities in charge.

The coronavirus has significantly affected our social and economic life, which is reflected in the data published by Google and the Statistics Poland. Mobility changes are linked to the restrictions imposed. In most of the places analysed, a significant drop in the number of visitors has been observed (Tab. 1), with the largest drops seen for retail and

Table 1. Mobility changes in Poland at different points at the beginning of the pandemic

Places	April 5	April 11	April 17	April 26	May 2	May 9
Retail & recreation (ie. restaurants, cafes, shopping centers, theme parks, museum, libraries, movie theaters)	-71%	-76%	-53%	-54%	-56%	-37%
Grocery & pharmacy (ie. Grocery markets, food warehouses, farmers markets, specialty food shops, drug stores, pharmacies)	+41%	-57%	-28%	+73%	-19%	-11%
Parks (ie. National parks, public beaches, marinas, dog parks, plazas, public gardens)	-59%	-57%	-44%	+10%	+25%	+79%
Transit stations (ie. Public transport hubs – subway, bus and train stations)	-68%	-64%	-61%	-53%	-50%	-32%
Workplaces	-27%	-48%	-42%	-14%	-28%	-10%
Residential	+12%	+17%	+20%	+7%	+8%	+2%

Baseline of each date: 6 weeks prior to the date.
Source: https://www.google.com/covid19/mobility/, date: 15.05.2020.

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recreation as well as transit stations. A continuous drop in visits to workplaces has also been observed. Where possible, people work from home during the pandemic. The only place where the number of visitors has gradually been increasing are residential places. In the case of two categories of places, namely grocery stores & pharmacies and parks, the number of visits has both decreased and increased recently. The initial increase in the number of people visiting grocery stores and pharmacies was due to people wanting to buy supplies of different products for a longer period of time and due to the uncertainty relating to the pandemic (there were even rumours that shops would be closed). The decrease in the number of people visiting stores may have been due to the limits on customer numbers in shops (queues were discouraging) as well as due to people buying larger quantities of products at a time or buying only essential goods, deterioration in the financial situation of Poles and the lack of fear that shops would be closed. When new, less strict guidelines relating to customer numbers in stores were introduced, a renewed increase in mobility could be observed.

Other relevant data regarding social and economic life was published by the Statistics Poland. It carried out surveys on consumer tendency [Statistics Poland, 2020a] and business tendency in manufacturing, construction, trade and services [Statistics Poland, 2020b]. According to the consumer tendency survey [Statistics Poland, 2020a], the current consumer confidence indicator[7] in April 2020 was lower by 37.7 percentage points compared with the previous month (and by 43.6 percentage points compared with April 2019). In turn, the leading consumer confidence indicator[8] was down by 45.4 percentage points (and by 51.2 percentage points compared with the same month in 2019). The survey was complemented with additional questions relating to the current situation. It is worth noting that for 95.4 per cent of the respondents, the epidemiological situation had an impact on their responses. According to 69.8 per cent of the respondents, the current epidemiological situation poses a big threat to the health of the population of Poland as a whole. Twenty-seven per cent of the respondents considered the threat to be moderate. According to the respondents, the epidemiological situation poses a smaller threat to their personal health – 50.7% of the respondents considered the threat to be big, while 38.7% considered it to be moderate. The respondents were quite unanimous in their assessment of the threat the epidemic poses to the Polish economy. Eighty-eight per cent of the respondents considered the threat to be big. For 49% of the respondents, the current situation is a big threat to everyday life in their local community, while 43.1 per cent of the respondents considered the threat to be moderate.

Business tendency in different areas of the economy during the pandemic was the worst since the surveys began [Statistics Poland, 2020b]. General business climate indicators (6) were lowest for accommodation and food service activities (-70), retail trade (-49.5), transportation and storage (-48.3). The lowest drops were observed for financial and insurance activities (-18.2) and information and communication (-19.4).

The above data shows that the COVID-19 pandemic has a huge impact on the social and economic life of the Polish society. Major changes are associated with concerns about the current situation and uncertainty about the future.

RESULTS

General fear of COVID-19 pandemic

The first question in the questionnaire concerned the respondents' fear of COVID-19. The respondents were asked to rate their fear on a scale of 1 ('not afraid at all') to 5 ('very afraid'). The breakdown of responses is as follows: 1 – 7.43%, 2 – 14.50%, 3 – 35.32%, 4 – 26.39% and 5 – 16.36%.

[7] Current consumer confidence indicator is the average of balances of the evaluations of changes in a household's financial condition, changes in the general economic situation of the country and currently made major purchases.

[8] Leading consumer confidence indicator is the average of balances of the evaluations of changes in a household's financial condition, general economic situation of the country, trends in the level of unemployment and savings in the next 12 months [Statistics Poland, 2020a].

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Keeping up to date with information on the COVID-19 pandemic and what implications it has

The next question related to whether the respondents keep up to date with information about the number of COVID-19 cases and deaths and to the potential impact of the information on the respondents' sense of safety (Tab. 2). The majority of the respondents keep up to date with the information (a total of 51.11% of the respondents). However, the impact it has on the respondents varies. The most frequently chosen answer was "I keep up to date with the information, but it seems unreliable and I am stressed about the current situation" (28.15%). The second most frequently chosen answer was: "I keep up to date with the information just to stay informed, but it does not affect my sense of safety" (20.37%). A significant number of the respondents (a total of 34.81%) declared that initially they had been keeping up to date with the information but had stopped doing so for various reasons, e.g. because they considered the information to be unreliable, because they got used to the situation or because it made them feel stressed. Of the respondents, 4.07% do not keep up to date with information about the number of COVID-19 infections and deaths.

A group of the respondents gave answers other than those included in the form. Some of the answers were very similar to those listed in the questionnaire, but there were also different or more elaborate answers. The most interesting ones were: "I check the information every couple of days, but I think that the information is false (the statistics are understated). It does not affect my sense of safety, but it makes me more and more angry at the government, which has shown that it really does not care about citizens at all – they only care about their political agenda", "I check the information from time to time to keep myself updated. There is too much information" and "Minimum verification of communications. I try to avoid stress, but I have to know the necessary information".

Table 2. Keeping up to date with, and the impact of, information about the number of coronavirus infections and deaths – % of respondents' answers

Answers	% of respondents' answers
I keep up to date with the information, but the information seems unreliable and I am stressed about the current situation	28.15
I keep up to date with the information just to stay informed, but it does not affect my sense of safety	20.37
Initially I was keeping up to date with the information, but I stopped doing so because the information seems unreliable	14.07
I keep up to date with the information and I feel stressed about the current situation	12.22
Initially I was keeping up to date with the information, but I stopped doing so because I got used to the current situation	12.22
Initially I was keeping up to date with the information, but I stopped doing so because it made me feel stressed	8.52
I keep up to date with the information and it improves my sense of safety	2.59
I do not keep up to date with the information because I do not want to get stressed	1.48
I do not keep up to date with the information because I assume that it is unreliable	1.48
I do not keep up to date with the information because I am not interested in it	1.11
Other	5.19

Source: own calculations based on the results of the survey questionnaire.

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Perception of safety in selected urban places before and during the COVID-19 pandemic

The next questions concerned the respondents' perception of safety in selected places before and during the COVID-19 pandemic. The respondents rated the following places: house/flat, staircase, workplace, own kitchen garden, own allotment, street, grocery store, pharmacy, post office, public transport stop, public transport (buses, trams) and place of religious worship. In the case of each of the places, the respondents felt safer before the pandemic than during it (Fig. 1 and Fig. 2)[9].

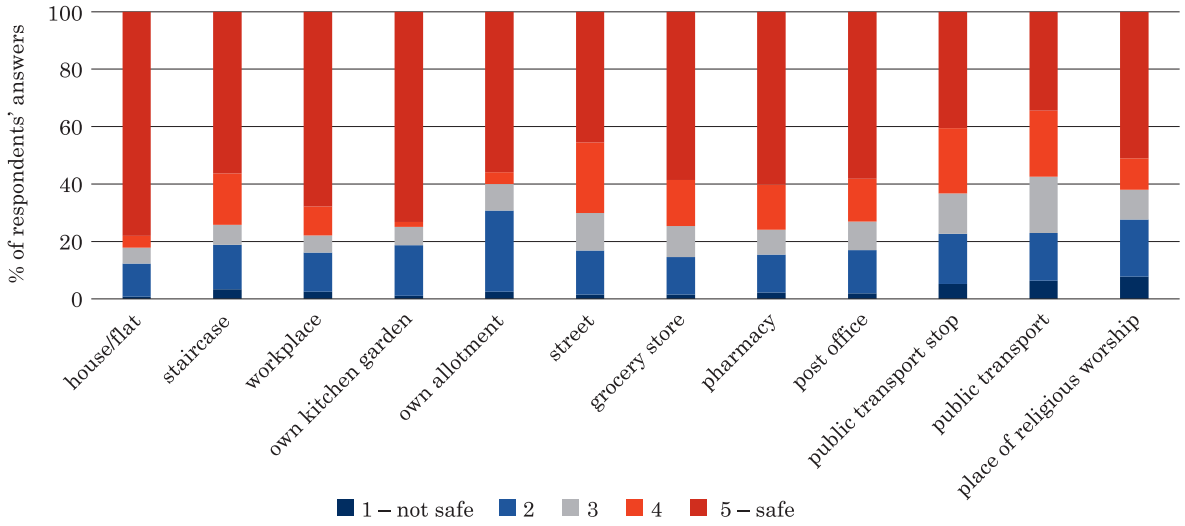

Fig. 1. Perception of safety in selected places before the COVID-19 pandemic – % of respondents' answers
Source: own analysis based on the results of the survey questionnaire.

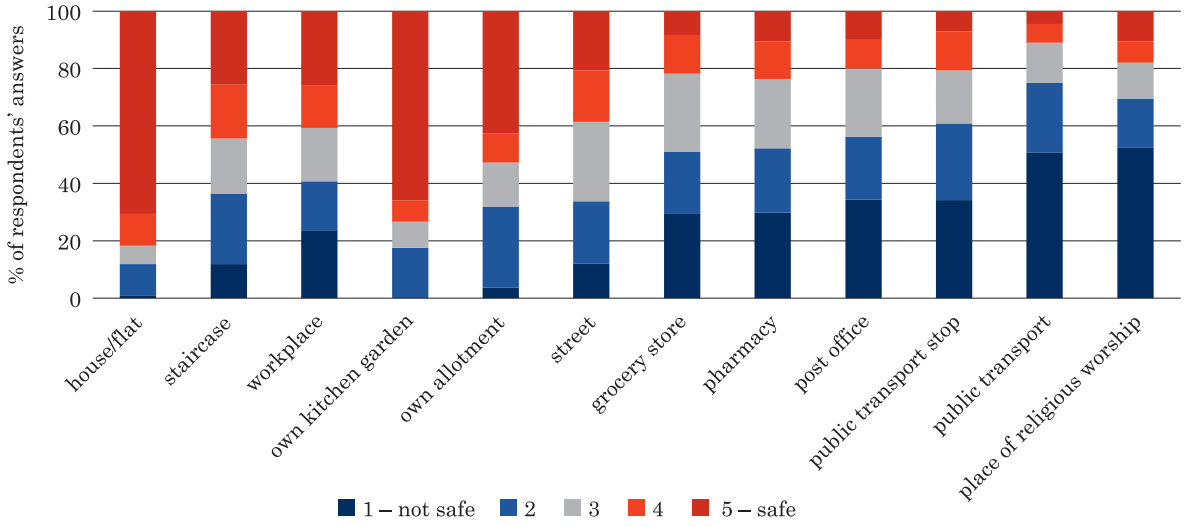

Fig. 2. Perception of safety in selected places during the COVID-19 pandemic - % of respondents' answers
Source: own analysis based on the results of the survey questionnaire.

[9] The structure of responses shown in the figures only relates to those respondents who rated a given place on a scale from 1 (unsafe) to 5 (safe). The respondents who answered "not applicable or I do not use the place" were not taken into account.

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Table 3. Perception of safety in selected places before and during the SARS-CoV-2 pandemic – statistical measures

Place	Mode		Median	
	Before the pandemic	During the pandemic	Before the pandemic	During the pandemic
house/flat	5	5	5	5
staircase	5	5	5	3
workplace	5	5	5	3
own kitchen garden	5	5	5	5
own allotment	5	5	4	4
street	5	2	5	3
grocery store	5	1	5	2
pharmacy	5	1	5	2
post office	5	1	5	2
public transport stop	5	1	4	2
public transport	5	1	4	1
place of religious worship	5	1	5	1

Source: own calculations based on the results of the survey questionnaire.

Before the pandemic, the respondents felt most safe in their own house/flat (82.16% – answers "4" and "5" combined), workplace (77.97%) and a pharmacy (75.94%). In general, in the case of all the places, the majority of ratings were positive. The lowest proportion of positive ratings was found for: public transport (57.45%), own kitchen garden (60%) and place of religious worship (61.98%). The highest proportion of negative ratings was found for: own allotment (30.83% – answers "1" and "2" combined), place of religious worship (27.60%) and public transport (22.98%).

The safety ratings for the same places during the pandemic were much lower (Fig. 2). Three of the places had predominantly positive ratings. These were house/flat (81.78%), own kitchen garden (73.40%) and own allotment (52.73%). Half of the places analysed had predominantly negative ratings (ratings "1" and "2" combined). The respondents feel least safe: on public transport (75.14%), in places of religious worship (69.54%) and at public transport stops (60.87%).

The basic statistical measures (mode and median) concerning the perception of safety in selected places before and during the COVID-19 pandemic are shown in Tab. 3.

Identification with selected statements concerning different aspects of life during the COVID-19 pandemic

In the next question, the respondents were asked to tick those statements that are true for them during the COVID-19 pandemic. A vast majority of the respondents leave their house/apartment only when they absolutely have to (70%). The second most frequently ticked statement related to concerns about the health and lives of loved ones. Some of the respondents even made additional comments[10] about it: "I am worried about my family members who are doctors. I am very worried about the health of my parents", "My life has changed a bit and I am a bit worried about the health of my dad and grandmother, but I know that the likelihood of infection is limited".

A group of statements concerned the professional activity of the respondents. A vast majority of the respondents work from home (60%). There were some who have lost their jobs during the pandemic (6.67%). Some of the respondents made various additional comments about their professional lives: "My working hours were reduced. I am employed

[10] Additional comments (the statements included the option 'other') were given by 7.41% of the respondents.

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under a contract of mandate", "I work partly from the office and partly from home (changes)", "I have not lost my job, but I am not working at the moment. I have difficulties obtaining the idle time benefit", "I am self-employed and my turnover has fallen". There were also comments from respondents who were worried about their professional future: "I am worried that the crisis will hit my industry in about 2 months and that it will be dealing with the impacts of the pandemic for a long time", "I am concerned about my financial situation and job security next year".

The survey showed interesting results regarding the financial situation of the respondents. The largest proportion of the respondents have a stable financial situation (45.19%). However, many of the respondents are worried about their financial security (39.63%). Some of the respondents have had their salary reduced (13.33%).

The pandemic has also affected the sense of safety of the respondents and their behaviour in public places. About one-fifth of the respondents feel nervous when leaving their home (20.37%). A large proportion of the respondents give other pedestrians a wide berth (45.22%). Being in grocery store or a pharmacy is stressful for 38.39% of the respondents. Almost one-fourth of the respondents try to order most products (groceries, cosmetics, etc.) to their home for safety reasons (24.44%). Fig. 3 shows a queue in front of a grocery store and a delivery to a parcel pick-up station.

A significant proportion of the respondents have stopped using public transport because they fear for their safety (38.52%). An increase in aggressive behaviour has also been observed (12.96%).

A large proportion of the respondents feel safe thanks to protective items (facemasks, single-use gloves, antibacterial gels, etc.) (21.11%). One additional comment made by one of the respondents was: "It irritates me that other people do not use masks and gloves properly (they take them off or touch them)".

According to few respondents, their lives have not changed. This answer was given by 11.11% of the respondents. The least frequently chosen answers were: "I feel safe thanks to the measures taken by the police/municipal police" (6.30%) and "I think that the health service is well prepared to deal with the COVID-19 pandemic" (4.81%).

Fig. 3. Queue in front of a grocery store and a delivery to a parcel pick-up station at Piaskowa Street in Poznań
Source: own photograph.

Some of the additional comments made by the respondents concerned leisure, and in particular physical activity: "I am not able to pursue my hobby", "I am not able to be physically active (walks, cycling)", "My life is almost like normal – I miss exercise, social contact and being able to go wherever I want", "I miss people, walks and libraries", "Let's not panic, let's keep a cool head. I think that outdoor physical activity is necessary". There were also comments about remote learning: "My school results are worse because of the switch to remote learning", "I learn at home" and "The remote education of my children is stressful for me". There were also comments about the work of the government during the pandemic: "I feel deceived by the authorities", "I am concerned about the government's and PiS's actions".

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Opinions on the restriction imposed during COVID-19 pandemic

The respondents were asked to express their opinion on the restrictions imposed during the COVID-19 pandemic (Fig. 4). The majority of the restrictions were rated positively by the respondents. The following restrictions were rated most positively: restrictions relating to the organisation of mass events and gatherings (77.86% – answers "4" and "5" combined), mandatory quarantine for people entering Poland (72.31%), restrictions relating to participation in religious events (71.95%) and suspension of passenger flights (70.87%).

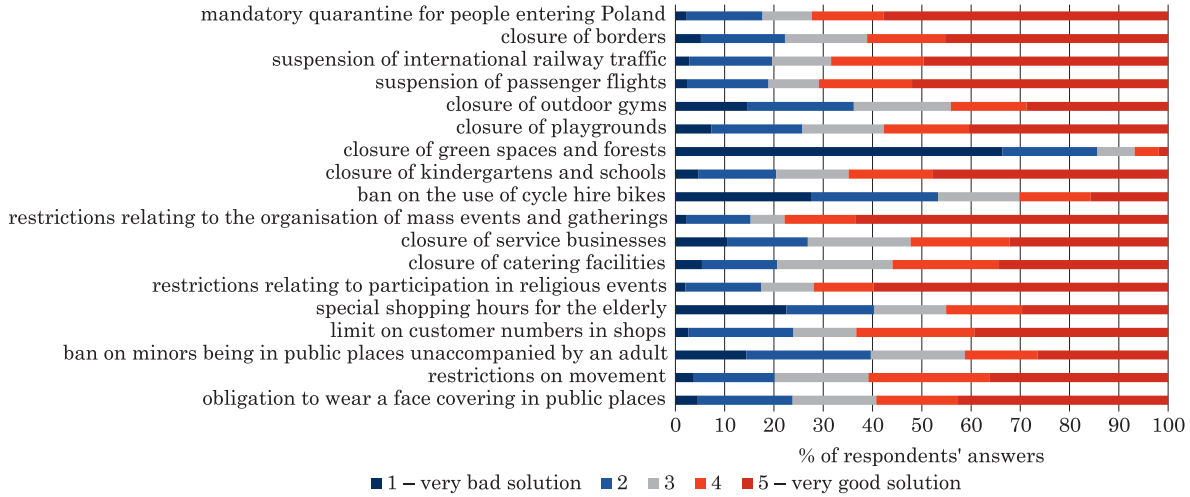

Fig. 4. Respondents' rating of the restrictions imposed during the COVID-19 pandemic – % of respondents' answers
Source: own analysis based on the results of the survey questionnaire.

Table 4. Respondents' rating of the restrictions imposed during the COVID-19 pandemic – statistical measures

Restriction/rule/ban	Mode	Median
obligation to wear a face covering in public places	5	4
restrictions on movement	5	4
ban on minors being in public places unaccompanied by an adult	5	3
limit on customer numbers in shops	5	4
special shopping hours for the elderly	5	3
restrictions relating to participation in religious events	5	5
closure of catering facilities	5	4
closure of service businesses	5	4
restrictions relating to the organisation of mass events and gatherings	5	5
ban on the use of cycle hire bikes	1	2
closure of kindergartens and schools	5	4
closure of green spaces and forests	1	1
closure of playgrounds	5	4
closure of outdoor gyms	5	3
suspension of passenger flights	5	5
suspension of international railway traffic	5	4
closure of borders	5	4
mandatory quarantine for people entering Poland	5	5

Source: own calculations based on the results of the survey questionnaire.

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Two of the restrictions were rated negatively by the respondents. These were: closure of green spaces and forests (85.66% – answers "1" and "2" combined) and the ban on the use of cycle hire bikes (53.31%).

The basic statistical measures (mode and median) concerning the respondents' rating of the restrictions, bans and rules imposed during COVID-19 are shown in tab. 4.

Fig. 5a shows green spaces when the ban on using them was in place, whereas Fig. 5b shows the green spaces after the ban was lifted. Even though people had a negative view on the closure of green spaces, they adhered to the restriction. Once the restriction was lifted, those areas once again teemed with life, as if there was no biological threat, as large numbers of people flocked to them and as catering points appeared there.

Fig. 5. Warta riverside areas in Poznań when the ban on using them was in place (a) and after the ban was lifted (b)
Source: own photographs.

DISCUSSION

The survey showed that the level of fear of the pandemic among the respondents varied. Similar findings were reported by the Public Opinion Research Centre (CBOS) [2020a] from an earlier survey carried out between March 5th and 15th, 2020, i.e. at the very beginning of the epidemic. The CBOS survey was conducted more than one month before our survey, and despite the variation in the opinions of the respondents, a decrease in the number of people who have a significant fear of coronavirus can be noticed. In addition, it is worth noting that according to half of the respondents (48%), there have always been some seasonal illnesses, influenzas, etc. and the current pandemic has been simply blown out of proportion by the media, while 46% of the respondents believed that the coronavirus epidemic might turn into a pandemic and have a lot of negative consequences for the world [CBOS, 2020a].

The majority of the respondents in our study keep up to date with information about the number of coronavirus infections and deaths. It should be noted that a large proportion of the respondents, both among those who keep up to date with the information and those who stopped doing so, believe that the information is unreliable. There is a lot of fake news in the media and, after some time, it becomes difficult to distinguish it from true news. In addition, a screaming headline that challenges our opinions may discourage us from reading a given text [Moravec et al., 2018].

A large number of people feel stressed about the current situation. As pointed out by McNaughton-Cassill [2001] and Bodas et al. [2015], stress may lead to numerous health problems. McNaughton-Cassill [2001] analysed the relation between exposure to negatively framed news on the media and anxiety and depression and found that negative stress is directly linked to anxiety and depression. In turn, a study by Bodas et al. [2015] showed that the number of people

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that tune into television newscasts increases during extraordinary events and that increased frequency of viewing newscasts is associated with reported anxiety, which may be reflected in uncontrolled fear, physiological hyperarousal, sleeping difficulties, and fearful thoughts.

Before the pandemic, the respondents felt safer in the places analysed, i.e. house/flat, staircase, workplace, own kitchen garden, own allotment, street, grocery store, pharmacy, post office, public transport stop, public transport (buses, trams) and place of religious worship. The respondents feel most comfortably in their houses/flats. The proportion of positive ratings for this space during the pandemic was only 0.38% lower compared with the ratings before the pandemic and the decrease was the lowest of the declines observed. As a result of the pandemic, the respondents feel significantly less safe. In the case of many of the places analysed, a significant decrease in safety ratings was observed. The biggest drop in the proportion of positive ratings was observed for: post office (-53.12%), grocery store (-52.82%) and pharmacy (-52.27%). During the survey, a strict limit on the number of people allowed in those places, namely four people per till/window at any one time, was in place. As a result, for example, only 12 customers were allowed in a grocery store with four tills at the same time. Consequently, large stores seemed empty, which could have potentially led to increased anxiety. There were large queues in front of stores and people observed the two-metre distancing rule. A significant decrease in safety ratings was also found for places where large numbers of people can usually be seen, namely public transport stops (-42.60%) and public transport (46.40%) as well as places of religious worship (-44.10%). It is in those places that a lot of people gather and often have contact with one another for a longer period of time. The Section for Urban Sociology of the Polish Sociological Association has started the "Empty towns" campaign, encouraging people to send photographs from different towns showing the impact of the pandemic on social life[11]. Photographs from many Polish towns were received, including: Gdańsk, Kraków, Krosno, Radom, Warszawa, Wrocław. There were also photographs of towns in countries other than Poland: Leuven (Belgium) and Lviv (Ukraine). One may say that the personal geographies of Poles shrank in the time of COVID-19, just like in Switzerland observed Wolfe [2020].

The COVID-19 pandemic has implications for our everyday behaviour. A vast majority of the respondents only leave their home when they absolutely have to (70%). In a survey by CBOS [2020b], the respondents were not asked directly about it. However, their answers to other questions (48% of them avoided public places and 34% limited their social life) show that the number of people choosing to stay home has increased as the pandemic has progressed.

Our behaviour in public places has, too, been affected by the pandemic – we give other pedestrians a wide berth and find being in a grocery store or a pharmacy, i.e. running basic errands, stressful. We have also stopped using public transport. As a result, trams and buses in towns are mostly empty.

The pandemic has also changed the way we work – a vast majority of the respondents work from home. Many people have adjusted their lifestyles to the pandemic and the numerous restrictions imposed. The respondents also expressed their concerns about their work – they worried that they may lose their jobs and that the crisis may soon hit their industry. The issue of work is inextricably linked to finance. Almost half of the respondents have a stable financial situation. However, many of the respondents fear for their financial security. A prolonged pandemic may have a negative impact on our professional lives. The results of the weekly surveys carried out by IMAS [2020] show that people are concerned about their work – more and more people worry that many companies will go bankrupt, that they will lose their job as a result of the pandemic or that they will not have sufficient financial resources for the next three months.

[11] Facebook page of the Section for Urban Sociology of the Polish Sociological Association: https://www.facebook.com/SekcjaMiastoPTS/.

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People fear for the health and lives of their loved ones. The surveys by IMAS [2020] show that more and more Poles are worried that they or their loved ones would get infected. This seems normal in view of the increasing number of COVID-19 infections and deaths and increased coverage of the coronavirus pandemic across the traditional and social media.

The respondents had varied views on the restrictions imposed during the coronavirus pandemic to curb its spread, which significantly affected the possibilities of using their living space. Most of the restrictions were rated positively, including in particular restrictions relating to the organisation of mass events and gatherings, e.g. religious events, and restrictions relating to travel, i.e. a mandatory quarantine for people entering Poland and suspension of passenger flights. Two of the restrictions were rated negatively, namely the ban on the use of green spaces and forests and the ban on the use of cycle hire bikes. Those bans have received wide coverage in the media. Poles indeed complied with the restriction on the use of green spaces and forests. However, once the restriction was lifted, those areas once again teemed with life, as if there was no pandemic. In turn, the ban on the use of cycle hire bikes, in the light of significant public transport restrictions (reduced services, number of passengers limited to 50% of the number of available seats) is not understandable.

CONCLUSIONS AND RECOMMENDATIONS

The study made it possible to elicit and reflect on the views of the respondents regarding the broadly understood sense of safety in Poland during the COVID-19 pandemic. The exceptional situation relating to the introduction of numerous restrictions relating to social and economic life has significantly affected the sense of safety among Poles and, thus, their behaviour in different places, as confirmed by the results of this study. The situation is unprecedented so far and therefore the results are revealing.

This raises several questions and doubts about the issue discussed. First, we do not know how long the pandemic will last and what further effects it will have on people's lives and their behaviour / sense of safety in different places.

Second, we do not know how the return to 'normality' will affect our functioning in different places and what consequences it will have for our behaviour / sense of safety in these places. One other question that needs to be addressed is: what is 'normality'? Does 'normality' mean the status quo of before the pandemic? Or maybe the pandemic is the so-called 'game changer' and we are facing a new reality?

Those questions/doubts confirm that further studies need to be conducted during the pandemic – once people have gotten used to the situation, immediately after the pandemic has ended – once the restrictions imposed have been lifted, and some time after the pandemic has ended – to check how the pandemic has really affected people's lives.

Author contribution: author has given approval of the final version of the article. Author developed the concept and design of the study, collected data, analysed and interpreted data, prepared draft of the article, revised the article.

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PRODUCTION EFFICIENCY OF SESAME PRODUCER FARM HOUSEHOLDS: THE CASE OF BENCH MAJI ZONE, SOUTHWEST ETHIOPIA

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ABSTRACT

Motives: Agricultural sector in Ethiopia is characterized by its poor performance, despite the livelihoods of the large population of the country depends on agriculture. Sesame is an important cash crop and plays vital role in the livelihood of many people in Ethiopia. However a number of challenges hindered the development of sesame sector along with the productivity.
Aim: This study attempted to analyze production efficiency of sesame producers in Bench Maji Zone of Southwest Ethiopia. The study used both primary and secondary data sources. Purposive sampling techniques were employed to draw 270 sesame producer farm households. Descriptive statistics and econometric models were used to analyze the data.
Results: The estimated stochastic production frontier model indicated that input variables such as inorganic fertilizer, sesame seed, oxen power, labor and chemicals found to be important factors in increasing the level of sesame output in the study area. The result further revealed significant differences in production efficiency among sesame growing farmers in the study area. Applying the Cobb-Douglas functional form the average, technical, allocative and economic efficiencies found are 50.72%, 86.83% and 44.2% for sesame producers, respectively. Also among fourteen variables used in the analysis of determinants, experience in sesame farming, education level, farm income, total cultivated land, social responsibility, frequency of extension contact, participation in off/non-farm activities, credit, proximity to market and soil fertility were found to be significant sources of technical, allocative and economic inefficiencies of sesame producer farmers. Strengthening education, extension service, credit access at affordable interest rate and accessibility of transport services and motivating farm household to participate different training as well as their experience sharing with other sesame producing farmers improve productivity of sesame production. Therefore, those important socioeconomic and institutional factors which are mentioned above must take into account to improve the productivity of sesame in the study area.

Keywords: Cobb-Douglas Function, Dual cost, Efficiency, Stochastic Frontier, Sesame.

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INTRODUCTION

Ethiopia's oilseed sector, which is rapidly growing to meet both local and foreign demand, plays a vitally important economic role in generating foreign exchange earnings and income for the country. A variety of oilseeds are grown in Ethiopia, of which sesame is by far the most important both in terms of volume, value and export earnings [NABC, 2015]. Sesame is one of the oldest oilseeds known to human being with a wide production dimension extending from the tropics to temperate zones. Globally, the top largest producers of sesame are Myanmar, India, China, Sudan, Uganda and Ethiopia [Girmay, 2018]. Evidence also indicated that Ethiopia ranked third in Africa in terms of sesame production [Wijnands et al., 2009, Hagose, 2017]. In terms of export potential, Ethiopia is the third world exporter of sesame seeds after India and Sudan [Alemu & Meijerink, 2010, Temesgen et al., 2017]. Sesame is the second major export cash crop in Ethiopia, next to coffee [Abebe, 2016].

In Ethiopia, sesame mainly grows in Tigray, Amhara and Oromia regions of Ethiopia. Southern Nations, Nationalities and Peoples Region is also becoming an area of sesame production and attraction for investors because it produces sesame that meets international standards. According to [CSA, 2017] reports on area and production of sesame by small farmers and medium/large commercial farms, the total production of sesame by both small farmers and commercial farms was 2,678,665.46 quintals from 337,926.82 hectares of land with productivity of 7.93 quintals per hectare. Bench Maji Zone is one of the potential areas for sesame production. According to Bench Maji Zone Agricultural Office 2017, the total sesame produce was 34,915.91 quintals and 8,215.35 hectares were covered by sesame with average productivity of 4.25 quintals per hectare.

Increasing agricultural production especially producing high value crops for export and productivity focusing on smallholder agriculture is continued to be a priority during the Second Growth and Transformation Plan (GTP II) as source of growth and poverty reduction through ensuring household and national food security [MoFEC, 2015]. Towards the realization of the above objectives, several policies and strategies were designed and implemented. According to studies of [Wijnands et al., 2009, Sorsa, 2009, Kostka & Scharrer, 2011, FAO, 2015, Girmay, 2018] Ethiopia has ample potential for sesame production. This is mainly linked to sesame natural flexibility to adopt different soil types and harsh environments as well as Ethiopian diversified agroecology and potential of arable land, water, labor force, and market opportunities. Additionally, there is a considerable demand for Ethiopian sesame seed at international markets [Sorsa, 2009]. This indicates that, growth and improvement of the sesame sector can substantially contribute to the economic development at national, regional and family levels.

However, despite the country has high potential to increase production and rapidly demand growth in the international market of Ethiopian sesame, the productivity of the crop is low as compared to its potential yield due to different production-related problems as indicated in studies by [Wijnands et al., 2007, Sorsa, 2009, FAO, 2015, Girmay, 2018, Hagose, 2017, Desale, 2017, Kedir, 2017]. Nowadays, sesame mainly grows in Bench Maji Zone in a wide range but its production and productivity is low as compared to national productivity. This all shows there was wider gap of inefficiency in sesame production in the study area. Although the analysis of technical efficiency of sesame farming is important, there are limited empirical studies in Ethiopia, particularly on the estimation of allocative and economic efficiencies of sesame farming in southwestern parts of the country. Understanding the levels of these efficiencies and their determinants will contribute a lot to the identification of production constraints at farm level and thereby improve the food security and income of farm households. This study, therefore, sought of analyzing production efficiency of sesame producer farm households in Bench Maji Zone, Southwest Ethiopia. Specifically, the study aimed to estimate the level of technical, allocative and economic efficiencies of sesame producers; to identify the determinants for variation of inefficiencies of sesame producers in the study area.

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RESEARCH METHODOLOGY

Description of the Study Area

Bench Maji Zone is one of the zones in Southern Nations, Nationalities and Peoples Region, Ethiopia. The zone has a total area of 19965.90 km^2. It lies between $5^0$33'-$7^0$21' latitude and $34^0$88'-$36^0$14' longitude with an elevation ranging 500 up to 2005 meters above sea level. The zone has a total estimated population (in 2015) of about 806,381 [CSA, 2013]. The agroecology of the zone, out of the total land size 52% Kola, 43% Weinadega and 5% Dega. The mean annual temperature of the zone ranges between 15.1–27^{0}C and the mean annual rain fall ranges 400–2000 mm. According to the land utilization data of the region, 174,678 ha cultivated land, 335,030 ha forest, bushes and shrub covered land, 79,248 ha grazing land, and 493,395 ha of land is covered by others [BMZAO, 2017].

Types, Sources and Methods of Data Collection

Both primary and secondary data sources were used. Primary data was collected from sample farm households using interview schedule. The questionnaire was pre-tested and amended based on the feedback received during pre-test. The enumerators, who can speak the local languages and are familiar with the culture of the local people was selected and trained on data collection procedures and interview techniques in order to simplify the complexity of data collection. Secondary data sources was obtained from Meinit Goldiya and Guraferda Districts Agriculture Office, governmental and non-governmental institutions reports and others including both published and unpublished documents.

Sampling Technique

Purposive and three-stage random sampling techniques were employed for this study. Two Districts, namely Meinit Goldiya and Guraferda, were purposively selected based on the potentiality of sesame production from 9 (Nine) districts of Bench Maji Zone. In first stage, *Kebeles*[1] in each District was grouped in to sesame growers and non-growers. In the second stage, among the sesame growing *kebeles*, seven *kebeles* (*Kushanta*, *Dega* and *Genbab kebeles* from Meinit Goldiya district and *Kuja*, *Gabika*, *Semerta* and *Sega kebeles* form Guraferda district) were selected randomly. Third stage, from the list of 9210 sesame producers in Bench Maji Zone, 270 sample households was selected randomly, using probability proportionate to size. Sample size was determined following a simplified formula provided by Yamane [1967]. Accordingly, required sample size at 95% confidence level with degree of variability of 5% and level of precision equal to 6% was used.

$$n = \frac{N}{1 + N(e)^2} = \frac{9210}{1 + 9210(0.06)^2} = 270 \quad (1)$$

Where, n sample size, N population size (sampling frame) and e level of precision considered 6%.

METHOD OF DATA ANALYSIS

Descriptive statistical tools such as mean, standard deviation, percentages and frequency were used. In the econometric analyses model the stochastic frontier model along with dual cost frontier is applied to estimate efficiencies and the relation between farm level socio-economic and institutional variables.

To estimate sesame production efficiency, the parametric stochastic efficiency decomposition approach, in which an additional random error v_i is added to the non-negative random variable u_i, was specified as follows in Equation 2.

$$y_i = f(x_i; \beta_j) + v_i - u_i \quad (2)$$

Where: i – is the number of sesame producing farmers, y_i – is sesame output measured in quintals, x_i – is a vector of input quantities used by the i^{th} sample farmer, β_i – is a vector of unknown parameter to be estimated, f(.) – is Cobb-Douglas production function, v_i – is the random error term, independently

[1] *Kebele* is the lowest administrative unit.

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Table 1. Description of the variables used in parametric stochastic production and cost frontier analysis

Variable Notation	Type	Description and measurement	Expected sign
Ln (SOUTP)	Continuous	Natural log of the total output of sesame obtained from the i^{th} farm in quintal	
Ln (LAND)	Continuous	Natural log of the total amount of land allocated for sesame in hectare by the i^{th} household	+
Ln (FERT)	Continuous	Natural log of the total amount of inorganic fertilizer in kilogram applied by the i^{th} household	+
Ln (OXN)	Continuous	Natural log of the total number of oxen days used by the i^{th} household	+
Ln (LABOR)	Continuous	Natural log of the labor force (family and hired) which is all measured in terms of man-days	+
Ln (SEED)	Continuous	Natural log of the quantity of sesame seed used by the i^{th} household measured in kilograms	+
Ln (PEST)	Continuous	Natural log of the quantity of chemicals such as herbicides or pesticides used as an input by the i^{th} household measured in Liters	+
Ln (C_i)	Continuous	Natural Log of the minimum cost of sesame production for the i^{th} household measured in Birr	
Ln (Px_1)	Continuous	Natural log of total rental price of land per hectare (Size of land * Price/hectare) measured in Birr	+/-
Ln (Px_2)	Continuous	Natural log of the total price of seed (Kilograms * price/kg) measured in Birr	+/-
Ln (Px_3)	Continuous	Natural log of the total price of fertilizer per hectare (Kilogram * Price/kg) measured in Birr	+/-
Ln (Px_4)	Continuous	Natural log of the total price of oxen days used by the i^{th} household measured in Birr	+/-
Ln (Px_5)	Continuous	Natural log of the total price of labor during farming measured in Birr	+/-
Ln (Px_6)	Continuous	Natural log of total price of chemicals such as pesticides and herbicides (Liter * price/liter)	+/-
Age	Continuous	Refers to the age of the household head measured in terms of years	-
Farming Experience	Continuous	Experience of household head in sesame farming; measured in years	+
EDUC	Continuous	Highest level of formal education (grades) completed in years	+
Family Size	Continuous	Number of people in the household in terms of count	+
Off/non-farm activity	Dummy	It is a dummy variable & measured as 1 if the household is involved in off/non-farm activities and, 0 otherwise	+
Livestock holding	Continuous	The number of livestock owned by the household in terms of TLU	+/-
Total cultivated land	Continuous	Refers to the area of cultivated land allocated to all crops that the house hold managed in terms of hectare	+
Farm Income	Continuous	It is the amount income obtained from farm activities measured in Ethiopian Birr	+
Frequency of ex-contact	Continuous	Frequency of the extension agents visit farm of households measured in terms of count	+
Credit Amount	Continuous	It is the amount of money that the household head borrowed from formal and informal financial institutions measured in Ethiopian Birr	+
Proximity to farm	Continuous	It is the average distance of the farm plots from the residence of the household measured in kilometers or walking minutes	+
Soil Fertility	Dummy	It takes a value of 1 if the household head perceives his/her plots as fertile and 0 otherwise	+
Proximity to Market	Continuous	Distance from the household's residence to the nearest market in terms of walking minutes	-
Social Responsibility	Dummy	It is a dummy variable that takes a value of 1 if the household head participate in social responsibility and 0 otherwise	-

Source: own elaboration.

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and identically distributed as $v_i \sim N(0, \delta_v^2)$ is intended to capture events beyond the control of farmers, u_i – it is a non-negative random variable as $u_i \sim N(\mu, \delta_u^2)$ is intended to capture technical inefficiency of the i^{th} farmer.

The technical efficiency (TE_i) of the i^{th} – farmers can be estimates by using the expectation of u_i conditional on the random variables (ε_i) as shown by Battese and Coelli [1995]. The TE_i of an individual farmer is defined in terms of the observed to the corresponding frontier output given the level of input can be calculates as

$$TE_i = \frac{y_i}{y^*} = \frac{exp(x_i\beta_j + v_i - u_i)}{exp(x_i\beta_j + v_i)} = exp(-u_i) \quad (3)$$

The functional relationship between input and output used in the SPF can be specified as follows:

$$LnSOUTP = f(\beta_0 + \beta_1 \ln LAND + \beta_2 \ln FERT + \beta_3 \ln OXN + \beta_4 \ln LABOR + \beta_5 \ln SEED + \beta_6 \ln PEST + \varepsilon_i) \quad (4)$$

Where: *SOUTP* – it is the total output of sesame obtained from the i^{th} farm in quintal[2], *LAND* – is the total amount of land allocated for sesame in hectare by the i^{th} household, *FERT* – is the total amount of Inorganic fertilizer in kilogram applied by the i^{th} household, *OXN* – the total number of oxen days used by the i^{th} household, *LABOR* – is the labor force (family and hired) which are all measured in terms of man-days, *SEED* – is the quantity of sesame seed used by the i^{th} household measured in kilograms, *PEST* – is chemicals such as herbicides or pesticides used as an input by the i^{th} household, $f(\ )$ = Appropriate functional form (e.g. Cobb-Douglas or Translog functional form), $\beta_{1-}\ \beta_6$ = vector of unknown parameters to be estimated, and ε_i = composed error term; and β_0 = is the y – intercept, and where: $\varepsilon_i = v_i - u_i$

The dual cost frontier was computed as:

$$LnC = \ln \alpha_o + \alpha_1 \ln P x_1 + \alpha_2 \ln P x_2 + \alpha_3 \ln P x_3 + \alpha_4 \ln P x_4 + \alpha_5 \ln P x_5 + \alpha_6 \ln P x_6 + \alpha_7 Y^* \quad (5)$$

Where, C – is minimum cost of production per sesame farmer, Px_1 – is the seasonal rent of a hectare of land in the study area (Birr), Px_2 – is the cost of seed (Birr), Px_3 – is the Cost of fertilizer (Birr), Px_4 – is the cost of oxen (Birr), Px_5 – is the cost of labor (Birr) and Px_6 – is the cost of chemicals (Birr), Y^* – is the output of sesame in quintals adjusted for statistical noise, α_1-α_6 are parameters to be estimated, a_0 is the y – intercept. It is expected a priori that the coefficients of Px_1, Px_2, Px_3, Px_4, Px_5 and Px_6 will be positive. The list of the variables used in the parametric stochastic Cobb-Douglas production, dual cost frontier and inefficiency effect model and their expected signs are summarized (Table 1).

RESULTS AND DISCUSSION

Descriptive statistics of variables used in the stochastic frontier model

The production function was estimated using six input variables. To draws some picture about the distribution and level of inputs, the mean and range of input variables presented in Table 2. The average sesame yield produced by farm households was 3.98 quintal per hectare, with a standard deviation of 3.31, maximum of 17.5 and minimum of 0.67 quintal per hectare which is dependent variable in the production function (Table 2). The higher standard deviation result shows high variability of sesame yield among the sample households in the study area. The land allocated for sesame production, by sampled farmers, ranges from 0.22 to 2.25 hectare with average land size and standard deviation of 0.69 hectare and 0.42 respectively. The average amount of inorganic fertilizers applied in the production of sesame by sampled households was 33.97 kg per hectare. There was high variation of fertilizer utilization in sesame production by sample households. Also, 42.59% of sesame

[2] 1 quintal = 100 kilogram.

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producers did not yet apply any fertility improvement inputs in their sesame farm (i.e., they perceive their soil fertility status as moderate or fertilizer). Whereas, the remaining 57.41% had applied inorganic fertilizer even though it was not as per the recommended rate (100 kilogram per hectare) for both inorganic fertilizers UREA and DAP (Table 2). Sample households, on average, use 42.41 man days per hectare of labour for the production of sesame during survey period. The average oxen power used by sample households was 11.67 oxen days per hectare. The other very important variable, out of which production is impossible, is seed. The amount of seed sample households' used was 12.70 kg, on average (Table 2). This indicates that the average seed rate application for sesame production by sample households is less than the research recommended seed rate of 7–10 kilogram under rain feed condition for broadcast planting. On average, sampled households applied 0.55 liter of chemicals such as herbicides, insecticides and pesticides per hectare in the study area for the protection of sesame farms (Table 2).

Table 2. Output and input variables used to estimate the production function

Variable description	Summary statistics			
	Mean	Standard deviation	Maximum	Minimum
Sesame output (Qt)	3.98	3.31	17.5	0.67
Land (Ha)	0.69	0.42	2.25	0.22
Seed (Kg/Ha)	12.70	11.12	38	2.12
Human labor (MDs/Ha)	42.41	20.82	128	14
Oxen power (ODs/Ha)	11.67	6.56	31.75	1.789
Inorganic fertilizer (Kg/Ha)	33.97	41.02	150	0
Chemicals (Lit/Ha)	0.55	0.78	2.75	0

Source: computed from survey data, 2018.

Econometric Model Outputs

This section presents the econometric model outputs of production function, individual efficiency scores and sources of differences in production efficiency in the study area are discussed.

Test of hypothesis

Tests of hypotheses for the parameters of the frontier model were conducted using the generalized likelihood ratio. Accordingly four hypotheses were tested, to select the correct functional form for the given data set, for the existence of inefficiency, for variables that explain the difference in efficiency.

The first test was made based on the value of likelihood ratio (LR) statistics, which can be computed from the log likelihood value obtained from estimation of Cobb-Douglas and Translog functional specifications. Then, this computed value is compared with the upper 5% critical value of the χ^2 at the degree of freedom equals to the difference between the numbers of explanatory variables used in the two functional forms (in this case df = 21). For the sample farm households, the estimated log likelihood values of the Cobb-Douglas and Translog production functions were -265.25 and -259.69, respectively. The computed value of likelihood ratio (LR = -2(259.69–265.25) = 11.12 is lower than the upper 5% critical value of the χ^2 with its respective degree of freedom (Table 3). Thus, the null hypothesis that all coefficients of the square and interaction terms in Translog specification are equal to zero was not rejected. This implies that the Cobb-Douglas functional form adequately represents the data.

Table 3. Generalized likelihood ratio tests of hypothesis for the parameters of SPF

Null hypothesis	LH_0	LH_1	Calculated χ2 (LR) value	Critical χ2 value	Decision
H_0: = $\beta_{7...}$ β_{27} = 0	-265.25	-259.69	11.12	32.67	Accept
H_0: γ = 0					Reject H_0
H_0: = δ_1 = … δ_{14} = 0	-286.03	-265.25	41.55	23.68	Reject H_0

Source: computed from survey data, 2018. *δ*

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The second null hypothesis was H_0: γ = 0, which specifies that the inefficiency effects in the stochastic production function were not stochastic. Since after fitting the function with the required defined variables the model output found that, log likelihood value = 265.25 (chibar^2 (01)-value = 20.64 and p< = 0.000). Hereafter, the decision of null hypotheses H_0: γ = 0, which specifies that the inefficiency effects are absent from the model is rejected at 1% level of significance for the sample households. The coefficient for the discrepancy ratio (γ) could be interpreted in such a way that about 96.3% of the variability in sesame output in the study area was attributable to technical inefficiency effect, while the remaining 3.7% variation in output was due to the effect of random noise (Table 3).

The third null hypothesis that the explanatory variables associated with inefficiency effects are all zero (H_0: $\delta_1=\delta_2\ldots=\delta_{14}=0$) was also tested. To test this hypothesis likewise, LR (the inefficiency effect) was calculated using the value of the Log-Likelihood function under the stochastic production function model (a model without explanatory variables of inefficiency effects: H_0) and the full frontier model (a model with explanatory variables that are supposed to determine inefficiency of each: H_1). The calculated value λ_{LR} = -2(265.25–286.03) = 41.55 is greater than the critical value of 23.68 at 14 degree of freedom (Table 3) the value of LR implying that, the null hypothesis (H_0) that explanatory variables are simultaneously equal to zero was rejected at 5% significance level.

Estimation of parameters of production function model

The result of the Cobb-Douglas stochastic production frontier showed that amount of seed, inorganic fertilizer, oxen power, human labour and chemicals such as pesticides and herbicides inputs were found to positively and significantly (at 1% significance level except inorganic fertilizer and chemicals which is at 10% level of significance) which are important variables in shifting the frontier output to the right as indicated in (Table 4). This indicated that at each and every unit of these variables there is a possibility to increase the level of output. But the amount of land under sesame is insignificant. This may imply absence of significant variation in the amount land used among households in sesame production in the study area.

One of the appealing features of the Cobb-Douglas functional form is the direct interpretation of its parametric coefficients as a partial elasticity of production with respect to the input used. This attribute allows one to evaluate the potential effects of changes

Table 4. OLS and Maximum likelihood estimate of stochastic production frontier model

	OLS estimate model		Maximum likelihood estimate of SPF	
Variable	Coefficients (Stand.Err)	t-value	Coefficients (Stand. Err)	Z-value
Ln(Land)	-0.00889 (0.05009)	-0.18	-0.00637 (0.03472)	-0.18
Ln(Fertilizer)	0.03114 (0.02130)	1.46	0.03058* (0.01629)	1.88
Ln(Oxen)	0.24008** (0.10039)	2.39	0.22676*** (0.07087)	3.20
Ln(Labor)	0.46759*** (0.14991)	3.12	0.45716*** (0.10412)	4.39
Ln(Seed)	0.20737 ** (0.09298)	2.23	0.23615*** (0.07539)	3.13
Ln(chemicals)	0.13667 (0.08667)	1.58	0.12063* (0.06671)	1.81
Intercept	-0.83388 (0.60268)	-1.38	0.01502 (0.45182)	0.03
Gamma (γ)			0.963***	
LR			-265.2526	
F statistics	5.72***			
Returns to scale			1.065	

*, ** and ***, means statistically significant at 10%, 5% and 1%, level of significance respectively
Source: computed from survey data, 2018.

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in the amount of each input on the output. The input variables inorganic fertilizer, sesame seed, oxen power, human labour, and chemicals are the main inputs in determining the output level of sesame for sample farmers in the study areas. Whereas, the elasticity of land allocated for sesame is very low implying that this have less effect in determining the output level at the best practice (the maximum technical efficiency score).

The positive coefficients of inputs indicate a 1% increase in inorganic fertilizer, sesame seed, oxen power, human labour and pesticides yields 0.03%, 0.24%, 0.23%, 0.46% and 0.12% increase in sesame output respectively. In other words, if all the inputs are increased by 1%, sesame output would increase by 1.065% as presented in Table 4 above. Labor was found to be statistically significant and with expected sign. Hence there may be shortage of labor during sesame production. This means there is overlapping of sesame farm activities with other crops usually happened and shared the available labors. Based on the estimated parameters of the Cobb-Douglas production function shown in Table 4, the parameters of the corresponding dual cost function were derived and formed the basis for computing allocative and economic efficiency indices. The dual cost frontier is given by:

$$LnC = 7.813 + 0.069Px_1 + 0.084Px_2 + 0.012Px_3 + 0.018Px_4 + 0.131Px_5 + 0.066Px_6 + 0.035Y^*$$

Production efficiency scores of sample households

As indicated in Table 5 below, the results of the efficiency scores indicated that there were wide ranges of differences in efficiency among sesame growing households in the study area. The mean technical efficiency of sample households during the survey period was 50.72%. The technical efficiency among households ranged from 7.06% to 91.35% (Table 5). This wide variation in household specific efficiency levels is consistent with study conducted by [Abu et al., 2012, Ike & Inoni, 2006, Ermiyas et al., 2015].

Table 5. Summary statistics of estimated TE, AE and EE of sample households

Description	Mean	Standard deviation	Maximum	Minimum
TE	0.5072108	0.2454264	0.9135043	0.0706201
AE	0.8683139	0.085605	0.9751402	0.5218924
EE	0.4420332	0.2212191	0.8209329	0.0633757

Source: computed from survey data, 2018.

Similarly, the average predicted allocative efficiency of smallholder sesame producers in the study areas is 86.83%, ranging from 52.19% to 97.51% (Table 5). Applying this procedure, the study found that the mean economic efficiency of sesame producers was 44.2% ranging from 6.34 to 82.09%. The mean economic efficiency found in this study for sesame producers is similar with the studies of [Endrias et al., 2013, Abu et al., 2012, Mekonnen et al., 2013, Ermiyas et al., 2015]. This also indicates the existence of substantial economic inefficiency in the production of sesame during the survey period (Table 5).

Determinants of efficiencies in sesame production

In previous section, information about the existence of production inefficiency and measuring its magnitude, examining the major factors causing this inefficiency level is the next most important step of this study. The driving force behind measuring households' efficiency in sesame production is to identify determinants to generate information in order to make an intervention and improve the existing level of efficiency. About 14 variables were hypothesized to affect level of technical, allocative, and economic inefficiency of sesame producers in the study areas, out of which three of them were dummy variables and the remaining were continuous variables. Most of the variables were discussed in the descriptive result section above. Hence, here only some of the variables in the inefficiency model were discussed.

The coefficient of sesame farming experience is positive as expected for both TE and EE significant at 1% and 5% respectively. This indicated that increased

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farming experience may lead to better assessment of importance and complexities of good farming decision, including efficient use of inputs. This result is in consistent with the finding of [Kingsley et al., 2015, Berhan, 2015]. As expected, education level of the household head has a positive and significant effect on TE at 5% but have unexpected sign for AE and EE of sesame production at 5 and 10% level of significance, suggesting that better educated household head can understand agricultural instructions easily, have higher tendency to adopt improved agricultural technologies, have better access to information, and are able to apply technical skills imparted to them than uneducated ones. Thus, the level of education of household head emerges as an important factor in enhancing efficiencies of sesame production in the study areas. This result is consistent with other similar studies such as [Arega & Reshid, 2005, Msuya et al., 2008, Sisay et al., 2016].

The model result shows that farm income have positive and significant effect on farmers' technical efficiency in production. This shows that households having better farm income would devote their time and effort in day to day farming activities and able to use improved technologies thereby production efficiency improved. Also, farmers with more income from the farming sector could have the chance of buying the required inputs for sesame production. This finding is in line with the studies of [Berhan, 2015, Penda & Asogwa, 2011, Daniel, 2016]. The result in Table 6 shows that, the coefficients of off/non-farm activities indicated that the variable affects the level of allocative efficiency positively and significantly. In other words, those households engaged in some off/non-farm activities are more efficient relative to those who were not engaged in activities other than their farm operations. The possible explanation is that it would assist the households to supplement other costs associated with their living, perhaps. The result obtained is consistent with studies conducted by [Hassen & Wondimu, 2014, Ermiyas et al., 2015]. This implies that farmers with more off/non-farm income were technically efficient than their counterparts even if it has insignificant in technical efficiency.

Table 6. Model results on production efficiency of sesame production significant variables

Variables	TE		AE		EE	
	Coefficient	Std.Err	Coefficient	Std.Err	Coefficient	Std.Err
Age	0.003756	0.010507	-0.001843	0.001887	-0.006608	0.008425
Sesame farming experience	-0.115749***	0.035325	0.003592	0.005218	-0.052338**	0.0233716
Education Level	-0.112688 **	0.047575	0.0287998*	0.014732	0.076292**	0.036524
Family size	0.037461	0.044289	-0.007470	.0074505	0.018363	0.033239
Off/non-farm activity	0.000100	0.000122	-0.007479***	0.002806	-0.000113	0.000097
Farm income	-0.000385***	0.0001063	0.0029776	0.075399	0.000225***	0.000079
Total cultivated land	-0.560713*	0.3197096	0.0857461	0.053451	0.368759*	0.219108
Extension contact frequency	-0.062574	0.0895049	0.0335769**	0.014158	0.0386882	0.0624756
Credit Amount	0.0196534	0.0123576	-0.005373**	0.002343	-0.0166639*	0.0100841
Livestock holding	-0.0483543	0.0317711	0.0035908	0.004796	0.0062035	0.0213434
Proximity to farm	0.0948362	0.0763032	0.0040572	0.008106	-0.0789699	0.0655422
Soil fertility status	-0.859717 ***	0.2578617	-0.0575575	0.04166	-0.774897***	0.1855452
Social Responsibility	-0.378203*	0.211051	-0.082360**	0.036374	-0.416829**	0.162718
Proximity to market	0.177999***	0.0568428	0.027953**	0.009679	0.159124***	0.043517
Constant	2.279698 **	1.076654	3.480399**	.7046029	0.7625497	0.806685

*, ** and ***, means statistically significant at 10%, 5% and 1%, level of significance respectively
Source: Model output, 2017/18.

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Extension contact has negative sign and is significant at 5% significance level. Thus, this result shows that consultation of extension agents increase sesame production by decreasing level of allocative inefficiency. This implies that the more the household had extension visit, the less he/she would become inefficient and the household thereby giving a room for improvement in farm efficiency. This result is in line with the results of [Fekadu, 2004, Musa, 2013, Hailemaraim, 2015]. Contrary to this, Jema [2008] found positive relationship between level of inefficiency and extension service. The coefficient of amount of credit had a positive and significant effect on both allocative and economic efficiencies at 5% and 10% significance level respectively. It is an important element in agricultural production systems. It allows producer to satisfy their cash needs induced by the production cycle. Credit availability shifts the cash constraint outwards and enables farmers to make timely purchases of those inputs that they cannot provide from their own sources. This finding was consistent with [Mussa, et al., 2012, Meftu, 2016].

Social responsibility of the household head has a positive and significant effect on TE, AE and EE of sesame production at 10 and 5% level of significance, suggesting that responsibility in different social and committee leadership give the farmers opportunity of sharing information on improved production techniques by interacting with other farmers and experts thereby improve efficiency of sesame production. Also, the coefficient of soil fertility status is positive and significant at 1% level of significance for TE and EE. This implies that, fertility of land is an important factor in influencing the level of inefficiency in the production of sesame or positively contributes to economic efficiency of sesame. This implies that households who allocated land which was relatively fertile were better in economic efficiency. The result is in line with the arguments of [Fekadu, 2004, Mustefa, 2014]. Finally, proximity to market negatively and significantly influenced the technical, allocative and economic efficiency of sesame production. Households located in proximity to the nearby markets are found to be more efficient than others. Nearby markets play a role in easily accessing the required farm inputs and sale of output without much cost/effort/ for transport, travel time and search for information. A study by [Hassen, 2011, Musa et al., 2015, Sisay et al., 2016, Daniel, 2016] also confirmed the negative association of distance of the farmers from the nearest market with efficiency.

CONCLUSIONS

Result of the production function indicated that, inorganic fertilizer, sesame seed, oxen power, human labor, and chemicals were limiting constraints, with positive sign as expected. The positive coefficients of these variables indicate that, increased use of these inputs will increase the production level to greater extent.

Based on the study results found, this study concludes that, there is a considerable variability in all efficiencies and efficiency score of sample households in the study area. Farming experience, education level, farm income, cultivated land, social responsibility, extension contact frequency, off/non-farm activities, credit, proximity to market and soil fertility were found to be significant sources of inefficiencies. This suggests that, there exists a considerable room to enhance the level of sesame production efficiency i.e., integrated development efforts that will improve the existing level of input use and policy measures towards decreasing the existing level of inefficiency will have paramount importance in improving the productivity. Thus, the following recommendations are forwarded based on the result of the study.

- Interventions by higher education institutions, research institutes/centers in collaboration with FTCs should plan, implement, and conduct practical demonstrations in comprehensive way considering issues like efficient resource use, cost reduction, input optimization so that farmers could be benefited from accelerated increase in productivity.
- The local government should give more attention to facilitate formal education for all to attain educated farmers in order to increase efficiency and agricultural productivity of the country in the long run.

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– Development programs should strength their support for farmers to improve and maintain fertility of land through awareness creation and introduction of technologies that maintains fertility for efficient production.
– Furthermore, attention should be given by local government and supporting institutions through developing crop specific extension packages, improve market integration, and financial accessibility which encourages the farmers to produce efficiently. Therefore, those important socioeconomic and institutional factors which are mentioned above should be taken into account to improve the productivity of sesame in the study areas.

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THE ACCESSIBILITY OF PUBLIC URBAN GREEN SPACE. A CASE STUDY OF BIAŁYSTOK CITY

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ABSTRACT

Motives: Urban green spaces have many functions in cities. They are used for recreational purposes, and they contribute to improving social interactions and community cohesiveness. For this reason, the location and area of urban green spaces should correspond to the size of the city and its population.
Aim: The main aim of this study was to analyze the accessibility of managed and publicly available urban green spaces, referred to as public urban green spaces (PUGS), in four functional and spatial zones in the city of Białystok. The analysis included parks, green squares (pocket parks, ornamental green squares, boulevards) and public forests. The accessibility of PUGS was determined in view of their size and role in the urban spatial structure. Spatial data were processed in GIS and quantitative analyses.
Results: The study demonstrated that the area of PUGS per capita meets the requirements of the World Health Organization (WHO), but the area of parks and green squares should be increased. The accessibility buffers of public green spaces often overlapped, in particular in downtown Białystok (Central zone) which is most abundant in these green infrastructure components. The analysis also revealed locations that do not have access to urban green spaces. The results of the study were used to formulate guidelines for incorporating new green spaces in Białystok and improving the urban spatial structure.

Keywords: green areas, city, accessibility of urban green spaces, Białystok.

INTRODUCTION

Urban green space, in particular those that are available to the general public, deliver a host of benefits. Their location is often determined by historical factors and successive stages of urban spatial development. Rapidly developing urban areas exert a negative impact on the natural environment by contributing to deforestation and the loss of biological diversity. Cities should feature large swathes of open areas, including urban green spaces that can be freely visited by the local inhabitants. Urban green spaces have positive implications not only for human health and social interactions, but also for business activities. Urban green spaces play an important role in the sustainable development of cities [Senetra et al., 2018,

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Fornal-Pieniek & Żarska, 2020, Szarek-Iwaniuk, 2021], and urban landscaping significantly improves the quality of life in the urban environment.

In the Act of 16 April 2004 on Nature Conservation, urban green spaces are defined as developed land that features technical infrastructure and buildings, is covered by vegetation and is open to the public, in particular parks, pocket parks, promenades, cemeteries, boulevards, zoos, botanical gardens, historical parks, playgrounds, roadside trees, green squares, green areas surrounding historical fortifications, buildings, airports, storage yards, railway stations and industrial sites. Numerous definitions of urban green spaces have been proposed in the literature. The term "urban green spaces" is often used interchangeably with "green areas". In the dictionary of the Polish language, green areas are defined as all types of land that are covered with vegetation and are used for recreational purposes in cities [https://sjp.pwn.pl, date: 1.06.2020]. Similar definitions can be found in the literature, where green spaces have been described as various types of land that are covered with vegetation and used primarily for relaxation and recreation [Siewniak & Mitkowska, 1998, Szumański, 2005]. Giedych [2009] defined green spaces are vacant land that is covered with vegetation and serves various recreational purposes. According to Czarnecki [1961], urban green spaces include not only green squares, public parks and boulevards, but also sites that are accessible to specific groups of users, such as hospital parks, allotment gardens and school gardens. The above author argued that only vegetated areas that are managed and maintained in line with the local zoning plan can be defined as urban green spaces. In other studies, green spaces were described as areas where vegetation is functionally and spatially arranged and serves recreational purposes. Fan et al. [2017] defined urban green spaces as public parks and other green areas that are available to the public and managed by the local authorities. A review of the existing definitions indicates that urban green spaces are closely associated with public spaces. Therefore, urban green spaces are an important part of public space. The presented definitions indicate that green spaces play a very important role in cities and constitute an integral part of urban public space [Chojecka, 2013].

The accessibility of urban green spaces significantly affects the quality of urban life by enhancing the residents' physical and mental well-being [Giles-Corti et al., 2005, Shin et al., 2011, Andersson et al., 2019, Nastran, 2020], promoting social integration [Kemperman & Timmermans, 2014], minimizing the discomfort associated with traffic noise [Senetra et al., 2014] and promoting air exchange between the urban core and the surrounding areas [Szulczewska, 2015]. Local residents are more likely to visit urban green areas that are situated in the vicinity of their homes. The vital role of green spaces in cities has led to the development of targets and standards for urban green provision. According to the guidelines of the European Environment Agency (EEA), urban residents should have access to green spaces within a walking distance of 15 minutes, which is approximately 900–1000 m [Wüstemann et al., 2017]. A study of green space provision in large German cities with a population higher than 100,000 demonstrated that nearly 93% of the German population have access to green spaces within a radius of 500 m from their homes [Wüstemann et al., 2017]. According to Coles and Bussey [2000], the size of urban green spaces should be linked with distance, and they argued that residents should be able to access at least 2 ha of urban green space within 5–10 minutes walking distance (100–400 m). Van Herzele and Wiedemann [2003] also linked distance with the size of green spaces and observed that urban dwellers should live within 5 minutes walking distance (approx. 400 m) from 1–10 ha of urban green space. The distribution of green spaces in cities should be determined by population, population density and the serviceability of urban districts [Oh & Jeong, 2007, Fan et al., 2017].

According to the World Health Organization (WHO), at least 9 m^2 of green space should be available per individual, and the ideal value is 50 m^2 per capita [Łukasiewicz & Łukasiewicz, 2016]. However, from the perspective of urban residents, the mere existence of urban green spaces is not sufficient or important if these areas cannot be easily accessed by all potential users. Many cities feature extensive open spaces that

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are located remotely and cannot be fully and equally used by local dwellers. The accessibility of urban green spaces can be impeded by various barriers, such as fencing, paid access, dangerous surroundings or a busy road that is difficult to cross [Biernacka et al., 2020]. In some cases, the accessibility of green infrastructure is determined in local zoning plans. The Local Land Use Plan adopted by the city of Łódź in 2018 defines the linear distance between the residents' homes and the nearest urban green space. For instance, the distance to urban green spaces in the center of the city should not exceed 800 m for green spaces larger than 3 ha, 400 m for green spaces with an area of 1–3 ha, and 200 m for green spaces smaller than 1 ha. As regards green spaces outside downtown Łódź, the corresponding distances are shorter at 500 m, 400 m and 200 m, respectively [Local Land Use Plan of the City of Łódź, 2018]. Senetra et al. [2018] analyzed the serviceability of public green spaces in the city of Tczew based on their area and functions in the urban fabric (municipal green spaces – distance of 1200 m, district green spaces – distance of 600 m, local green spaces – distance of 300 m). Areas with access to various categories of green infrastructure often overlapped. The cited study identified urban districts and locations without access to public green spaces. According to Gajda [2015], a distance of 500 m between the residents' homes and the nearest urban green space can be easily traveled, and it does not discourage potential users from visiting these sites. In most cases, the linear distance to the nearest urban green space is defined at 500–1500 m. In a study of the Warsaw Suburban Garden Tricity Area (Brwinów town and municipality, and the towns of Milanówek and Podkowa Leśna), green space provision was set within an accessibility buffer of 1250 m around households [Gajda, 2015].

Research indicates that the size of urban green spaces should be linked with their accessibility (distance) in local zoning plans. Green space provision is becoming an increasingly important consideration in urban planning. Green spaces are appreciated not only by the local residents, but also by architects and civil officers. Green spaces promote relaxation, recreation and social integration. In many cities, green infrastructure is a part of public spaces that play a representative or symbolic role. In such sites, green spaces should occupy an extensive area, and they should be adequately maintained [Trzaskowska & Adamiec, 2017, Biernacka et al., 2020].

High-quality urban green spaces not only exert a positive impact on the quality of urban life [Branas et al., 2011, Demuzere et al., 2014], but they also significantly affect the value of residential real estate. Research indicates that home prices are higher in the proximity of attractive landscapes, including urban green spaces. In a study by Wachter and Wong [2008], home prices were 7–11% higher within 4,000 feet (more than 1200 m) of curbside plantings. According to Karanikolas et al. [2011], greening projects increase the prices of residential property by 2% to 35%. Green surroundings in residential areas significantly influence home-purchase decisions. A survey of real estate professionals in Olsztyn revealed that more 54% of home buyers were willing to pay a higher price for property situated in the proximity of green spaces, which are regarded as the most important environmental factor in the home-buying process [Szczepańska et al., 2016].

The aim of this study was to determine the quantity, distribution and accessibility of urban green spaces in the city of Białystok in north-eastern Poland. Various types of green spaces and the area of urban green spaces per capita were taken into consideration. The distribution and accessibility of the following types of public urban green spaces (PUGS) were analyzed: parks, green squares (pocket parks, ornamental green squares) and public forests. The study covered four functional and spatial zones defined by the Local Land Use Plan of the City of Białystok in 2019 [Local Land Use Plan of the City of Białystok, 2019]. The results were used to formulate guidelines for incorporating new managed green spaces in Białystok and improving the urban spatial structure. The proposed methodology can be applied in spatial planning and green space management to promote orderly and sustainable development of cities.

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MATERIALS AND METHODS

The accessibility of urban green spaces was analyzed in Białystok, the capital city of Podlaskie Voivodeship in north-eastern Poland (Fig. 1). Białystok has a population of 297,554, area of 102.13 km^2 [Local Data Bank of Statistics Poland, date: 25.02.2021], and population density of 2,913/km^2.

Fig. 1. Location of Białystok and Podlaskie Voivodeship on a map of Poland
Source: own elaboration.

The accessibility of urban green spaces was analyzed in PUGS, including parks, green squares (pocket parks, ornamental green squares, boulevards) and public forests. The urban green spaces included in the analysis had a minimal area of: parks – 2 ha; green squares, pocket parks, ornamental green squares, boulevards – 0.10 ha. Forests were selected for the study if they promoted active recreation, walking and relaxation. The accessibility of green infrastructure was analyzed in four functional and spatial zones that had been introduced by the Local Land Use Plan of the City of Białystok in 2019. These zones had been established to account for the presence of permanent barriers that divide the city – railway lines and the ring road around the urban core. Each zone serves different functions, including residential, services, production, recreation, traffic and utility networks, which are taken into account in local zoning plans. Population data were obtained from the Local Land Use Plan of the City of Białystok [2019], and they account only for the permanent residents of Białystok. Zones I, II, III and IV are marked in maps illustrating the distribution and accessibility of urban green areas. Each zone is characterized in Table 1.

Spatial analyses was performed using geoprocessing tools. A tool such as intersection (trimming), buffering or linking was used. The data useful for the study was downloaded from the website http://download.geofabrik.de/ in the shape format for the Podlaskie Voivodeship. By using database filtering, only the objects necessary for the analyses were left. By using the raster base with an orthophotomap of Poland loaded from the geoportal (geoportal.gov.pl) new objects – polygons – were added. In addition, in the attribute table, information about its name and area was placed for each of the objects, which allowed to calculate:

- the area of selected PUGS (ha);
- percentage share of each PUGS category in the area of each zone and in total city area (%);
- the urban green space index expressed by the area of PUGS (in each zone and in the city) in m^2 per resident.

Table 1. Description of functional and spatial zones in the city of Białystok

Zone	Area (ha)	Population	Population density ('000/km^2)	Apartment buildings (%)	Single-family homes (%)	Services (%)	Green spaces and forests (%)	Traffic routes (%)	Farmland (%)
Central (I)	810	69.2	8.6	33.8	2.1	26.5	10.2	24.7	0.1
Southern (II)	3665	54.3	1.5	1.4	14.0	7.3	40.3	10.7	18.4
Western (III)	3215	116.3	3.6	10.4	9.2	6.8	17.7	17.0	28.1
Eastern (IV)	2513	39.6	1.6	4.9	13.2	7.2	30.2	14.0	23.6

Source: own elaboration based on Statistics Poland data and the Local Land Use Plan of the City of Białystok.

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The accessibility of PUGS was determined by calculating the linear distance to the evaluated sites. This method was adopted because Białystok has a relatively simple street network. The calculated distance is a measure of the quality of the urban environment. The distance to urban green spaces was determined within a radius of 700 m around parks and public forests, and within a radius of 300 m around green squares. Radius values were adopted based on an analysis of the results of numerous studies discussed in the Introduction. Extreme values (200 m and 1500 m) were eliminated. The results are presented graphically on maps generated in the QGIS program.

RESULTS

Public Urban Green Spaces

All categories of urban green spaces have numerous functions and play important roles in cities. However, green spaces that are managed and available to the general public are characteristic of the urban fabric. The total area of the analyzed PUGS is presented in Table 2.

The area of PUGS per resident was very high (65.6 m^2) because Białystok abounds in large public forests. In a study by Senetra et al. [2018], the area of PUGS per capita in Tczew was determined at 11.3 m^2, but forests were not included in the analysis due to their small area in the town. In large German cities with a population higher than 100,000, the average green space provision per capita was determined at 8.1 m^2 [Wüstemann et al., 2017]. In the above study, the distance to urban green spaces was examined within a 500 m buffer around the place of residence, and considerable variations were observed between cities – from 2.5 m^2 per capita in Schwerin to 36.3 m^2 per capita in Bergisch Gladbach.

In Białystok, the area of PUGS per resident was calculated based on the area and location of each PUGS category. Municipal parks are visited mainly for recreational purposes, and they are among the most popular leisure-time destinations for the residents. Białystok has 11 municipal parks, six of which have conservation status (Table 3). Historical parks are meticulously landscaped and feature design elements characteristic of the 19th century.

Table 3. Area of municipal parks in the city of Białystok

Park	Area (ha)	Total area (ha)	Area per resident (m^2)
Historical parks			
Prince Józef Poniatowski Old Park	5.40		
Planty Park	9.24		
Lubomirski Park	14.38		
Konstytucji 3 Maja Park	16.03		
Branicki Park	9.06		
Zygmunt Kościałkowski Boulevards	5.42	59.53	2.0
Municipal parks			
Municipal park on Fredry St.	3.36		
Jadwiga Dziekońska Park	2.32		
Central Park	4.46		
Antoniuk Park	12.65	27.36	0.9
Public green space on Marczukowska St.	4.57		
Total		86.89	2.9

Source: own elaboration based on the results of GIS analyses.

The location of parks with 700 m accessibility buffers is presented in Figure 2.

Most parks are situated in downtown Białystok (Central zone) and in the Western zone, and their buffers often overlap due to a small distance between the parks in the spatial structure of the city. Park buffers cover more than 70% of the Central zone, and the local residents can choose from a variety

Table 2. Area of public urban green spaces (PUGS) in the city of Białystok

Area (ha)	Population	Area of PUGS (ha)	Area of PUGS per resident (m^2)	Area of parks (ha)	Area of parks per resident (m^2)	Area of green squares (ha)	Area of green squares per resident (m^2)	Area of public forests (ha)	Area of public forests per resident (m^2)
10213	279.4	1832.49	65.6	86.89	3.1	17.08	0.6	1728.51	61.9

Source: own elaboration based on the results of GIS analyses.

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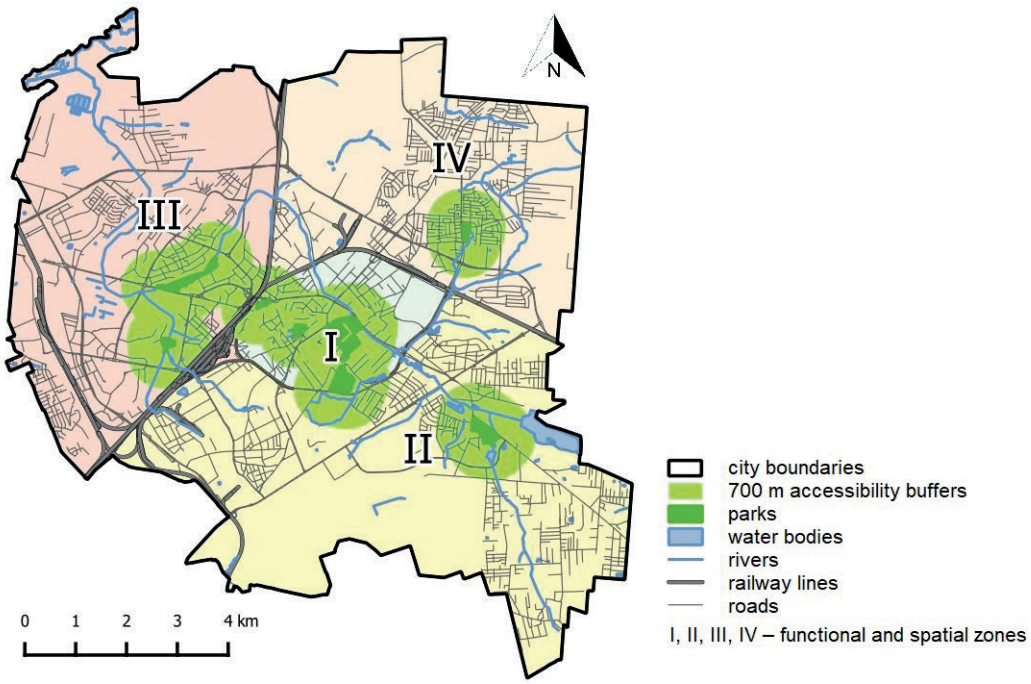

Fig. 2. Location of parks in functional and spatial zones with 700 m accessibility buffers in the city of Białystok
Source: own elaboration.

of recreational sites. The Eastern zone and the Southern zone feature one park each. Park area per resident was determined at 2.9 m^2. In a study of municipal parks in Gdańsk, park area per capita ranged from 0 to 33.0 m^2, and 24 out of 34 city districts did not have parks [Korwel-Lejkowska & Topa, 2017].

Białystok has 14 green squares (pocket parks, ornamental green squares, boulevards) with a combined area of 17.08 ha. The area of green squares per resident was determined at 0.6 m^2 (Table 4).

The combined area of green squares, pocket parks and ornamental green squares in Białystok is very small, accounting for only 0.17% of the city's area. The location of green squares with 300 m accessibility buffers is presented in Figure 3.

Green squares are used for casual leisure and short walks, and they often accompany representative buildings. Most green squares are located in downtown Białystok (Central zone), as well as in Western and Eastern zones. Their buffers often overlap, mainly in the Central zone. The close proximity of green squares and parks creates numerous recreational options for the local residents.

Table 4. Area of green squares in the city of Białystok

Green square	Square area (ha)	Total area (ha)	Area per resident (m^2)
Tamara Sołoniewicz Square	2.65	17.08	0.6
Wygoda Square	0.95		
Włodzimierz Zankiewicz Square	1.38		
Armii Krajowej Square	1.23		
Anna Markowa Square	0.22		
Mordechaj Tenenbaum Square	1.03		
Ludwik Zamenhof Square	0.28		
Father Michał Sopoćko Square	1.68		
Small park at 11 Rzemieślnicza St.	0.10		
Father Stanisław Hałko Boulevards	0.80		
Father Aleksander Chodyka Boulevards	0.24		
Irena Sendlerowa Boulevards	0.82		
Father Henryk Szlegier Square	1.49		
Blessed Bolesława Lament Square	1.48		
Green square on Herberta St.	1.54		
Green square with a Monument to the Defenders of Białystok	1.19		

Source: own elaboration based on the results of GIS analyses.

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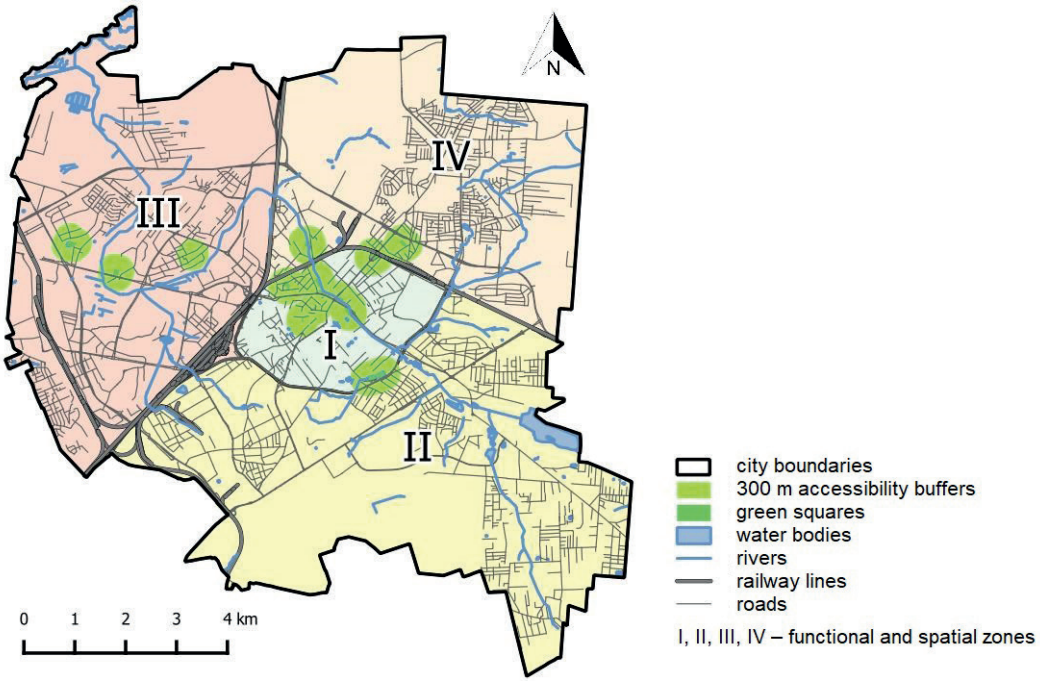

Fig. 3. Location of green squares with 300 m accessibility buffers in the city of Białystok
Source: own elaboration.

Forests are undoubtedly the most valuable component of the natural landscape. Forest cover is generally low in large cities with high population density and a high percentage of built-up land. In Białystok, forests are situated on the northern and southern outskirts of the city. State-owned forests occupy an area of 1500.22 ha, and municipal forests span an area of 228.29 ha (Table 5).

Table 5. Area of public forests in the city of Białystok

Forest	Area (ha)	Forest cover in the city (%)	Forest area per resident (m^2)
State-owned forests	1500.22	16.9	58.0
Municipal forests	228.29		
Total	1728.51		

Source: own elaboration based on the results of GIS analyses.

Public forests in Białystok have a combined area of 1728.51 ha and cover 16.9% of the city area. Forest area per capita was determined at 58.0 m^2. The location of public forests with 700 m accessibility buffers is presented in Figure 4.

Forests are located along the outer edge of the city, and they are accessible to the residents of peripheral districts. These areas are devoid of parks and green squares, and forests act as urban green spaces in peripheral zones. Forests well complement public green spaces on the outskirts of the city. Forest cover is highest in Southern and Eastern zones. The Central zone is devoid of forests.

The serviceability and population of functional and spatial zones should be considered in analyses of the location, area and accessibility of urban green spaces in each zone. The area occupied by different categories of PUGS in each zone was determined in a GIS analysis. The area of PUGS per resident was calculated in each zone. The results are presented in Table 6.

Public urban green spaces occupy the largest area in the Southern zone (26.2% of zone area), which can be attributed to the presence of extensive public forests (946.80 ha). In the Eastern zone, PUGS occupy 20.5% of the zone's area, and public forests span 511.84 ha. The Central zone is least abundant in PUGS which

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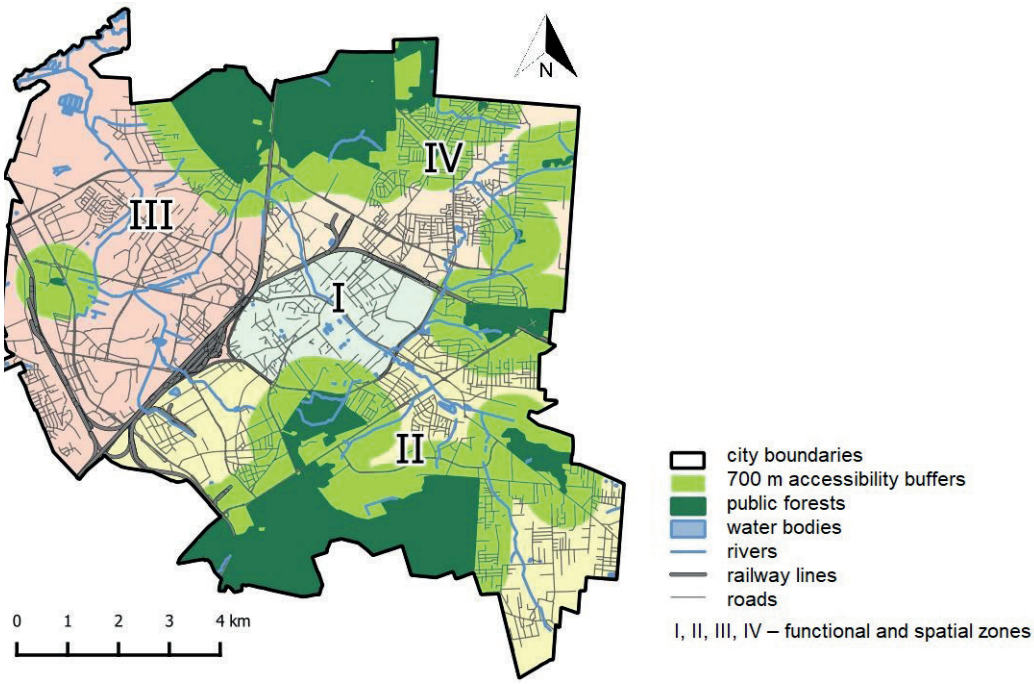

Fig. 4. Location of public forests with 700 m accessibility buffers in the city of Białystok
Source: own elaboration.

Table 6. Area of public urban green spaces (PUGS) in the functional and spatial zones of the city of Białystok

Zone	Area of PUGS (ha)	% PUGS in zone area	Area of PUGS per resident (m^2)	Area of parks (ha)	Area of parks per resident (m^2)	Area of green squares (ha)	Area of green squares per resident (m^2)	Area of public forests (ha)	Area of public forests per resident (m^2)
Central	63.63	7.9	9.2	51.94	7.5	11.69	1.7	0	0
Southern	961.18	26.2	180.0	14.38	2.7	0	0	946.80	174.4
Western	289.83	9.0	24.9	17.22	1.5	2.74	0.2	269.87	23.2
Eastern	517.85	20.5	130.8	3.36	0.8	2.65	0.7	511.84	129.3

Source: own elaboration based on the results of GIS analyses.

occupy only 7.9% of the zone's area. This zone features only parks and green squares.

A synthetic analysis of the accessibility of the analyzed categories of PUGS is presented in Figure 5.

The combined area of PUGS accessibility buffers in each zone is presented in Table 7.

The overlap between the accessibility buffers of each PUGS category was analyzed to identify areas in each zone that do not have access to the examined types of PUGS. The accessibility of PUGS was high

Table 7. Combined area of the accessibility buffers of public urban green spaces (PUGS) in the city of Białystok

Zone	Zone area (ha)	Area of PUGS accessibility buffers (ha)	% of zone area
Central	810	593	73
Southern	3665	2483	68
Western	3215	1202	37
Eastern	2523	1965	78

Source: own elaboration.

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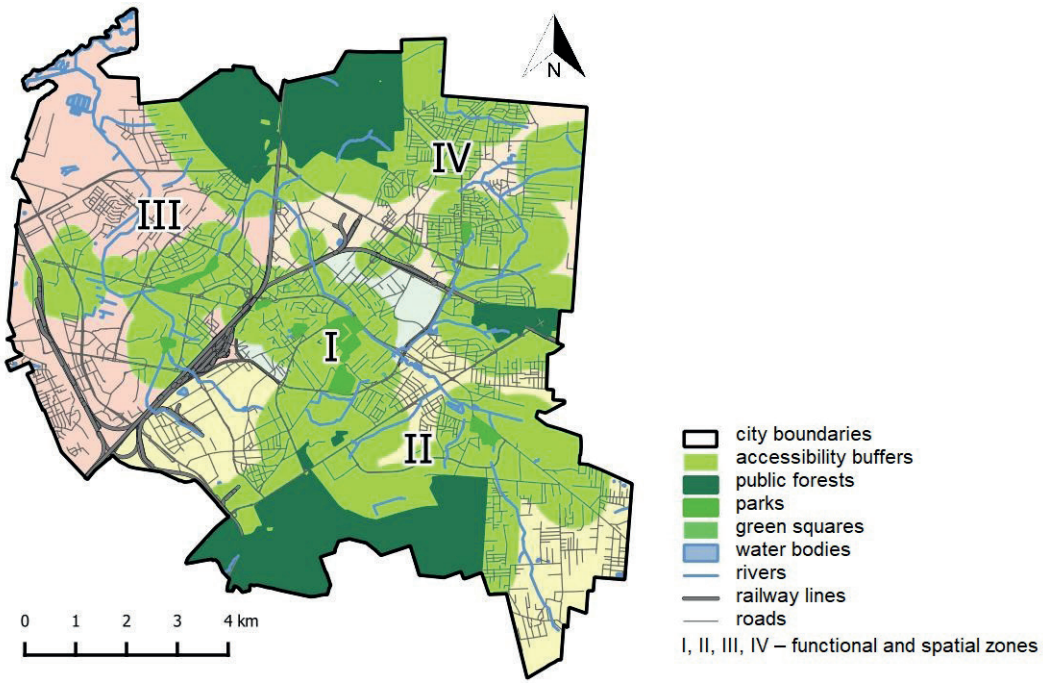

Fig. 5. Accessibility of the analyzed categories of public urban green spaces (PUGS) in the city of Białystok
Source: own elabotation.

in Central and Eastern zones, and the absence of accessibility buffers was noted in only 25% of their area. Accessibility buffers spanned the smallest area in the Western zone which is most deficient in PUGS (37%). This is a highly unsatisfactory result because the Western zone has the largest population (116,300). However, the Western zone abounds in farmland that could be converted to PUGS. The accessibility buffers of PUGS cover 64% of Białystok's total area, which is a satisfactory result relative to that reported in a study of municipal parks in Gdańsk [Korwel-Lejkowska & Topa, 2017]. In Gdańsk, nearly 78% of the city's area does not have access to parks within a walking or commuting (public transport) distance of 20 minutes.

The Central zone has the smallest percentage of PUGS in total area (7.9%) and the smallest area of PUGS per resident (9.2 m^2). This zone is also characterized by the highest population density (8,600/km^2) due to the prevalence of apartment buildings (33.8%). In the Central zone, the accessibility buffers of the examined PUGS often overlap and occupy 73% of the zone's area. More satisfactory results were reported by Senetra et al. [2018] in Tczew, where the area of PUGS per resident was determined at 37.2 m^2 in the town's greenest Old Town district (with similar functions to Białystok's Central zone).

In the Southern zone, PUGS occupied an area of 961.18 ha (26.2% of the zone's area), with a predominance of public forests (946.8 ha). The area of PUGS per resident was determined at 180.0 m^2. This zone features one park and the accessibility buffer of a park located in the Central zone. Residential districts in the Southern zone feature mostly single-family homes (14.0% of the zone's area). The local inhabitants rely mostly on their home gardens for relaxation and recreation, which is why extensive municipal parks and green squares are not required in this zone.

The Western zone is characterized by the highest population and the smallest area of PUGS per resident (9.0 m^2). Parks and green squares occupy an area of 19.96 ha, and public forests are the main category of PUGS (269.87 ha). Apartment buildings and single-family homes cover around 10% of the zone's area each.

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Accessibility buffers cover only 37% of the Western zone, which suggests that new PUGS should be planned in this part of the city.

In the Eastern zone, PUGS occupy 517.85 ha and cover 20.5% of the zone's area, which can be attributed to very high forest cover (511.84 ha). New PUGS are not required in this zone due to small population (39,600), low population density (1,600/km^2) and a predominance of single-family homes (13.2% of the zone's area).

CONCLUSIONS AND RECOMMENDATIONS

An analysis of the structure of the urban natural environment in the city of Białystok demonstrated that the area of PUGS is sufficient to meet local community's needs. However, the examined PUGS have an undesirable structure and are unevenly distributed in the city. In the studied city, green space provision is limited by its accessibility. The area of PUGS per resident was determined at 65.6 m^2, which meets WHO recommendations. However, forests account for a large proportion of PUGS in the city, and the area of the remaining categories of PUGS is insufficient. The present findings indicate that Białystok is relatively deficient in parks and green squares. The Western zone and the central part of the Eastern zone feature the highest number of areas where the distance to the nearest PUGS exceeds 700 m. In the remaining parts, only individual areas are located more than 700 m away from PUGS. Białystok is characterized by considerable fragmentation of PUGS. New open spaces should be designed to guarantee the optimal distribution of PUGS in the city, i.e. a ring-radial pattern, which will contribute to the continuity of green infrastructure and will promote the exchange of air between the urban core and the surrounding areas. Both the area and the number of PUGS that serve recreational purposes should be increased. The analysis of the accessibility buffers surrounding the examined PUGS indicates that new PUGS should be introduced in Białystok's functional and spatial zones:

- Central zone – this zone is characterized by the highest number of parks and green squares, and the highest population density. Public urban green areas and their accessibility buffers cover 73% of the zone's area. New PUGS could be difficult to establish in the Central zone due to the low availability of vacant land (farmland) that could be utilized for this purpose. There is no need to incorporate new PUGS into this zone, but they should be introduced in the neighboring Southern zone;
- Southern zone – PUGS and their accessibility buffers occupy around 68% of the zone's area. This zone is characterized by the lowest population density (1,500/km^2). Farmland that could be potentially converted to green infrastructure covers 18.4% of the zone's area. New PUGS should be designed in the proximity of the border with the Central zone;
- Western zone – this zone is characterized by the largest population and relatively high population density (3,600/km^2). Public urban green spaces and their accessibility buffers cover only 37% of the zone's area. Farmland accounts for 28% of the zone's area; therefore, new PUGS could be relatively easily established. The demand for green infrastructure in the Western zone is relatively high because apartment buildings occupy 10.4% of the zone's area;
- Eastern zone – this zone is characterized by low population density (1,600/km^2), the largest area of PUGS and their accessibility buffers (78% of the zone's area). The Eastern zone abounds in farmland (23.6%) that could be converted to public services, in particular PUGS. New PUGS should be established in the vicinity of the border with the Central zone.

It should be noted that the use of smaller or larger accessibility buffers would change the size of areas that are excluded from access to PUGS in each zone. The current study demonstrated that PUGS and their accessibility zones occupy 64% of Białystok's area.

The proposed method of calculating the accessibility buffers of PUGS supports the identification of areas that do not have access to green infrastructure in the urban fabric. This approach can be used to iden-

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tify areas and districts where new urban green spaces should be created to improve the quality of life and promote the exchange of air between the urban core and the surrounding areas. The described method can be applied to evaluate the accessibility of urban green spaces in cities with a similar size, spatial structure, and social and cultural environment.

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DETERMINATION OF THE LEVEL OF SUSTAINABLE DEVELOPMENT OF THE CITIES – A PROPOSAL FOR A METHOD OF CLASSIFYING OBJECTS BASED ON NATURAL BREAKS

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ABSTRACT

Motives: The problem of measuring the level of sustainable development is a subject addressed by many authors in their research.
Aim: In this article the Authors proposed a new method of classifying objects based on Jenks' Natural Breaks to measure the level of sustainable development. The analysis was carried out on the basis of the data obtained from Statistics Poland. An important element of the research was the development of the process of selection and rejection of input data on the basis of a variety of statistical indicators. This resulted in a set of data which, on the one hand, is statistically justified and, on the other, describes the examined phenomenon in a comprehensive way.
Results: The research objects were 66 Polish district cities; Authors obtained a ranking of cities in terms of its Sustainable Development Level. The authors decided to verify the correlation of the results obtained from a proposed method of classifying objects based on natural breaks, with those from the chosen taxonomic method (Hellwig's method) and the Classic Ranking. The fact of receiving highly correlated results confirms the validity and reliability of the proposed method.

Keywords: sustainable development, Jenks' Natural Breaks, Hellwig's method, Classic Ranking method.

INTRODUCTION

Sustainable development is usually defined, in the words of The Brundtland Report "Our Common Future", as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [World Commission on Environment and Development, 1987]. The report highlighted three fundamental components of sustainable development: environmental protection, economic growth, and social equity. The definition of sustainable development can be found in Polish legislation – it is defined in the Environmental Protection Act [Act of 27 April 2001 Environmental Protection Law, 2001] as the socio-economic development integrating political, economic and social actions, balanced with environmental protection and permanence of basic natural processes, in order to ensure the possibility of satisfying the basic

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needs of communities or individual citizens in both the present and future generations.

Sustainable development is a sort of compromise between social, economic and environmental goals, representing the well-being of present and future generations.

The social aspect is identified with education and acquiring the ability to solve major social problems as well as participation in the development processes of the whole system. Within the social domain, the following areas are analyzed: access to labor market, criminality, demographic changes, determinants of health, old-age income adequacy, poverty and living conditions, public health, road accidents, and sustainable consumption patterns. The economic aspect of sustainable development, on the other hand, means not only meeting present needs, but also securing the resources necessary to meet the needs of future generations (within this domain there are the areas of: intellectual and social capital, economic development, and transport). Whereas the environmental aspect means establishing the limits of the natural system for human activities and not exceeding them. Within the environmental domain, the following areas are analyzed: climate change, energy, land use, biodiversity, and waste management.

The approach of the Polish authorities is consistent with the EU approach. The definition included in the Environmental Protection Act corresponds to the assumptions adopted for the European Union area. Similar sets of indicators are used to measure Sustainable Development both in Poland and in other EU countries, which is in line with current EU guidelines [European Commission, 2016].

Sustainable development is nowadays one of the main component used in the spatial development [Alkhalidi et al., 2018, Antonopoulos, 2018, Bell & Morse, 2018, Ciski et al., 2019]. All existing definitions of sustainable development indicate a very broad scope of this concept. In scientific research, many authors propose different ways of measuring the level of sustainable development, but due to the broad nature of the concept, these methods are very diverse and are based on different methodological approaches [Atkinson et al., 1997, Dasgupta, 2007, Moran et al., 2008, Moreno Pires et al., 2014, Mortensen, 2013, Nourry, 2008, Pearce et al., 1996; Tanguay et al., 2010]. In this article, the Authors decided to propose a method of classifying objects based on natural breaks for this purpose.

Classification methods have been applied to many applications in various fields of science [Aly, 2005, Sharma et al., 2016, Tharwat, 2018]. Data classification is a complex process that may be affected by many factors [Lu & Weng, 2007]. Different techniques are used for classification, including probabilistic methods, decision trees, rule-based methods, instance-based methods, support vector machine methods, and neural networks [Aggarwal, 2014]. There are qualitative and quantitative research methods among them [Toloie-Eshlaghy et al., 2011]. Jenks natural breaks optimization method is one of the most popular data clustering methods used to classify objects [Chen et al., 2013, Khamis et al., 2018], it is used to determine the best distribution of values in different classes. Jenks' algorithm uses an iterative approach to find the best groupings of numbers based on how close they are together (based on variance from the group's mean) while also trying to ensure the different groupings are as distinct as possible (by maximizing the group's variance between groups). Thus, the Jenks optimization method aims to minimize the average deviation of each class from the average class; reducing variance within classes and maximizing variance between classes. Jenks optimization method's algorithm can be presented in the following repeated steps:

1. Compute the sum of squared deviations from the class means (SDCM).

2. Compute the sum of squared deviations from the array mean (SDAM).

3. After inspecting each SDCM, a decision is then made to move one unit from a class with a larger SDCM to an adjacent class with a lower SDCM.

New class deviations are then computed, and the process is repeated until the sum of the within class deviations reaches a minimal value [Jenks, 1967]. Taxonomic methods are used to describe and classify complex socio-economic phenomena expressed by a large set of variables [Bąk, 2016, Podogrodzka,

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2011, Prus & Król, 2017, Senetra & Szarek-Iwaniuk, 2019]. Taxonomic methods can be divided into hierarchical and non-hierarchical, agglomeration and divisional, area-based, and optimization [Grabiński et al., 1989]. Among the hierarchical methods, linear ordering methods are an important group; these methods determine the linear hierarchy of objects based on the distance from the computed so-called "development pattern". All methods allow for carrying out classifications on a multidimensional set of variables, but they differ mainly in computational algorithms. Hierarchical methods allow for separating the full hierarchy, i.e. the focus on the higher level includes detachable of the lower levels forming cluster structures. In non-hierarchical methods it is not possible to present the process of cluster formation as a structure. In agglomeration methods, each of the research objects is initially a separate cluster, and the process ends with the merger of all objects into one group. Divisional methods treat a set of objects as one group, successive divisions lead in the final effect to the separation of the number of groups equal to the number of objects. In area-based methods, hyper-area is divided into separable areas, while in optimization methods, using different criteria, there are to further approximations of the division of the collection [Grabiński et al., 1989, Kuciński, 2015, Prus & Król, 2017]. To perform a multidimensional spatial analysis of phenomena, a classification procedure can be applied, which consists of separating homogeneous subsets in a set of multi-characteristic objects. The classification is based on the assumption that objects belonging to the same cluster will be similar (homogeneous), while those belonging to different clusters will be heterogeneous [Hellwig, 1981]. Separation of homogeneous groups of objects makes it possible to carry out in-depth analyses within those groups taking into account a larger number of variables. This approach allows for a better understanding of the factors determining the level and structure of the examined phenomenon, and consequently for a more accurate assessment of the reality and identification of possible causes differentiating the compared objects [Gorzelak, 1981].

The choice of the variables (features) is one of the most important steps in research; variables used in applied research should be selected carefully [Tarka, 2010]. Diagnostic features to classify objects should have specific properties. This was written about as early as 1957, by one of the precursors of taxonomic methods, Prof. Fierich. According to [Fierich, 1957], variables ought to:

- include the most important properties of the analyzed phenomena, therefore only the necessary properties should be taken into account;
- be simply and logically connected;
- be clearly and strictly defined and directly or indirectly measurable and expressible by absolute (similarity of magnitude) or relative (similarity of structure) quantities;
- have high spatial variability in the set of tested objects and cannot be easily influenced by the environment;
- be independent of each other, but related to characteristics not included in the study;
- have high coefficients of variation within the initial community and, within groups, as low as possible.

The requirements for variables were also similarly defined in other subsequent studies. For example, according to [Gorzelak, 1979], a good set of variables are those that:

- are strictly defined;
- are unambiguous;
- represent as accurately as possible the phenomena and processes falling within the scope of research;
- have a high information content;
- are uncorrelated.

Based on the research of its predecessors, the problem of the properties of diagnostic features has been described most extensively by [Grabiński et al., 1989] and is still the basis for this type of research. According to this, the diagnostic features should:

- capture the most important properties of the analyzed phenomena and represent it accurately;
- be simple, clear, and precise;
- be logically connected;
- contain a high content of information;

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– be directly or indirectly measurable, which boils down to the existence of reliable and easily accessible statistical data;
– be expressed in natural rather than valuable units, rather than in absolute terms;
– be characterized by high spatial variability;
– not be highly correlated;
– be highly correlated with undiagnostic and synthetic variables;
– enable mutual control (through knowledge of the statistical and substantive relationships between individual variables);
– not to describe specific phenomena and processes;
– be characterized by the consistency of proportions between the number of variables characterizing a given aspect of the examined phenomena and their substantive significance.

The main aim of the article was to propose a method of classifying the level of sustainable development on the basis of natural breaks. This method was used to determine the level of sustainable development of 66 Polish cities. In order to verify the usefulness of the proposed method, the results were compared with the results obtained using the Classic Ranking method and the selected taxonomic method – Hellwig's method.

MATERIALS AND METHODS

Research carried out in this study can be divided into three stages:

Stage I: the selection of diagnostic variables.

Stage II: determination of the sustainable development level using the proposed method.

Stage III: determination of the sustainable development level using Classic Ranking and Hellwig's methods.

Selection of diagnostic variables

The selection of diagnostic variables used to determine the level of sustainable development of cities was primarily based on a literature analysis and datasets of indicators available on the Internet to assess sustainable development [Azapagic & Perdan, 2000, Bossel, 1999, Drastichová, 2017, European Commission, 2015, Hák et al., 2016, Klopp & Petretta, 2017, Mori & Christodoulou, 2012, Morton et al., 2017; Schleicher-Tappeser, 2018, Shen et al., 2011, Spangenberg, 2015, United Nations, 2007, 2015]. The results of sustainability studies carried out by different researchers for different objects, such as countries, administrative parts of countries, etc., were also analyzed [Bąk & Cheba, 2018, Czermińska, 2002, Koszel & Bartkowiak, 2018, Moran et al., 2008, Mortensen, 2013, Stafford-Smith et al., 2017]. An equally important element of determining the selection of diagnostic variables was its availability and reliability. Therefore, the authors decided to choose a set of indicators published in the Sustainable Development Indicators (SDI) service [Sustainable Development Indicators, 2017]. All data comes directly from Statistics Poland, the central office of government administration in Poland, which collects and shares statistical information. The SDI service is used to disseminate and demonstrate indicators for monitoring sustainable development at national, regional, provincial, and district levels. Currently, it is difficult to obtain detailed data for Poland's territorial division units – data in the new Sustainable Development Goals panel in Statistics Poland adapted to United Nations Sustainable Development Knowledge Platform [United Nations, 2015] are published only at the national level. In order to examine the level of sustainable development of Poland's largest cities, the Authors have used data from 2016, i.e. the last year for which the data were published in the "Sustainable Development Indicators" service.

The input data for analysis is divided into four levels, taking into account the data hierarchy and based on the detail of the data:

1. Domains – the first level, grouping areas, and indicators; these are the four main branches of statistical data that make up the idea of sustainable development: Social, Economic, Environmental, and Institutional-political.

2. Areas – the second level, grouping indicators; areas consist of more specific data, for example Demographic changes, Poverty and living conditions, Criminality, Openness and participation, etc.

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3. Indicators – statistical indicators, embedded in the idea of sustainable development; the indicators are, for example Demographic dependency ratio, Average useful floor area of dwelling per capita, Ascertained by Police crimes total per 1,000 population, etc.

4. Dimensions – indicators are additionally divided into different dimensions; most indicators are described by two or more dimensions, for example: "Length of bicycle lane" indicator is described with "per 10 thousand km^2" and "per 10 thousand population" dimensions.

The input database consisted of 119 indicators, divided into four domains with 21 areas. The following four tables prepared separately for each domain, list all indicators. The first column in the tables is the number of the indicator – from X_1 to X_{119}; each row means one indicator. The second column contains the thematic groups of the indicators. Many indicators vary in dimension while sharing the same group; in such cases, to make tables more readable, the indicator group cells have been merged. The third column contains the dimension and information about the units of measurement of indicators.

The first table contains information about the social domain. There are 59 indicators in this domain, nearly 50% of the total input data. The indicators included in this domain describe the standard of living of local communities in the analyzed cities; it concerns demographic changes, health and living conditions, labor market, but also crime and road accidents. Table 1 shows the list of social domain indicators.

The second table gathers information on the economic domain describing the economic situation of the analyzed cities, including: investment expenditures in enterprises, expenditures on innovative activities in enterprises, natural persons conducting economic activity, as well as data on public roads and expenditures on public roads. The economic domain consists of 34 indicators, which represent almost 29% of the input data. Table 2 contains a list of all the indicators in the economic domain.

Data on the condition of the environment of the studied cities is presented in the third table. The environmental domain contains information on, among others: electricity consumption, carbon dioxide emissions and other air pollutants, forest cover and green belts, as well as municipal waste. The environmental domain comprises a total of 14 indicators, representing almost 12% of all input data; the full list of indicators is presented in Table 3.

The last institutional-political domain contains 12 indicators (i.e. only 10% of all input data) and describes the activity of the society in foundations, associations and social organizations, the structure of local legislative bodies, but also expenditures from municipal budgets and the effectiveness of local spatial planning. Table 4 contains an overview of all indicators in the institutional-political domain.

Table 1. List of indicators from social domain

No. of indicator	Thematic groups of indicators	Dimension [unit of measurement]
1	2	3
	Demographic changes	
X1	Natural increase per 1000 population	total [-]
X2		deviation at points (percentage points) from the voivodeship value [-]
X3	Demographic dependency ratio	post-working age population per 100 persons of working age [person]
X4		post-working age population per 100 persons of working age – voivodeship=100 [%]
X5		non-working age population per 100 persons of working age [person]
X6		non-working age population per 100 persons of working age – voivodeship=100 [%]
X7		post-working age population per 100 persons of pre-working age [person]
X8		post-working age population per 100 persons of pre-working age – voivodeship=100 [%]

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cont. Table 1

1	2	3
		Public health
X9	Infant deaths per 1000 live births	total [per mil]
X10		deviation at points from the voivodeship value [per mil]
X11	Deaths of people aged up to 65 years per 1000 population at this age	total [-]
X12		deviation at points from the voivodeship value [-]
		Poverty and living conditions
X13	People in households benefiting from the social assistance at domicile in the percentage of the total population	deviation from the voivodeship value [pp]
X14		total [%]
X15	Average monthly gross wages and salaries (economic entities which employ more than 9 persons)	total [PLN]
X16		voivodeship=100 [%]
X17	The average useful floor area of dwelling per capita	total [m^2]
X18		voivodeship=100 [%]
		Education
X19	Children covered by preschool education in percentage of the total number of children at the age 3–5	total [%]
X20		total – deviation from the voivodeship value [pp]
X21		in rural areas – deviation from the voivodeship value [pp]
X22	Ratios the quality of education and the level of students' knowledge	Passing the exam maturity examination in the vocational upper secondary schools [%]
X23		Passing the exam maturity examination in the vocational upper secondary schools – deviation from the voivodeship value [pp]
X24		Passing the exam maturity examination in general secondary schools [%]
X25		Passing the exam maturity examination in the general secondary schools – deviation from the voivodeship value [pp]
		Access to the labor market
X26	Long-term unemployed persons in registered unemployed persons total	total [%]
X27		deviation from the voivodeship value [pp]
X28	Registered unemployed persons in relation to persons of working age	unemployed persons, females [%]
X29		unemployed persons, females - deviation from the voivodeship value [pp]
X30		unemployed persons with tertiary education, total [%]
X31		unemployed persons with tertiary education, total – deviation from the voivodeship value [pp]
X32	Graduates – registered unemployment (yet not working) in the percentage of the total registered unemployed persons	total [%]
X33		total – deviation from the voivodeship value [pp]
X34		graduates – females [%]
X35		graduates – females – deviation from the voivodeship value [pp]

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cont. Table 1

1	2	3
X36	Registered unemployment rate	total [%]
X37		deviation from the voivodeship value [pp]
	Sustainable consumption patterns	
X38	Number of passenger cars per 1000 population	total [pcs]
X39		voivodeship=100 [%]
X40	Consumption of water, electricity, and gas in households during the year per capita	electricity [kWh]
X41		electricity – voivodeship=100 [%]
X42		gas [m^3]
X43		gas – voivodeship=100 [%]
X44		water [m^3]
X45		water – voivodeship=100 [%]
	Old-age income adequacy	
X46	Long-term unemployed persons aged 55–64 in relation to registered unemployed persons aged 55–64 total	total [%]
X47		deviation from the voivodeship value [pp]
X48	Persons at post-working age in households benefiting from social assistance at domicile in percentage of the total number of people at this age	total [%]
X49		deviation from the voivodeship value [pp]
	Determinants of health	
X50	Persons injured in accidents at work per 1000 employed persons	total [person]
X51		deviation at points from the voivodeship value [person]
X52	Out-patient departments per 10 thousand population	total [facilities]
X53		voivodeship=100 [%]
	Criminality	
X54	Rate of detectability of the delinquents of ascertained by Police crimes	total [%]
X55		deviation from the voivodeship value [pp]
X56	Ascertained by Police crimes total per 1000 population	total – voivodeship=100 [%]
X57		total [-]
	Road accidents	
X58	Victims of road accidents per 100 thousand registered motor	injured [person]
X59		injured – voivodeship=100 [%]

Source: own elaboration, based on [Sustainable Development Indicators, 2017].

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Table 2. List of indicators from economic domain

No. of indicator	Thematic groups of indicators	Dimension [unit of measurement]
1	2	3
	Economic development	
X60	Investment outlays in enterprises (current prices; without economic entities employing up to 9 people) per capita at working age	per capita at working age [PLN]
X61		per capita at working age – voivodeship=100 [%]
X62	New-registered entities of the national economy recorded in the REGON register per 10 thousand population at the working age	total [-]
X63		voivodeship=100 [%]
X64	Expenditure on innovation activities in enterprises by a group of sections in the percentage of the total expenditure on innovation activities in enterprises (up to 9 employees)	agriculture, hunting and forestry; fishing – deviation from the voivodeship value [pp]
X65		industry and construction [%]
X66		industry and construction – deviation from the voivodeship value [pp]
X67		trade; repair of motor vehicles; transportation and storage; accommodation and catering; information and communication [%]
X68		trade; repair of motor vehicles; transportation and storage; accommodation and catering; information and communication – deviation from the voivodeship value [pp]
X69		financial and insurance activities; real estate activities [%]
X70		financial and insurance activities; real estate activities – deviation from the voivodeship value [pp]
X71		other services [%]
X72		other services – deviation from the voivodeship value [pp]
	Employment	
X73	Natural persons conducting economic activity per 100 persons of working age	total [-]
X74		voivodeship=100 [%]
X75	Entities by size classes per 10 thousand population at the working age	total [-]
X76		total – voivodeship=100 [%]
X77		Micro (up to 9 employees) [-]
X78		Micro (up to 9 employees) – voivodeship=100 [%]
X79		Small (from 10 to 49 employees) [-]
X80		Small (from 10 to 49 employees) – voivodeship=100 [%]
X81		Medium (from 50 to 249 employees) [-]
X82		Medium (from 50 to 249 employees) – voivodeship=100 [%]
X83		Large (over 250 employees) [-]
X84		Large (over 250 employees) – voivodeship=100 [%]
	Transport	
X85	Length of bicycle lane	per 10 thousand km^2 [km]
X86		per 10 thousand km^2 – voivodeship=100 [%]
X87		per 10 thousand population [km]
X88		per 10 thousand population – voivodeship=100 [%]

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cont. Table 2

1	2	3
X89	Length of local public roads per 100 km^2	surfaced [km]
X90		surfaced – voivodeship=100 [%]
X91	Expenditures of municipalities on public roads in the percentage of their total expenditure	total [%]
X92		deviation from the voivodeship value [pp]
X93	Expenditures of districts on public roads in the percentage of their total expenditure	deviation from the voivodeship value [pp]

Source: own elaboration, based on [Sustainable Development Indicators, 2017].

Table 3. List of indicators from environmental domain

No. of indicator	Thematic groups of indicators	Dimension [unit of measurement]
	Climate change	
X94	Emissions of carbon dioxide from plants especially noxious to air purity	total [t/y]
	Energy	
X95	Electricity consumption per capita	total [kWh]
X96		total – voivodeship=100 [%]
X97		in urban areas [kWh]
X98		in urban areas – voivodeship=100 [%]
	Air protection	
X99	Emissions of air pollutants from plants especially noxious to air purity	gases [t/y]
X100	Pollutants retained or neutralized in pollutant reduction systems in polluting plants especially noxious to air purity in percentage of the generated	particulates – deviation from the voivodeship value [pp]
	Land use	
X101	Forest cover	total [%]
	Biodiversity	
X102	Green belts in percentage of the total area	total [%]
X103		deviation from the voivodeship value [pp]
	Waste management	
X104	Mixed municipal waste from household collected during the year per capita	total [kg]
X105		voivodeship=100 [%]
X106	Treated industrial and municipal wastewater in percentage of the total value of the industrial and municipal wastewater requiring treatment	total [%]
X107		deviation from the voivodeship value [pp]

Source: own elaboration, based on [Sustainable Development Indicators, 2017].

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Table 4. List of indicators from institutional–political domain

No. of indicator	Thematic groups of indicators	Dimension [unit of measurement]
	Openness and participation	
X108	Foundations, associations and social organizations per 10 thousand population	total [-]
X109		voivodeship=100 [%]
X110	Structure of councilors in the organs (legislative bodies) in municipalities and districts	females [%]
X111		females – deviation from the voivodeship value [pp]
X112		people with higher education [%]
X113		people with higher education – deviation from the voivodeship value [pp]
	Economic instruments	
X114	Expenditure from the budgets of municipalities and districts on public debt in 1000 PLN per total revenue budgets of municipalities and districts	total, (include municipalities and powiats) [PLN]
X115		total, (include municipalities and powiats) – voivodeship=100 [%]
X116	Investment expenditures of municipalities and districts in percentage of their total expenditure	total, (include municipalities and powiats) [%]
X117		total, (include municipalities and powiats) – deviation from the voivodeship value [pp]
X118	Area covered by the local spatial development plans in percentage of the total area	total [%]
X119		deviation from the voivodeship value [pp]

Source: own elaboration, based on [Sustainable Development Indicators, 2017].

For the collected diagnostic variables, it should be examined whether these variables are characterized by sufficiently high variability by eliminating quasi-constant variables. For this purpose, the coefficient of variation V can be calculated for each j–th variable. Its value is a relative measure of dispersion, and it is calculated by using the Equation (1) below.

$$V_j = \frac{S_j}{\bar{x}_j}, (j = 1, \dots, m), \quad (1)$$

where: $\bar{x}_j$ – the arithmetic mean of the j–th variable (2), S_j – standard deviation for the j–th variable (2).

$$\bar{x}_j = n^{-1} \sum_{i=1}^{n} x_{ij}, (i = 1, \dots, n);$$

$$S_j = \sqrt{n^{-1} \sum_{i=1}^{n} (x_{ij} - \bar{x}_j)^2}, \quad (2)$$

From the set of variables, unequal variables can be eliminated.

$$|V_j| \leq V^*, \quad (3)$$

where V* is the critical value of the variation coefficient. The value of V* was arbitrarily set at 0.10.

Afterward, the strength of the relationship between the other variables should be tested. For this purpose, the correlation between variables must be determined with the value of the Pearson coefficient. Highly correlated variables are removed from the data set (Pearson's coefficient >0.7) [Schober et al., 2018].

Covariance is a measure of the joint variability of two random variables. The covariance of variables shows how variables are linearly related to each other. Positive covariance indicates a positive linear relationship between variables, while negative covariance indicates the opposite. If the variables are not linearly related, the covariance value is close to zero. The covariances must be computed for the analyzed variables.

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Determination of the sustainable development level using the proposed method

Each variable has been separately classified using the Jenks optimization algorithm. Separate classification of each of the variables will ensure the reliability of the method – the range of each variable may vary significantly. Using Natural Breaks, a class has been assigned to each city and the values of these classes have been averaged for each city to obtain an indicator of Sustainable Development Level (SDL).

The method proposed above was used to compute the Sustainable Development Level (SDL) for all 66 district cities in Poland. These are the largest cities in the country. Its locations are shown on Figure 1.

Determination of the sustainable development level using Classic Ranking and Hellwig's methods

Analogous research was done by using the Classic Ranking method and Hellwig's method, then the results were examined using the Pearson correlation coefficient. Ranking of Polish cities in terms of the level of sustainable development was created. This approach is used e.g. on Eurostat's SDI websites [EUROSTAT, 2019]. The Classic Ranking was computed for the same variables for which the sustainable development level was computed using the proposed method of classifying objects based on Natural Breaks; for the value of each indicator in each of the analyzed cities a number was assigned based on the position. This means that position 1 is the highest and position 66 the lowest. In the case of indicators described as stimulants, the city with the highest value of the indicator was given the number 1, the city with the lowest – 66 (the situation is the opposite for indicators described as destimulants). The results for the cities were averaged. The compilation of the obtained results and their interpretation sought the basis for discussion and conclusions in the last chapter.

Taxonomic methods are most often used to determine the level of development of a given area or objects. These are statistical methods used to classify objects described by many of its properties. Analysis of the literature indicated that, in the case of research similar to the research carried out in this article, linear ordering methods are most often used. As a result, it was decided to choose the "Hellwig's method", a method proposed in 1968 by Polish scientist Zdzisław Hellwig. This method is commonly used in this type of research [Dorożyński et al., 2019, Jaworska & Luty, 2009, Łogwiniuk, 2011, Malina, 2020, Niemczyk, 2001, Podstawka & Suchodolski, 2018, Pomianek, 2010, Rząsa et al., 2019, Salamon, 2005, Senetra & Szarek-Iwaniuk, 2020, Sołek & Sowa, 2019, Stec, 2012, Ziemiańczyk, 2010]. Hellwig's method is based on the computation of a synthetic development index which allows for presenting the situation of diversity in the level of the studied phenomenon, covering many categories: economic, social, ecological, and spatial [Hellwig, 1968, Nowak, 1990]. The adopted methodology of the research procedure is characterized by great transparency, as it makes it possible to present the results with a single numerical value. This is a great advantage of this method and a premise for its selection [Ilnicki, 2002]. The construction of a synthetic developmental index requires several stages, starting from the selection of a set of objects and diagnostic variables, through normalization of features, determination of stimulants and destimulants, to the computation of the index value, as a distance from the constructed developmental index.

The numerical description of the set of objects can be presented in the form of an observation matrix **X**, taking the form of Equation (4) below.

$$\mathbf{X} = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix}, \quad (4)$$

where x_{ij} means the value of the j–th variable for the i–th object (i = 1, 2,…, n; j = 1, 2,…, m).

In the first step, after selecting the variables, according to the rules described in "Selection

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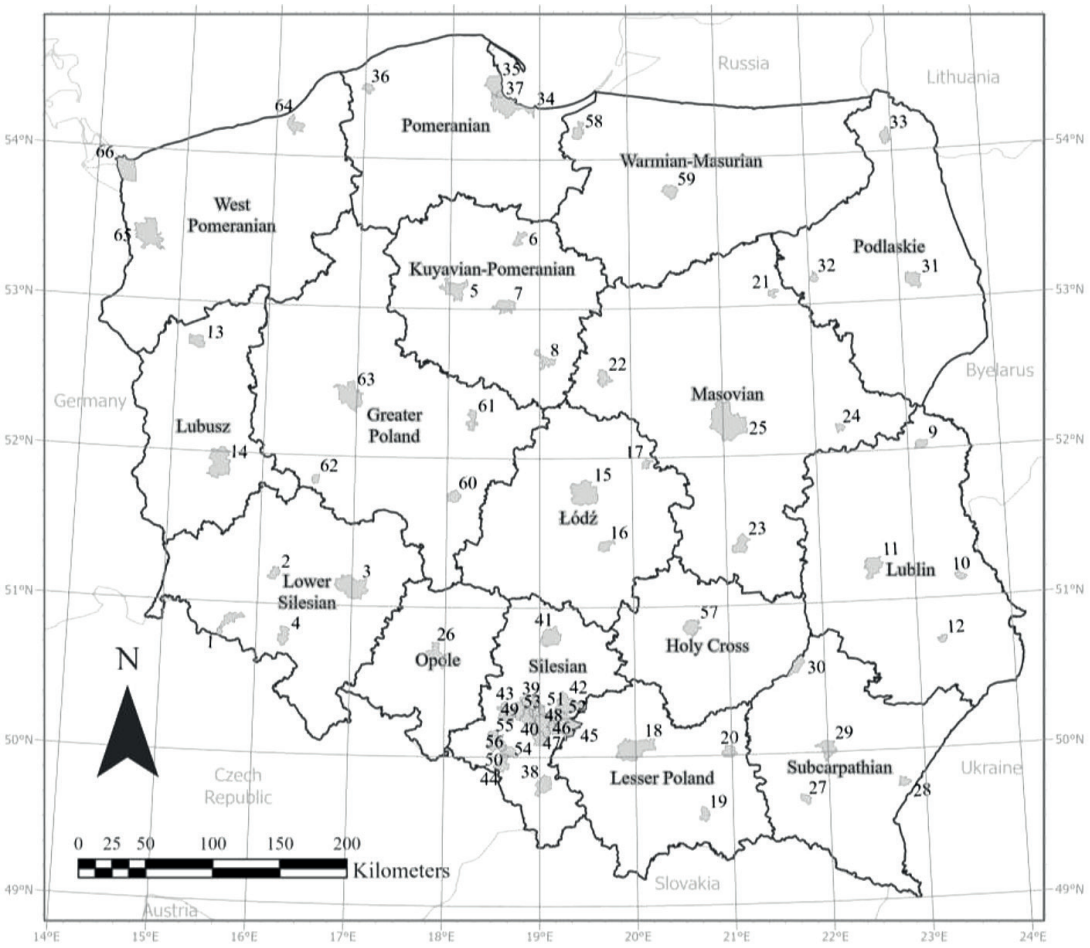

Analyzed cities
Voivodeships
Countries

1 - Jelenia Góra	17 - Skierniewice	39 - Bytom	61 - Konin
2 - Legnica	18 - Kraków	40 - Chorzów	62 - Leszno
3 - Wrocław	19 - Nowy Sącz	41 - Częstochowa	63 - Poznań
4 - Wałbrzych	20 - Tarnów	42 - Dąbrowa Górnicza	64 - Koszalin
5 - Bydgoszcz	21 - Ostrołęka	43 - Gliwice	65 - Szczecin
6 - Grudziądz	22 - Płock	44 - Jastrzębie-Zdrój	66 - Świnoujście
7 - Toruń	23 - Radom	45 - Jaworzno	
8 - Włocławek	24 - Siedlce	46 - Katowice	
9 - Biała Podlaska	25 - Warszawa	47 - Mysłowice	
10 - Chełm	26 - Opole	48 - Piekary Śląskie	
11 - Lublin	27 - Krosno	49 - Ruda Śląska	
12 - Zamość	28 - Przemyśl	50 - Rybnik	
13 - Gorzów Wielkopolski	29 - Rzeszów	51 - Siemianowice Śląskie	
14 - Zielona Góra	30 - Tarnobrzeg	52 - Sosnowiec	
15 - Łódź	31 - Białystok	53 - Świętochłowice	
16 - Piotrków Trybunalski	32 - Łomża	54 - Tychy	
	33 - Suwałki	55 - Zabrze	
	34 - Gdańsk	56 - Żory	
	35 - Gdynia	57 - Kielce	
	36 - Słupsk	58 - Elbląg	
	37 - Sopot	59 - Olsztyn	
	38 - Bielsko-Biała	60 - Kalisz	

Fig. 1. Location of the studied cities in relation to Polish voivodeships
Source: own elaboration using ArcGIS Pro 2.5, based on [Polish National Register of Borders, 2020].

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of diagnostic variables" section, the variables must be unified. To unify variables, the characteristics should be normalized by standardizing it, according to Equation (5).

$$Z_{ij} = \frac{(x_{ij} - \bar{x}_j)}{S_j}, (j = 1, \ldots, m), \quad (5)$$

where: is the arithmetic mean of j–th variable and S_j is the standard deviation for the j–th variable. This way, a matrix of standard values of the **Z** characteristics is obtained in Equation (6) below.

$$\mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1m} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nm} \end{bmatrix}, \quad (6)$$

where z_{ij} is a standardized value of x_{ij}.

The matrix (6) formed is the basis for determining the reference object P_0. It is an abstract object (eg. city) with standardized values $z_{01}, z_{02}, \ldots, z_{0j}$, where:

$$\begin{pmatrix} z_{0j} = \max\limits_i z_{ij}, \text{when } X_j \text{ is a stimulant} \\ z_{0j} = \min\limits_i z_{ij}, \text{when } X_j \text{ is a destimulant} \end{pmatrix}, \quad (7)$$

The P_0 object obtained in this way is treated as a development pattern.

In the next step, the Euclidean distances of the tested objects from the determined pattern should be calculated. This can be completed based on Equation (8).

$$D_{i0} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{0j})^2}, \quad (8)$$

For the $D_{10}, D_{20}, \ldots, D_{n0}$ distance values obtained in this way, the average value should be calculated (9).

$$\bar{D}_0 = n^{-1} \sum_{i=1}^{n} D_{i0}, \quad (9)$$

As well as standard deviation (10):

$$S_0 = \sqrt{n^{-1} \sum_{i=1}^{n} (D_{i0} - \bar{D}_0)^2}, \quad (10)$$

The level of sustainable development is obtained from Equation (11) below.

$$d_i = 1 - \frac{D_{i0}}{D_0}, \quad (11)$$

where:

$$D_0 = \bar{D}_0 + 2S_0, \quad (12)$$

A string of $d_1, d_2, \ldots, d_n$ values is obtained in this way, using the range [0.1].

The higher the measure of the d_i value of the tested object (i.e., its values are close to the pattern), the higher its level of development is. The lower the d_i value is (i.e., the values of the tested object are further away from the pattern), the lower its level of development is.

Two parameters of the taxonomic measure can be used to classify the examined objects, according to the level of sustainable development: geometric mean ($\bar{d}_i$) and standard deviation (S_{di}). Six sustainable development classes of cities can be distinguished in this way, depending on the value of d_i:

1. Sixth class (the lowest level of development): $d_i < \bar{d}_i - 2S_{di}$
2. Fifth class (low level of development): $\bar{d}_i - 2S_{di} \leq d_i < \bar{d}_i - S_{di}$
3. Fourth class (medium level of development): $\bar{d}_i - S_{di} \leq d_i < \bar{d}_i$
4. Third class (medium–high level of development): $\bar{d}_i \leq d_i < \bar{d}_i + S_{di}$
5. Second class (high level of development): $\bar{d}_i + S_{di} \leq d_i < \bar{d}_i + 2S_{di}$
6. First class (the highest level of development): $d_i \geq \bar{d}_i + 2S_{di}$

Determination of classes is usually a necessary element for analyses using Hellwig's method, but in the case described in the article it would be an unnecessary rounding – instead, the exact d_i values for each city will be used for the analysis using the Pearson correlation coefficient.

RESULTS

Preparation of the data

The process of verifying the indicators for usefulness and usability in the proposed method, described in "Selection of diagnostic variables"

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section, involves the rejection of indicators based on the requirements of the method and consists of four steps:

1. Pre-selection of indicators based on dimensions and the possibility of using it for national analysis (60 rejected indicators).

2. Rejection of indicators with low variation coefficient (5 rejected indicators).

3. Rejection of indicators with a high level of correlation – Pearson's linear correlation analysis (17 rejected indicators).

4. Verification of linearity of diagnostic variables – covariance analysis (2 rejected indicators).

All indicators for analysis have been marked continuously from X_1 to X_{119} – the numbering will be preserved until the end of the study to clearly depict the rejected indicators in each of the four steps. In the first step, the usage of indicators was examined on the basis of thematic groups and dimensions. The only reason for the rejection of the indicators turned out to be a relation to data for the voivodeship – all 60 indicators were rejected on this basis. Originally, the data is published in the form of data packages for a single voivodeship, in which each district is one row. Referring data for districts to the average value for a voivodeship is relevant in the case of analyzing a voivodeship; in the case of synthetic analysis of individual districts from different voivodeships in the whole country, the use of such data has no substantive value. The rejected indicators belonged to all domains.

The next step of rejection of indicators was the analysis of the variation coefficient. Five indicators for which the computed value of this coefficient was in the range <-0.1;0.1> were rejected. All rejected indicators belonged to the social domain.

The implementation of Pearson's linear correlation analysis was the third step of verifying the indicators. The generated matrix of coefficients was used to reject 17 indicators whose correlation coefficients were higher than 0.7. The rejected indicators belonged to all domains.

The last step of the rejection of indicators was a covariance analysis, which resulted in the rejection of two indicators from the social domain. A matrix of covariance coefficients was generated and the basis for the rejection was the result in the range <-0.1; 0.1>.

In the process of verifying the input data, a total of 84 indicators out of 119 were rejected. In the first step – the pre-selection of indicators based on dimensions – the following indicators were rejected: X_2, X_4, X_6, X_8, X_{10}, X_{12}, X_{13}, X_{16}, X_{18}, X_{20}, X_{21}, X_{23}, X_{25}, X_{27}, X_{29}, X_{31}, X_{33}, X_{35}, X_{37}, X_{39}, X_{41}, X_{43}, X_{45}, X_{47}, X_{49}, X_{51}, X_{53}, X_{55}, X_{56}, X_{59}, X_{61}, X_{63}, X_{64}, X_{66}, X_{68}, X_{70}, X_{72}, X_{74}, X_{76}, X_{78}, X_{80}, X_{82}, X_{84}, X_{86}, X_{88}, X_{90}, X_{92}, X_{93}, X_{96}, X_{98}, X_{100}, X_{103}, X_{105}, X_{107}, X_{109}, X_{111}, X_{113}, X_{115}, X_{117}, X_{119}. Analysis of the variation coefficient led to the rejection of the indicators: X_5,

Table 5. Overview of rejected indicators

Area/domain	Step 1	Step 2	Step 3	Step 4
Demographic changes	4	1	1	1
Public health	2	0	1	1
Poverty and living conditions	3	1	0	0
Education	4	3	0	0
Access to labor market	6	0	4	0
Sustainable consumption patterns	4	0	0	0
Old-age income adequacy	2	0	1	0
Determinants of health	2	0	0	0
Criminality	2	0	0	0
Road accidents	1	0	0	0
Social domain	**30**	**5**	**7**	**2**
Economic development	7	0	2	0
Employment	6	0	6	0
Transport	5	0	0	0
Economic domain	**18**	**0**	**8**	**0**
Climate change	0	0	0	0
Energy	2	0	0	0
Air protection	1	0	1	0
Land use	0	0	0	0
Biodiversity	1	0	0	0
Waste management	2	0	0	0
Environmental domain	**6**	**0**	**1**	**0**
Openness and participation	3	0	1	0
Economic instruments	3	0	0	0
Institutional-political domain	**6**	**0**	**1**	**0**
Overall	60	5	17	2

Source: own elaboration.

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X_{17}, X_{19}, X_{22}, X_{24}. On the basis of Pearson's linear correlation analysis, the following indicators were rejected: X_7, X_{11}, X_{28}, X_{30}, X_{34}, X_{36}, X_{46}, X_{62}, X_{67}, X_{73}, X_{75}, X_{77}, X_{79}, X_{81}, X_{83}, X_{99}, X_{108}. The last step, the analysis of covariance has resulted in the rejection of indicators X_1 and X_9. The overview of rejected indicators by steps and areas is presented in Table 5.

The last step of data preparation is to assign an explanatory variable to each variable. A variable can be a stimulant or a destimulant; for a stimulant, an increase in the value of the explanatory variable leads to an increase in the variable, for a destimulant, an increase in the value of the explanatory variable leads to a decrease in the variable.

Results for the proposed method

Step "Preparation of the data" was performed for 119 indicators characterizing sustainable development of Poland's biggest cities. After appropriate rejection of the variables, the remaining variables became the basis for classification using the proposed method. The classification process described in "Determination of the sustainable development level using the proposed method" section has become the basis for determining Sustainable Development Level (SDL) for the analyzed cities. The results for cities with the highest and the lowest SDL values are presented in Table 6. All results are shown in Table 9 below.

Table 6. Cities with the highest and the lowest SDL values

TERYT code	City name	SDL using Natural Breaks
1261000	Kraków	4.2857
3064000	Poznań	4.1429
0264000	Wrocław	4.0857
2261000	Gdańsk	4.0857
1465000	Warszawa	4.0286
	…	
0462000	Grudziądz	3.0286
0464000	Włocławek	3.0286
2478000	Zabrze	3.0286
1461000	Ostrołęka	2.9714
2063000	Suwałki	2.9143

Source: own elaboration.

Results for Classic Ranking and Hellwig's methods

The process described in "Determination of the sustainable development level using Classic Ranking and Hellwig's methods" section allowed to compute Sustainable Development Level (SDL) using Hellwig's taxonomic method, Table 7 shows the results of the research – results for cities with the highest and lowest d_i value. All results are shown in Table 9 below.

In tables above, the best results section contains four identical cities, while the worst results section contains two identical cities. The last step was

Table 7. Cities with the highest and the lowest d_i values

TERYT code	City name	SDL using Hellwig's method (di value)
3064000	Poznań	0.3107
1465000	Warszawa	0.3093
2264000	Sopot	0.3020
0264000	Wrocław	0.3007
1261000	Kraków	0.2754
	…	
0464000	Włocławek	0.0477
2063000	Suwałki	0.0471
1062000	Piotrków Trybunalski	0.0465
1262000	Nowy Sącz	0.0338
1864000	Tarnobrzeg	0.0264

Source: own elaboration.

Table 8. Cities with the highest and the lowest SDL values, computed using Classic Ranking

TERYT code	City name	SDL using Classic Ranking
0264000	Wrocław	42.5143
1261000	Kraków	42.4000
3064000	Poznań	42.2286
2261000	Gdańsk	40.6571
2264000	Sopot	39.9714
	…	
0664000	Zamość	27.1143
0462000	Grudziądz	26.3714
0464000	Włocławek	26.0857
2063000	Suwałki	25.3714
1461000	Ostrołęka	24.9714

Source: own elaboration.

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to compute the SDL using the Classic Ranking. The following Table 8 contains the results for the cities with the highest and the lowest score. All results are shown in Table 9 below.

In the case of results from the Classic Ranking, all five cities in the top of the table are identical, and for the bottom of the table – four.

Final results

The results of the research – SDL using the proposed method, Hellwig's method, and Classic Ranking method – are summarized in Table 9.

The highest SDL value was obtained by the city of Kraków, definitely ahead of other cities such as: Poznań, Wrocław, Gdańsk, Warszawa, and Sopot. Both the highest and the lowest results are described by a lack of concentration in one voivodeship – five cities with the highest SDL values are located in different voivodeships, as well as four cities with the lowest values. Table 10 below contains the computed basic descriptive statistics indicators for the results of SDL using different methods.

In order to compare the results obtained with the proposed method with the results obtained with the Hellwig's method and the Classic Ranking method,

Table 9. Results of the research – Sustainable Development Level of analyzed cities

TERYT code	City	SDL using the proposed method		SDL using Hellwig's method (di value)		SDL using Classic Ranking	
		value	position	value	position	value	position
1	2	3	4	5	6	7	8
1261000	Kraków	4.29	1	0.28	5	42.40	2
3064000	Poznań	4.14	2	0.31	1	42.23	3
0264000	Wrocław	4.09	3	0.30	4	42.51	1
2261000	Gdańsk	4.09	3	0.27	6	40.66	4
1465000	Warszawa	4.03	5	0.31	2	39.91	6
2264000	Sopot	4.03	5	0.30	3	39.97	5
1661000	Opole	4.00	7	0.21	8	39.63	7
1061000	Łódź	3.97	8	0.18	17	37.97	9
2862000	Olsztyn	3.94	9	0.17	21	38.86	8
2262000	Gdynia	3.89	10	0.18	19	36.17	15
2464000	Częstochowa	3.86	11	0.16	22	37.46	10
2473000	Rybnik	3.86	11	0.11	41	37.14	11
3063000	Leszno	3.80	13	0.18	20	35.89	17
2479000	Żory	3.77	14	0.14	31	35.51	20
3262000	Szczecin	3.74	15	0.18	16	35.94	16
1262000	Nowy Sącz	3.71	16	0.03	65	33.14	28
2469000	Katowice	3.71	16	0.24	7	36.43	12
0463000	Toruń	3.69	18	0.21	9	35.69	18
0862000	Zielona Góra	3.69	18	0.14	30	35.11	22
2461000	Bielsko-Biała	3.69	18	0.19	14	35.49	21
2465000	Dąbrowa Górnicza	3.69	18	0.14	32	35.63	19
2468000	Jaworzno	3.69	18	0.19	13	36.20	14
2472000	Ruda Śląska	3.69	18	0.15	29	36.40	13
0663000	Lublin	3.66	24	0.20	12	34.91	23
3261000	Koszalin	3.66	24	0.15	26	33.91	26

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cont. Table 9

1	2	3	4	5	6	7	8
2061000	Białystok	3.60	26	0.14	33	32.37	34
2471000	Piekary Śląskie	3.60	26	0.11	42	32.26	36
2477000	Tychy	3.60	26	0.21	10	34.74	24
0662000	Chełm	3.57	29	0.07	52	32.80	32
1863000	Rzeszów	3.57	29	0.16	25	33.06	29
2463000	Chorzów	3.57	29	0.19	15	33.83	27
0861000	Gorzów Wielkop.	3.51	32	0.16	24	34.20	25
2263000	Słupsk	3.51	32	0.13	34	33.03	30
2470000	Mysłowice	3.51	32	0.10	45	32.57	33
0261000	Jelenia Góra	3.49	35	0.15	27	32.91	31
2062000	Łomża	3.49	35	0.11	39	31.37	40
1464000	Siedlce	3.46	37	0.18	18	31.89	38
3061000	Kalisz	3.46	37	0.16	23	31.31	42
2661000	Kielce	3.43	39	0.10	46	32.17	37
0461000	Bydgoszcz	3.40	40	0.15	28	30.69	44
2466000	Gliwice	3.40	40	0.21	11	32.31	35
2476000	Świętochłowice	3.40	40	0.08	49	29.83	49
1862000	Przemyśl	3.37	43	0.10	47	31.54	39
2861000	Elbląg	3.37	43	0.09	48	30.37	46
0262000	Legnica	3.34	45	0.13	36	31.06	43
1063000	Skierniewice	3.34	45	0.13	35	31.34	41
1463000	Radom	3.34	45	0.10	44	30.06	48
3062000	Konin	3.34	45	0.07	57	29.71	50
0661000	Biała Podlaska	3.31	49	0.07	53	30.51	45
0265000	Wałbrzych	3.26	50	0.08	50	30.29	47
1864000	Tarnobrzeg	3.26	50	0.03	66	28.66	53
1062000	Piotrków Tryb.	3.23	52	0.05	64	28.66	53
1462000	Płock	3.23	52	0.12	38	28.83	52
2467000	Jastrzębie-Zdrój	3.23	52	0.08	51	27.97	56
2474000	Siemianowice Śl.	3.23	52	0.07	58	28.60	55
3263000	Świnoujście	3.23	52	0.13	37	27.23	61
1861000	Krosno	3.20	57	0.10	43	27.57	58
0664000	Zamość	3.17	58	0.11	40	27.11	62
1263000	Tarnów	3.17	58	0.07	56	27.83	57
2475000	Sosnowiec	3.14	60	0.06	60	29.40	51
2462000	Bytom	3.06	61	0.07	55	27.43	60
0462000	Grudziądz	3.03	62	0.07	59	26.37	63
0464000	Włocławek	3.03	62	0.05	62	26.09	64
2478000	Zabrze	3.03	62	0.07	54	27.54	59
1461000	Ostrołęka	2.97	65	0.05	61	24.97	66
2063000	Suwałki	2.91	66	0.05	63	25.37	65

Source: own elaboration.

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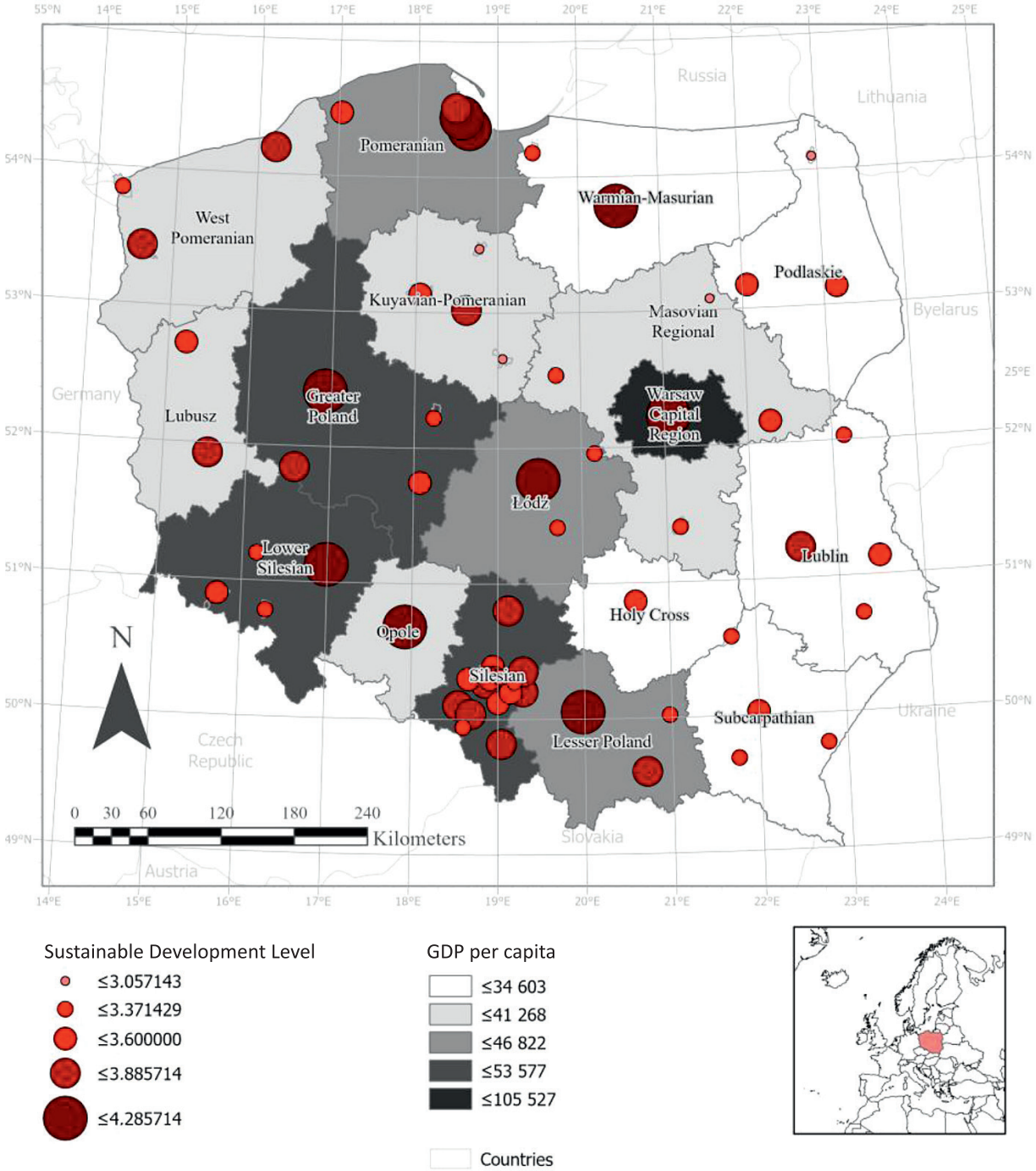

Fig. 2. Sustainable Development Level and GDP per capita
Source: own elaboration using ArcGIS Pro 2.5, based on results and [Urząd Statystyczny w Katowicach, 2018].

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Table 10. Descriptive statistics for SDL values

Descriptive statistics	SDL using the proposed method	SDL using Hellwig's method (di value)	SDL using Classic Ranking
Mean	3.5260	0.1404	32.8944
Standard error	0.0390	0.0087	0.5387
Median	3.5143	0.1340	32.4714
Standard deviation	0.3170	0.0707	4.3763
Variance	0.1005	0.0050	19.1519
Kurtosis	-0.5186	0.0382	-0.5006
Skewing	0.2405	0.6917	0.3328
Minimum	2.9143	0.0264	24.9714
Maximum	4.2857	0.3107	42.5143
Range	1.3714	0.2843	17.5429

Source: own elaboration.

Table 11. Pearson correlation coefficient for SDL values

	Proposed method	Hellwig's Method	Classic Ranking Method
Proposed Method		0.81	0.98
Hellwig's Method			0.85
Classic Ranking Method			

Source: own elaboration.

the correlation between the results was examined, using the Pearson correlation coefficient. Table 11 contains a set of correlation coefficients.

The results show a high correlation; a greater correlation between the proposed method and the Classic Ranking method can be observed – the value of Pearson's correlation coefficient is as high as approximately 0.98.

Sustainable development level values were used to develop a spatial distribution map using ArcGIS Pro 2.5 software (Fig. 2). Geographic Information System was used to process and visualize data – this is a powerful tool to support decision-making processes in many fields of science [Ciski & Rząsa, 2018]. The values of SDL were visualized using the graduated symbols method. For further discussion of the results, as a background by using the cartogram method the GDP per capita by NUTS units was displayed (the NUTS division is identical to the division into voivodeships, with the exception of the Masovian Voivodeship divided into the Masovian Regional and the Warsaw Capital Region).

CONCLUSIONS

The research conducted in this article and its results confirms the possibility of applying the proposed method of classifying objects based on natural breaks in analyses of the level of sustainable development of cities. The ranking of 66 Polish cities in terms of its sustainable development level was obtained. Therefore, the assumed aim of the research has been achieved.

The authors decided to verify the correlation of the results obtained with those from Hellwig's Method and the Classic Ranking. A higher correlation was observed with the Classical Ranking (Pearson's correlation coefficient reached approximately 0.98), which indicates a very strong correlation between these methods. The proposed method and Hellwig's method indicate lower but still high correlation (Pearson's correlation coefficient was approximately 0.81). By analyzing Hellwig's method, it can be indicated that it takes greater account of the variation in values within the variables for different objects. The classic ranking refers only to the positions on the list. The Hellwig's method and the Classic Ranking method are commonly used in this type of analysis and research; the fact of receiving highly correlated results confirms the validity and reliability of the proposed method. An overall trend of the results is confirmed by such a high result (e.g. the same four cities are in the top five). However, as can be seen in Table 9 (columns 5 and 7), the positions in the ranking of individual cities differ quite clearly from each other.

The results obtained by the Authors are also confirmed by other authors' research, using other methods (other taxonomic methods, multidimensional analysis, etc.) [Adamowicz & Janulewicz, 2016, Koszel & Bartkowiak, 2018, Laskowska & Dańska-Borsiak, 2018, Łuczak & Kurzawa, 2017, Matras, 2017, Mikuła, 2020]. The very order of the cities in the ranking is obviously different using different methods, but some general trend is maintained.

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The number of indicators rejected in the research may raise some doubts (the final analysis took into account 35 out of 119). However, this is due to the requirements for the proper selection of variables. In this regard, the authors have adjusted to the requirements related to the statistical elaboration in order to obtain reliable and credible results. A large number of original indicators were more related to the form of its publication in different dimensions than to thematic diversity. The 35 indicators adopted in the research were fully representative of the level of sustainable development and covered all the domains analyzed thematically. Even the percentage share of indicators from individual domains (taken into account in the computation in relation to the original number) was maintained with great approximation, which also confirms the validity of the selection of the thematic coverage by variables of sustainable development concepts.

The results obtained were certainly influenced by the economic condition of the voivodeships (expressed as GDP per capita) in which the analyzed cities are located. Analyzing the cartodiagram presented in Figure 2, it can be seen that the four out of five cities that obtained the highest level of sustainable development in the research are located in the voivodeships with the two highest classes of GDP/inhabitant. This is also confirmed by the results obtained by other authors in the analysis of sustainable development, as well as socio-economic development performed for the voivodeships [Drabarczyk, 2017, Klóska, 2017, Michoń, 2017, Misiewicz et al., 2019]. The obtained results were also influenced by the density of cities in particular voivodeships. In Silesian Voivodeship there are 19 cities, and in Opole and Holy Cross Voivodeships – only one each.

One can observe a certain correlation between the results obtained and the size of cities expressed in terms of their population. However, this relationship is not a linear relationship indicating that larger cities are higher in the ranking. There are several deviations from this claim. Among the 66 analyzed Polish cities, one can distinguish: 5 cities with a population of up to 50,000 inhabitants, 22 – with a population of 50,000–100,000 inhabitants, 28 – with a population of 100,000–250,000, 6 – with a population of 250,000–500,000, 4 – with a population of 500,000–1 million and one – with a population over 1 million. Among the five cities which obtained the highest sustainable development level are: Kraków, Poznań and Wrocław (500,000–1 million residents), Gdańsk (250,000–500,000 residents), and Warsaw (over 1 million residents). Among the five cities with the lowest sustainable development level are: Grudziądz, Ostrołęka, and Suwałki (50,000–100,000 residents), and Włocławek and Zabrze (100,000–250,000 residents).

The methodology proposed by the authors may be very widely used in various studies. It can be used to compare not only cities but also e.g. other territorial division units both in a given country, or to compare different countries. The thematic areas of the analyses may also be different. The proposed methodology can also be used e.g. to assess the differences in the level of economic and social development, or the smart-city level – very popular in recent years.

The results of the analyses obtained by the Authors, as well as the research methodology itself, can be used to create various rankings of cities or local government units. Such results can be e.g. used by local authorities in activities related to the promotion of a given city, attracting new residents or investors, or other activities related to territorial marketing. On the other hand, for cities with the worst results, it may constitute a developmental stimulus, justifying e.g. taking various not necessarily popular decisions by local authorities.

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CONTROL OF TECHNOLOGICAL PROCESSES USING A FUZZY CONTROLLER OF THE SYSTEM FOR MANAGEMENT OF CARGO DELIVERY BY RAILWAY

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ABSTRACT

Motives: One of the final indicators of service reliability of the transport system is the cargo delivery time, compliance of which is not yet controlled due to the lack of appropriate methods and tools of operational management. The concept of quality of assessment of cargo delivery, namely the reliability of compliance with the time obligations by transportation participants, is associated with the process modeling and the accuracy of determination of the estimated time of completion of each stage of the technological process of cargo delivery.
Aim: The purpose of the study is to present the model of a fuzzy controller as a principle of forming of a railway process management system, which is based on the possibility to operate with linguistic representations of elements.
Results: A new solution to an important problem is obtained – the formation of managerial influence using a fuzzy controller for management of technological processes of cargo delivery by rail at the current level of requirements for the efficiency of transportation organization. The usage of the offered method provides a solution to the problems of operational control practice in the formation of tools for operational control of technological processes for the railway dispatcher unit.

Keywords: transport system, delivery time, cargo, client-oriented approach, management of technological processes, fuzzy controller.

INTRODUCTION

One of the solutions to the problem of management of technological processes on the railway is to determine possible deviations from the standard time of the state and operations with objects managed by dispatcher units in order to take timely measures to reduce possible losses. The dispatcher unit is often forced to make decisions in unexpected situations and in conditions of uncertainty. On the other hand,

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compliance with cargo delivery time is one of the most important requirements to the operation of the transport system. In paper [Gruntov, 1986] it is noted that one of the final indicators of service reliability of the transport system is the cargo delivery time, compliance of which is not yet controlled due to the lack of appropriate methods and tools of operational control. The author of the paper states that the available technologies do not allow to ensure the accuracy of cargo transportation [Prokhorchenko, 2016].

It should be noted that real operational situations differ significantly from those taken into account when drawing up the long-term regulatory and technological documents [Levin, 2018]. The operational management unit analyzes events that have already occurred and makes decisions using experience and intuition.

At the same time, a significant number of transportation participants, which we have now, and an increase in their number in the future, make it necessary to accurately comply with the standards of technological processes. In order to implement technology management and to make a decision, the dispatcher unit needs a forecast, because the events that have occurred can be only analyzed [Petrashevsky, 2006, pp. 53–58, Kozachenko et al., 2016, pp. 39–47]. Brandimarte and Zotteri in their paper [Brandimarte & Zotteri, 2007, pp. 342–343] indicate the need for accurate forecasting of time points; they are interpreted as "transit points" (LTg), which is necessary especially in complex material management models in multi-echelon delivery chains. The researchers present a classification of prediction methods by classical statistical methods for modeling freight delivery processes. The decision-making process of the dispatcher, in turn, requires information support for obtaining managerial influence on the implementation of operations and stages of the technological process. At the same time, deciding on the most efficient operation of the transport system, the choice of optimal delivery technology from a variety of alternatives should be carried out using optimization models noted in [Hammadi & Ksouri, 2013]. Multifactor models which take into account the characteristics of the transport process and the availability of constraints allow for operational control in real-time and coordination of the delivery process participants in the innovative transport system [Bobrovskii et al., 2014].

The modern market principle of client-oriented approach also provides for the delivery of cargo on time. In a number of special issue papers [Karimi et al., 2015], the authors cite the view that, complex logistics processes and supply chains are among the most important activities in the modern society economy in recent years. They are affected by rapid changes in consumer demand, changes in orders, transport and communication stoppages, and the like. The supply chains are considered [Zhixiang & Svenja, 2014], taking into account social and environmental components.

The authors of the book [Teodorovic & Janic, 2016] define the central problem of transportation network development as a lack of integration between transportation modes and methodological approaches, and, in their work, do not draw any dividing lines between modes of transportation, the authors use essential common topics such as "traffic flow", "capacity and level of service", traffic control, transportation planning, and environmental impacts. In this aspect of the problem under consideration, it is especially important to predict the time of the transfer of goods from one mode of transport to another and compliance with time requirements. The concept of quality of assessment of cargo delivery, namely the reliability of compliance with the time obligations by transportation participants, is associated with modeling of the process and the accuracy of determination of the estimated time of completion of each stage of the technological process (TP) of cargo delivery. Obviously, the control of transportation time is the main factor in the management of technological processes, including the cases, when several subsystems interact, the way this happens at ports, on the borders of countries, or when railways and powerful industrial enterprises cooperate [Levin, 2020, Gapanovich & Shabelnikov, 2010, pp. 23–25].

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LITERATURE REVIEW

The papers [Strelko et al., 2019b, Butko et al., 2019, Strelko et al., 2019a, Babyak et al., 2020, Strelko et al., 2020] study the indicator of the assessment of operational deviation by stages of transportation and that allows us to numerically estimate the degree of implementation of technological processes occurring in cargo transportation, and the quality of management of cargo transportation by rail. TP performance assessments are provided to dispatcher's unit in real time using linguistic definitions of transportation conditions to make managerial influence and monitor the implementation of rolling stock performance indicators. Authors of the papers [Strelko et al., 2019b, Butko et al., 2019, Strelko et al., 2019a] offer to accumulate data on the transportation process, including data on deviations from the estimation in the existing information base to control the adequacy and evolution of the model. German scientists [Haehn et al., 2020, pp. 1611–1614] use probabilistic methods to minimize spreading of initial delays that occur at the train departure. Secondary delays occur due to conflicts with the schedules of other trains. The method offered in this paper increases the stability of the train schedule, but does not solve the problem of management of the technological processes of current operational work.

MATERIALS AND METHODS

Thus, the compliance with TP standards may not be a priority task of the dispatching management system due to the lack of methods and tools for processes execution control. This creates the need to develop new methods and algorithms for obtainment of a management decision for the implementation of operations and stages of the technological process and to develop a tool for solving the problem of transportation technology management. At the same time, it should be taken into account that transportation processes are characterized by such properties as uncertainty, randomicity and irregularity. The traditional mathematical language based on theory of sets and two-valued logic is not sufficiently adapted to describe such uncertainties [Sergin, 2004]. Therefore, we will consider the possibilities of solving TP management problems by means of mathematical modeling of processes with uncertainty using the concept of fuzzy sets [Grigorak & Savchenko, 2015, Danko et al., 2008].

Purpose of the study is to present the model of a fuzzy controller as a principle of forming of a railway technical process management system, which is based on the possibility to operate with linguistic representations of elements.

RESULTS

In order to form a management system for technological processes at the railway, the following actions were carried out:

1. The structure of the fuzzy controller was developed.
2. The methodology for management of the technological process was developed.
3. The methods for construction of all elements of a fuzzy controller are described.
4. The simulation of TP with (and without) fuzzy control was performed.
5. It was shown that setting the fuzzy controller allows to bring the objective function closer to the optimal value and to improve the TP, including within the frame of management of the delivery time.

Further the structure of the fuzzy controller was studied as part of circuit of the transportation process management within the consideration of the indicator "Cargo Delivery Time" (Fig. 1).

To manage the process, it is necessary to synthesize a fuzzy controller based on data on the actual cargo delivery process. The information system shall contain the following data for the previous period, as shown in Chart 1.

Statistical parameters:

– Minimal delivery time: 25.00 hours;
– Maximal delivery time: 63.50 hours;
– Average delivery time: 34.98 hours;
– First, second (median) and third quartiles: 32.66, 34.36 and 36.34 hours accordingly.

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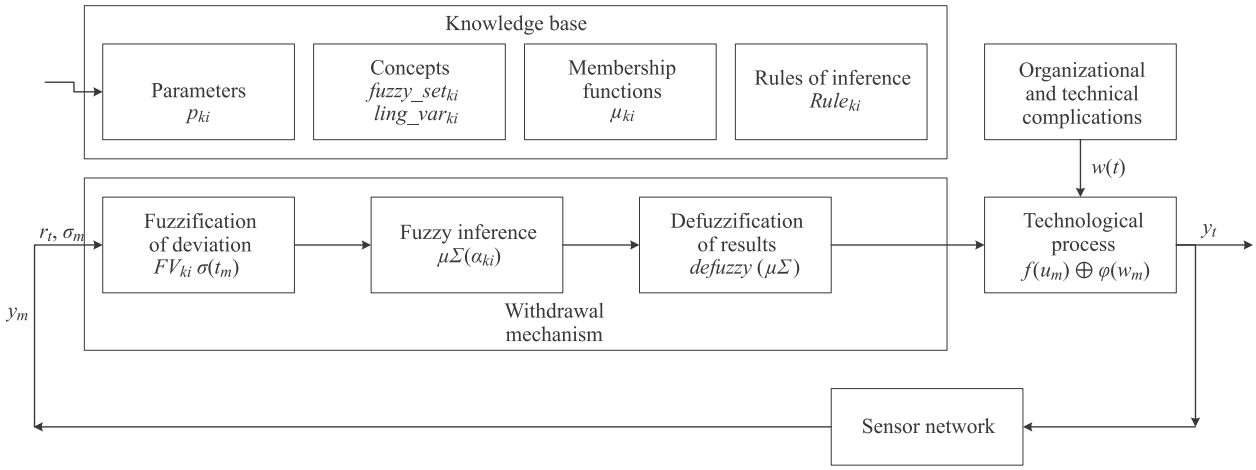

Fig. 1. Circuit of the fuzzy transportation process management
Source: own elaboration.

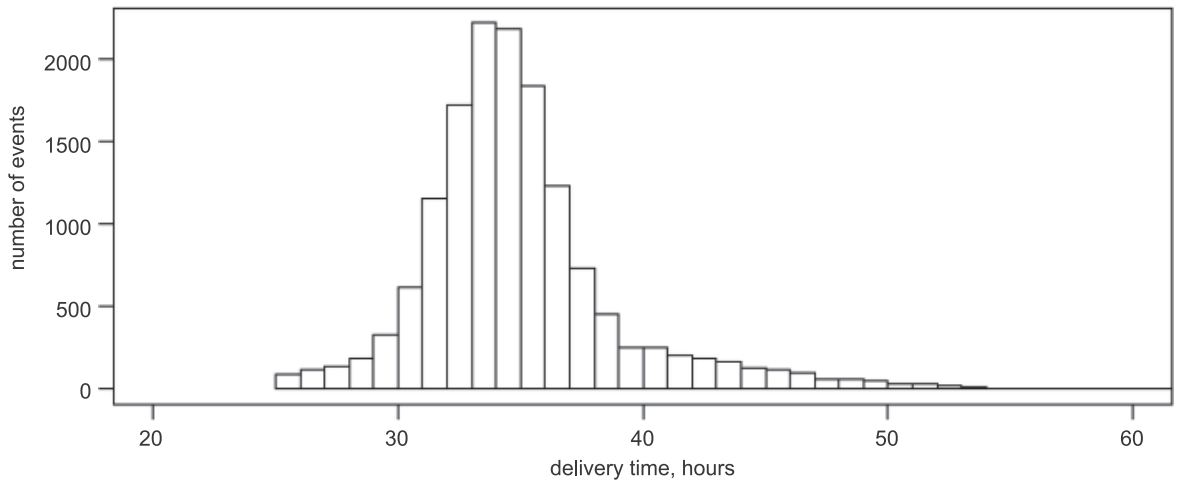

Chart 1. Data on cargo delivery time
Source: own elaboration.

The same data in the form of deviation from the schedule is shown in Chart 2.

Statistical deviation parameters:
– Minimal deviation of delivery time: -9.98 hours;
– Maximal deviation of delivery time: 28.53 hours;
– Average deviation of delivery time: 00.00 hours;
– First, second (median), and third quartiles: -2.32, -0.62, and 1.36 hours accordingly.

Let us accept the universe – the range of deviation values that can occur in the operation of the system: for example, U = [-15 hours; 30 hours].

We introduce concepts for estimations of the current state and fuzzy values that correspond to them:
1. Approximately on time, let's mark it as SV;
2. Delay approximately:
   a. for 1 hour – Z1;
   b. for 2 hours – Z2;
   c. for n hours – Zn;
3. Arrival ahead of schedule approximately:
   a. 1 hour ahead – V1;
   b. 2 hours ahead – V2;
   c. n hours ahead –Vn;

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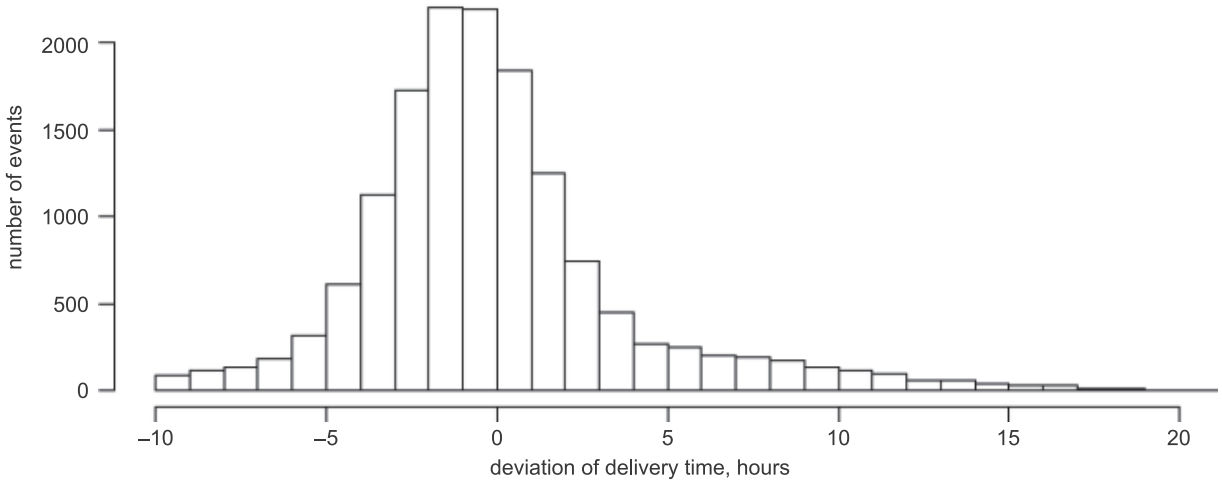

Chart 2. Deviation in cargo delivery time
Source: own elaboration.

We introduce concepts for estimations of the target state and fuzzy values that correspond to them:

1. Approximately on time delivery, we will mark it as G0;
2. Delivery behind the schedule, approximate delay on:
   a. for 1 hour – GZ1;
   b. for 2 hours – GZ2;
   c. for n hours – GZn;
3. Delivery ahead of schedule, approximate early arrival:
   a. 1 hour ahead – GV1;
   b. 2 hours ahead – GV2;
   c. n hours ahead – GVn.

We introduce, for example, triangular membership functions for fuzzy input and output functions.

Chart 3 shows examples of membership functions for input variables SV, Z1, Z3, and V4.

The membership functions of the input and output variables are constructed in the same way for the entire universe U = [-15; 30] (Chart 4). In this case, they are a topping of triangular functions with a base length of 2 hours, constructed for all possible (according to our assumption) deviations in the delivery time.

Inference rules can be formed in the form of productions:

IF the deviation is State THEN the goal is Goal

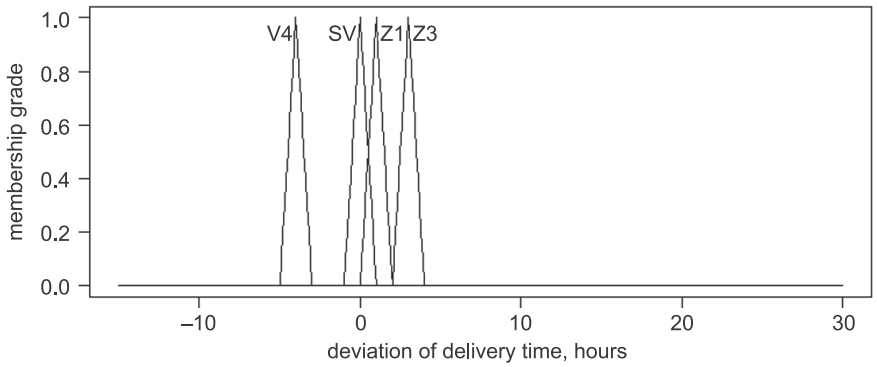

Chart 3. Graphic representation of four membership functions
Source: own elaboration.

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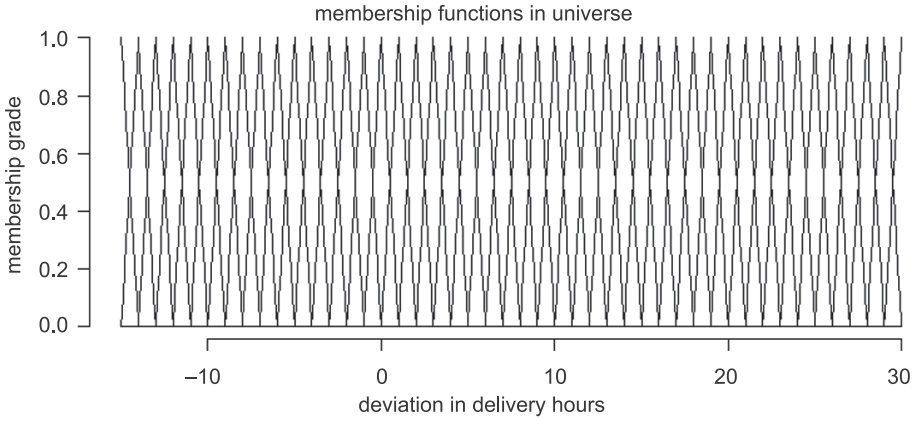

Chart 4. Membership functions over universe U = [-15; 30]
Source: own elaboration.

For example:
1. IF the deviation is SV, THEN the goal is G0;
2. IF the deviation is Z1, THEN the target is G0;
3. IF the deviation is Z2, THEN the target is GZ1;
4. IF the deviation is Z3, THEN the target is GZ2;
5. IF the deviation is V1, THEN the goal is G0;
6. IF the deviation is V2, THEN the target is GV1;

Rule 1 prescribes not to change deviations, that is, to perform work at a planned pace.

Rules 2–4 provide for reduction of delay by about one hour, that is, they require completing tasks at an accelerated pace.

Rules 5–6 provides for reduction of the arrival ahead of schedule by about one hour, that is, they require completing tasks in a slower pace.

The same rules can be presented in the form of a table 1.

Table 1. The inference rules

Input value	*V2*	*V1*	*SV*	*Z1*	*Z2*	*Z3*
Target value	*GV1*	*G0*	*G0*	*G0*	*GZV1*	*GZV2*

Source: own elaboration.

The considered components "Knowledge Base" make up the content of the blocks "Parameters", "Concepts", "Membership functions" and "Inference rules", respectively, and can vary or be supplemented depending on the specific aspects of the control task.

The mechanism of inference of fuzzy rules on sets in production form implements Mamdani Fuzzy Inference (algorithm of Mamdani Fuzzy Inference) with implementation options determined by the applied t-norms, t-conorms, defuzzification methods, and so on.

The problem of process identification is solved at the stage preceding the estimation of the values of simple statistics (such as the average value, median, standard deviation, percentiles, etc.) since it involves identification of the actual adequate statistical scheme or process model.

Chart 5 shows data on deviations from the standard values during performance of certain technological operations in the form of a histogram. The data indicate a certain asymmetry of deviations, but the statistical significance of the observed asymmetry is not obvious. Based on such data, in addition to calculation of statistical moments and ordinal statistics, it is possible, if necessary, to construct a fuzzy set "deviation from the standard" with the membership function, which is defined as the normalized function of distribution density shown in Chart 5 as a detailed approximation. However, such detailed approximation may be excessive and instead of detailed, it is possible to construct a simple approximation, such as a triangular membership function.

The bimodal nature of statistics often indicates an existing combination of two processes, and a simple

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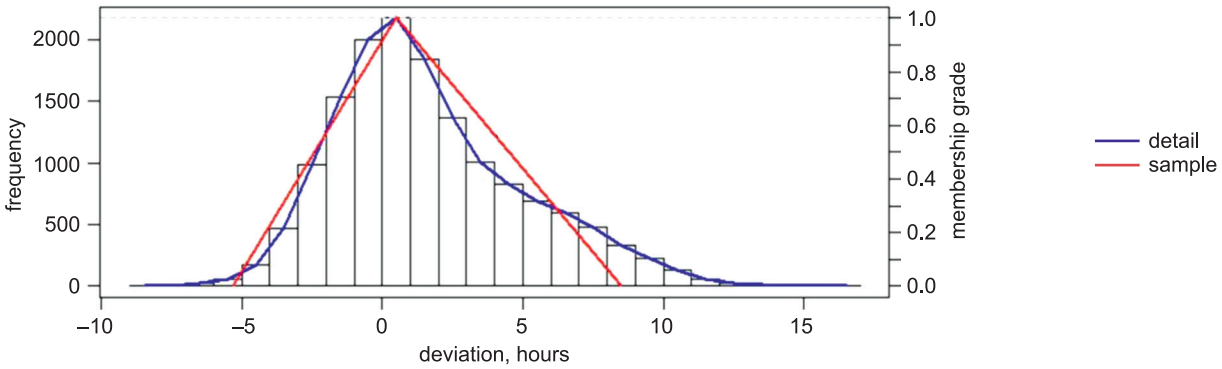

Chart 5. Membership function according to survey data
Source: own elaboration.

approximation looks excessively rough, as can be seen from Chart 6.

This situation requires additional analysis of the process, possibly restructuring of the component model, highlighting other or additional factors, etc.

To build a simulation model of technological process management, we assume the following assumptions.

The standard cargo delivery time is considered known and corresponds to the technical and organizational capacity of the operational mechanism.

In this case we can limit ourselves to considering only the deviation δ of processing time from the standard value.

We consider the entire processing time to be divided by *N*. At each i-th section, nv events occur that increase or decrease the deviation δ by a random variable w.

The numbers nv have a Poisson distribution with an average value of *v*. The distribution of w values is selected according to the simulated situation.

The total increase or decrease in deviation at the i-th section is calculated as the sum of

$$\delta_i = \sum_{j=1}^{n_v} \Delta w_j.$$

If the deviation of cargo processing time is normalized by the maximum value, we calculate the significance of the i-th section bi as the ratio of the standard processing time on the section to the standard time on the entire route. In the case of a uniform division into N sections, $b=1/N$.

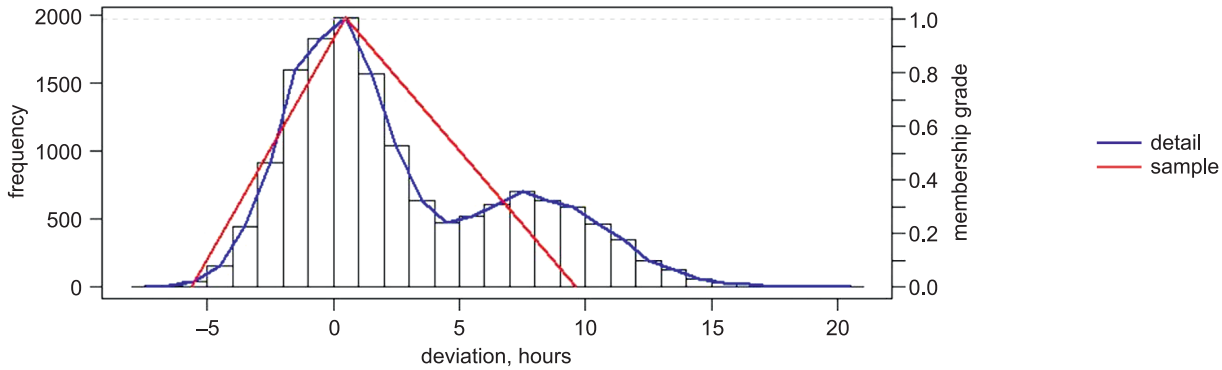

Chart 6. Data with suspicion of combination of processes
Source: own elaboration.

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The total accumulated deviation δ_k^Q on the *k-th* section of the route is determined in the following way:

if a fuzzy controller is not used: $\delta_k^Q = \sum_{i=1}^{k} \Delta b_i \delta_i$,

in particular, on the entire route $\delta = \sum_{i=1}^{N} \Delta b_i \delta_i$.

if a fuzzy controller is used: $\delta_k^Q = \psi(\delta_{k-1}^Q) + b_i \delta_i$,

in particular, on the entire route $\delta = \psi(\delta_{N-1}^Q) + b_i \delta_i$,

where $\psi(\delta_{k-1}^Q) = u(t_{k-1})$ is the management solution of the inference mechanism of the fuzzy controller on the k – th section of the route.

Target value of deviation δ_{target}=0.

The values of w_i, δ_i, δ_k^Q and are conveniently measured in fractions of one:

w_i = -0,03 means that a random event occurred that resulted in a decrease of the deviation by 3%

δ_i = 0,03 means that the deviation at the *i*-th section is 3%

δ = 0,11 means that the total deviation on the route is 11%

δ_k^Q = 0,08 means that the total deviation at the *k*-th section of the route is 8%.

Significance of the section $b_i = 1/N$

Average number of precedents at the section $v = 3$

Maximal expected deviation value at the section $\delta_{max} = 0.15$

The fuzzy variables *State* and *Goal* are shown in Chart 7.

The inference rules provide for acceleration in the case of arrival behind the schedule and deceleration in the case of arrival ahead schedule. Such management is fully justified in case of availability of a schedule that fully corresponds to the capabilities and goals of operational mechanisms.

Table 2. The inference rules

State	*E6*	*E5*	*E4*	*E3*	*E2*	*E1*	*InT*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*
Goal	*P5*	*P4*	*P3*	*P2*	*P1*	*M*	*M*	*M*	*L1*	*L2*	*L3*	*L4*	*L5*

Source: own elaboration.

Let us assume that the processing time disturbance *w* are evenly distributed in the interval [[-δ_{max}; δ_{max}], i.e. the arrival behind and ahead of schedule are considered equally probable. The result of simulation of the processing time for the assumptions made and the centroid defuzzification method is shown in Chart 8. When a fuzzy controller is used, the deviations are reduced, on average, by 2.2 times.

If the delays are more likely, i.e. w are evenly distributed over the interval [-⟦0,8δ⟧_max; 1,2δ_max], the behavior of the system changes significantly: there is a system delay drift from the schedule, as the mathematical expectation of w values is now positive, however, the regulator is able to correct and minimize deviations in time using the accepted parameters and rules of the model with the "meanmax" defuzzification method, as can be seen in Chart 9.

The case, when the standard cargo delivery time is considered unknown or unrealistic for execution

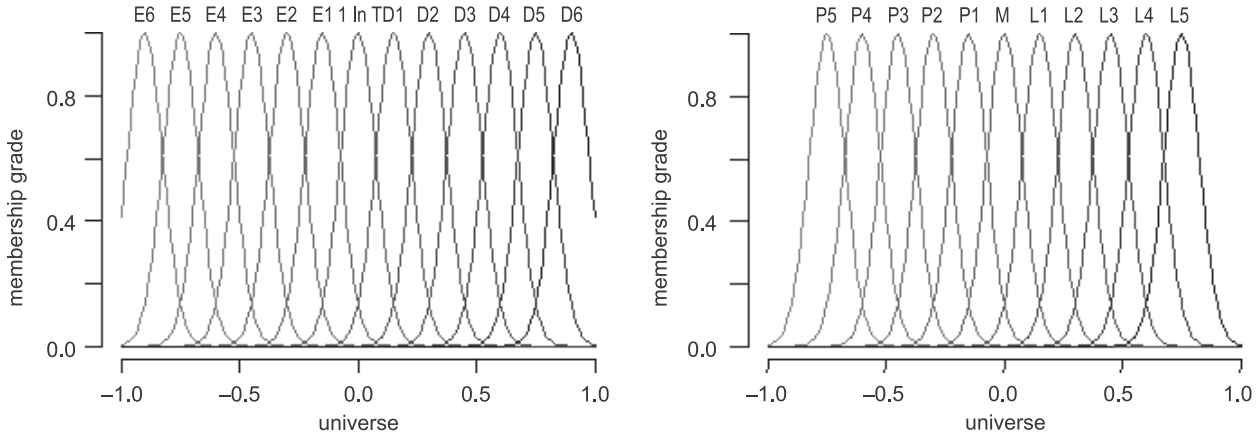

Chart 7. Membership function of values of fuzzy variables
Source: own elaboration.

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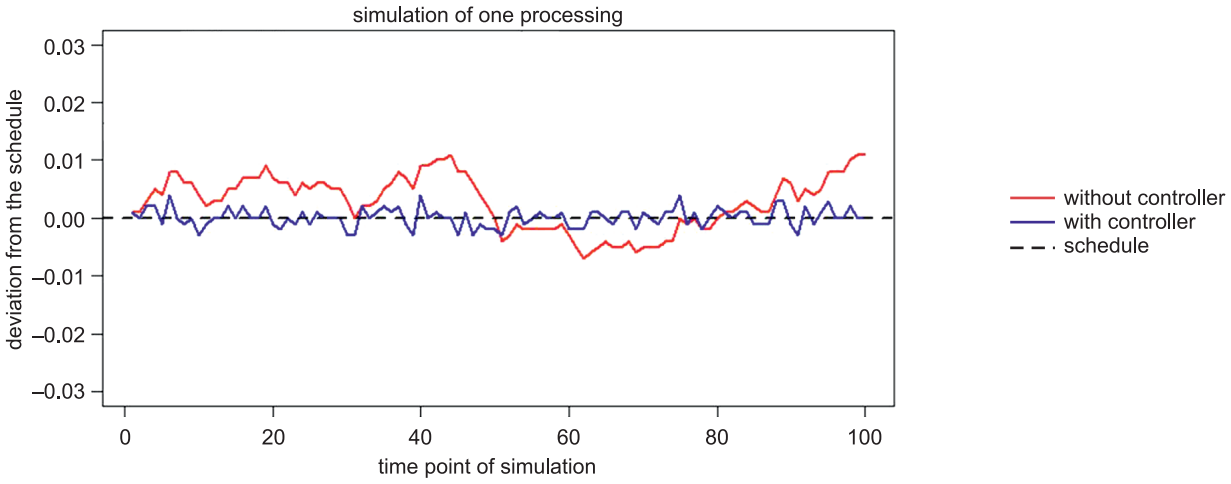

Chart 8. Processing time taking into account equally probable deviations
Source: own elaboration.

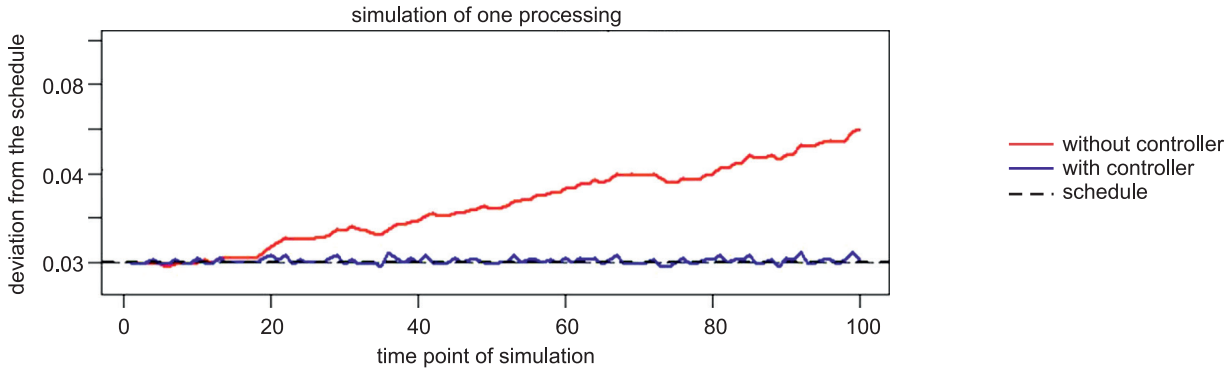

Chart 9. Processing time taking into added positive mathematical expectation of time disturbance of processing time *w*
Source: own elaboration.

(which is the same thing), requires separate consideration.

The results obtained are the principles of automated management of technological processes for railway transport, which are based on:

Justification of data: Data on the execution of all TP steps is saved automatically with a sufficient level of detail in IC.

Adequacy of representations: Statistical models of operational mechanisms (TP steps) are regularly updated based on the data of the last period.

Consistency of goals: management goals and objectives of operational mechanisms (TP steps) are linked through economic performance results.

Safety of standardization: standard indicators are based on current stable statistical criteria and evolve towards improvement of the economic efficiency of TP.

The use of the offered principles provides a solution to the problems of operational practice in the formation of tools for operational management of technological processes for the railway dispatcher units.

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CONCLUSIONS

1. The scheme and means of simulation modeling of technological processes of cargo delivery with and without the use of fuzzy control have been developed. The structure of a fuzzy controller and methods for constructing all its elements are developed.

2. The simulation modeling of technological processes with and without the use of a fuzzy controller is performed. Setting up a fuzzy controller allows to reduce the deviation of indicators of technological process performance from standard values and to improve the technological processes of cargo delivery management.

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DIGITALIZATION IN THE FIELD OF LAND USE: LEGAL ASPECTS

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ABSTRACT

Motives: In the near future modern technologies enable to create an environment for a high-tech digital platform for land use, which will ensure the minimization of the human factor, accompanying corruption and errors, automate the collection of statistical, tax and other reports, and ensure decision-making based on an analysis of the real situation. It is important to mention that the President of Russia has identified digital transformation as a national development goal until 2030.
Aim: The purpose of the article is to research the legal problems of digitalization of land use in Russia. The authors implement an attempt to consider comprehensively various aspects of the digitalization of land use in agriculture, forestry, as well as on industrial and other special-purpose lands.
Results: The research methodology is based on scientific methods such as dialectical, logical, predictive methods, system analysis, content analysis, as well as private scientific methods (statistical, technical legal, comparative legal methods).
The authors consider the legal problems of digitalization of land use as the initial, basic directions enshrined in strategic planning documents that underlie the legal regulation of land relations in Russia. The article also highlights the issues of land use and the inclusion in the economic turnover of territories affected by both anthropogenic human activities, man-made and natural emergencies.

Keywords: digitalization, land use, land resources, strategic planning documents, legal regulation, legislation.

INTRODUCTION

Today, the "digital" economy offers ample opportunities for the development of the state land administration system. In the near future modern technologies enable to create an environment for a high-tech digital platform for land use, which will ensure the minimization of the human factor, accompanying corruption and errors, automate the collection of statistical, tax and other reports, and ensure decision-making based on an analysis of the real situation [Keshelava et al., 2019, Zhavoronkova & Shpakovsky, 2019a].

It is important to mention that the President of Russia has identified digital transformation as a national development goal until 2030 [Decree No. 474, 2020].

Digitalization of land use gives the opportunity to create and implement an intelligent system for

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planning and optimizing agricultural landscapes and land use at different levels of generalization (economy, municipality, region, country, foreign territories), operating on the basis of digital, remote, geoinformation technologies and computer modeling methods [Zhavoronkova & Shpakovsky, 2019b].

The purpose of the article is to reserach the legal problems of digitalization of land use in Russia. The authors implement an attempt to consider comprehensively various aspects of the digitalization of land use in agriculture, forestry, as well as on industrial and other special-purpose lands.

For analysis, the authors take a significant array of legal acts of the Russian Federation regulating land relations, the collection and processing of information about land resources and rightholders, the organization of cadastral registration, state monitoring of lands and other issues, etc.

The article also highlights the issues of land use and the inclusion in the economic turnover of territories affected by both anthropogenic human activities, man-made and natural emergencies.

MATERIALS AND METHODS

From the point of view of legal research, land use as an integral and unified object of digitalization is an extremely complex and multifactorial subject of analysis. This complexity is due to a whole range of problems of both legal and institutional nature.

Among them, we highlight the following:

- the definition and content of the concept of "land use". It can be considered as an environmental, economic, political, social, infrastructural, financial, spatial, accounting, investment, legal category. This multiplicity of functions makes it difficult to create a single content of the legal object of digitalization;
- categories, types and forms of land use. According to the Land Code of the RF [2001], there are 7 types (categories) of land use – agricultural, industrial and transport, forestry, water, environmental, "settled", "reserve" and several dozen "subspecies". In turn, these "categories" are superimposed on the problems of ownership and use (permanent, rental, concession);
- according to Art. 72 of the Constitution of the Russian Federation [1993], land use is a subject of joint jurisdiction of the federal center and the constituent entities of the Federation, which implies the ownership, use, and disposal of land. Separately – local government bodies and "special" land users;
- responsibility for a particular type (category) of land use is borne by specially authorized state bodies in the field of agriculture, forestry, water management, environmental protection, urban planning, as well as authorities and administrations of the constituent entities of the Russian Federation and local governments.

It is necessary to "add" a plurality of extremely confusing normative legal acts regulating land relations, departmental disunity, shortcomings of the informational component of land management, methodological problems of sectoral approaches to "digitalization", the need to collect, store and process a huge array of different quality and not interconnected data, "embedding" them into the public administration system, determining the feasibility, relevance, efficiency of application of departmental information systems for users. The list of organizational, legal and technological problems and difficulties is quite large and both semantic and legal correction of acts in the field of digitalization of land use as a single object is required.

It is difficult to talk about a unified concept and the creation of organizational and legal mechanisms for digital modernization of land use, but this is a task of paramount importance. In general, digitalization of land use is a complex systemic task affecting public administration, ecology, economy and other areas.

In our opinion, the country's land management system, as a result of successful digitalization, will lead to structural changes in the economy of natural resource management, increased management efficiency, changes in the mechanism of interaction between government and departmental structures, and the unity of all information resources. And most importantly, it will help to find the optimal

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combination between the needs of the economy and the environment, to organize the use of natural resources without detrimental effect.

Noting the organizational, legal and technological difficulties of digitalization of land use, it is worth noting such an important factor as the role of strategic management and its impact on the legislative process.

In our opinion, the Russian Federation has created a unique, perhaps unparalleled in the world, strategy system, which enables on the basis of forecasts and goal setting to concentrate available resources (including economic, managerial, legislative) for selected goals.

These strategic planning documents include the Strategy for the Development of the Information Society of the Russian Federation for the period 2017–2030, the Strategy for the Scientific and Technological Development of the Russian Federation for the period up to 2030, the Program "Digital Economy of the Russian Federation", the Strategy for the Innovative Development of the Russian Federation for the period until 2020. In addition, national projects, state programs as normative documents make it possible to single out breakthrough projects of an inter-sectoral and inter-territorial nature and concentrate resources on their implementation.

The Strategy for the Development of the Information Society defines and reveals the meaning of the "digital economy". The digital economy is defined as "an economic activity in which the key factor of production is digital data, processing of large volumes and the use of the analysis results of which, in comparison with traditional forms of management, can significantly increase the efficiency of various types of production, technologies, equipment, storage, sale, delivery. goods and services" [Decree No. 203, 2017].

In our opinion, the "ecosystem" of the digital land use economy is determined by goal-setting, the unity of methods and the interaction of technological platforms, Internet services, analytical and information systems capable of processing large databases and coordinating the management process.

As part of the basic concepts of the Strategy, the digital economy is defined as an economic activity, where the key success factor is digital data, the processing of extremely large volumes of which and the use of the results of the analysis enable to achieve a significant increase in the efficiency of various activities (production, equipment, technologies, sales, storage, delivery of services and goods) in comparison with traditional forms of management [Evchenko & Vertakova, 2020].

According to the formed priority scenario of the future development of the information society in the Russian Federation, the state creates favorable conditions for the use of information and communication technologies.

What digitalization can provide in the field of land use? First of all: growth of labor productivity and reduction of transaction costs due to standardization of processes, simplification of interaction between subjects of management, introduction of new information and telecommunication technologies; simplification of document flow and court procedures for the implementation of most legally significant actions in electronic form; ensuring human rights and fundamental freedoms in one of the most sensitive areas of life – land use; preservation of the natural qualities of land, optimization of its use based on compliance with environmental safety measures, modeling of alternative land use options.

Digitalization of land use involves the improvement of existing and the emergence of new technologies.

As we have already noted, according to the Land Code, land use in Russian legislation is presented in the form of 7 categories in turn, breaking up into dozens of others. The creation of a single digital unified resource for different categories of land is a priority issue. Today, the most difficult and simultaneously bearing economic, legal, social, environmental, managerial, investment burden is a digital resource called "The Unified State Register (Cadastre) of Real Estate".

The Unified State Register of Real Estate (USRN) is a collection of reliable and systematized information about real estate, which is registered in the cadastre, rights to real estate, the grounds for their occurrence,

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right holders and other data [Federal Law on state registration of real estate, 2015].

The USRN, according to the current legislation, includes the following registers:

1. *Real estate cadastre.* It contains basic and additional information about the property. For example, the type of object, its cadastral number, description, area are indicated as the main ones, and the cadastral value, the address of the object (if any), the category of land, the results of land supervision, the presence of a dispute about the boundaries, the purpose of the building, structure and premises are the supplementary ones;
2. *Register of rights to real estate.* This registry contains:
   a. information about the rights, restrictions on rights and encumbrances of the real estate object, real estate transactions subject to state registration;
   b. additional information. These include, for example, information about an objection to a registered right;
3. *Register of boundaries.* This register contains, for example, information about zones with special conditions for the use of territories, administrative-territorial division, an approved land-surveying project, and public easements.

Information about land use, real estate objects, cartographic material is kept in the public domain and in the form of interactive maps available (free of charge) to any citizen. There are many resources on the Internet that allow to automatically receive all available information about the subject of law and objects of land use right.

A well-"digitized" organizational and legal basis for urban planning is complex and rather controversial. Land use in settlements, unlike, for example, agricultural use, is dynamic, affects the interests of many parties and is regulated by the Urban Planning Code, the Land Code, laws "On Environmental Protection", acts of the authorities of the constituent entities of the Federation and local authorities.

All land in Russia is divided into zones and territories, which are taken into account when determining the types of their use. Regulation of land use in cities and settlements is based on functional zoning, in accordance to which there are:

- zones for which boundaries and functional purpose are defined by territorial planning documents;
- urban planning zoning – the zoning of the territories of municipalities in order to define territorial zones and establish urban planning regulations;
- territorial zones – zones for which boundaries are defined in the rules of land use and development and urban planning regulations are established.

One of the key regulations that secure zoning are the rules for land use and development. Although the rules for land use and development refer to land legal relations, the legal interpretation of this act is contained in Art. 1 of the Civil Code. Land use and development rules are an act of urban planning zoning, the content of which includes: a description of territorial zones operating at the municipal or regional level; regulations, i.e. conditions for the construction of capital construction objects, determination of their location, purpose and parameters, mode of sites and underground utilities; the order of application, i.e. provision of official data to citizens and companies, issuance of permits, etc.

At present, its own rules for land use and development have been advanced and approved in each region, cities of federal significance, and municipalities. Moreover, these documents are subject to mandatory inclusion in the USRN database.

Another important "land user" tool is urban planning regulations. It establishes, within the boundaries of the relevant territorial zone, the types of permitted use of land plots, as well as everything that is above and below the surface of land plots and is used in the process of their development and subsequent operation of capital construction objects, the limiting (minimum and (or) maximum) sizes of land plots, plots and limiting parameters of permitted construction, reconstruction of capital construction facilities, restrictions on the use of land plots and capital construction facilities, as well as in relation to territories within the boundaries of which it is envisaged to carry out activities for the integrated development of the territory, the calculated indicators

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of the minimum permissible level of provision of the corresponding territory with communal, transport, social infrastructures and calculated indicators of the maximum permissible level of territorial accessibility of these facilities for the population [Urban Planning Code, 2004].

The information base containing real estate cadastres has been and will remain the fundamental for land use in the context of ownership and disposal. The cadastre is directly related to the "land plot" and does not work without a geographic (topographic) reference.

However, it should be noted that "land use" is not reducible to real estate, but is a much more complex legal object.

RESULTS AND DISCUSSION

As part of the research of the issues of legal regulation of digitalization of land use, the authors focus on the most significant areas of land relations.

Agriculture

Agriculture is one of the largest land users in Russia. Considering land resources, land use, land relations as a single object, we must plan in advance not only the "digitalization" of land use, but a much more important aspect – increasing the efficiency of the entire nature use and management, since land use is only part of the management system.

In accordance with Art. 77 of the Land Code [2001], agricultural land includes land located outside the settlements, provided for the needs of agriculture, which in agriculture are the main means of production, the main source of production of their own food products and agricultural raw materials for industry. The composition of the lands of this category includes agricultural lands – pastures, arable lands, hayfields, land deposits occupied by perennial plantations: gardens, vineyards, technical and other perennial crops.

An important aspect of the development of digitalization of agricultural land use is digital land management. Digital land management is a system of information support for management, economics, planning, including the processing of huge flows of environmental, geographical, economic, biological, statistical and other information (big geo data). Digitalization of land use ultimately serves the rational application of natural resources, effective management, improvement of tax, investment, legal, structural, spatial, urban planning programs.

Today our country, which accounts for more than 10% of the world's agricultural land, is the largest reserve of agricultural land on the planet. The area of the land fund of the Russian Federation amounted to 17.22 million hectares (by January 1, 2015), of which about 13% is agricultural land [Moiseikina & Darda, 2015].

The Government of the Russian Federation, considering the current state of development of state monitoring of agricultural lands within the framework of the Concept for the development of state monitoring of agricultural lands and the formation of state information resources about these lands for the period until 2020, stated the following:

- the country lacks an up-to-date cartographic basis, which does not allow solving the assigned tasks of land monitoring in many regions of the Russian Federation;
- the control over vast agricultural areas within the boundaries of the fields of individual crop rotations is complicated, which is a consequence of the lack of digital thematic maps for such areas;
- topographic maps available in most constituent entities of the Russian Federation date back to the mid-80s – early 90s of the last century, while the pace of work on their centralized updating has significantly decreased;
- the data of the processing results of the All-Russian Agricultural Census of 2006 are largely unreliable due to the fact that their submission to the statistical reporting system was carried out directly by agricultural producers.

According to the Ministry of Agriculture of Russia, the area of unused arable land in 2016 was 20.3 million hectares, of which 10 million hectares were at that time suitable for introduction into production

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without capital investment costs. By January 1, 2020, institutions and enterprises subordinate to federal executive bodies were provided with 6,911 land plots from federal agricultural lands, for a total area of 1,347,205.25 hectares.

Improving the efficiency of agricultural land use can serve as the streamlining and optimization of land use and land management on the basis of consolidated electronic passports of agricultural land, from cadastral numbers to soil characteristics. In addition, in the field of land use, digital technologies can also be applied to control land use.

Currently, the main information resource for digital land management is the Unified Federal Information System on Agricultural Lands.

This system provides the Ministry of Agriculture of the Russian Federation and subordinate organizations with operational, relevant and reliable information on agricultural lands, obtained in the course of state monitoring of these lands. Within its framework, obtaining, storing, processing and analyzing information about agricultural land, accounting for land, reclamation systems and hydraulic structures, systematic monitoring of the state and use of land, supplying stakeholders with information about agricultural land are provided.

The system contains information about: borders and areas of agricultural land and crops; data on land users; indicators of soil fertility; information about negative processes, objects and structures of land improvement and other information.

One important aspect of digitalization should be emphasized. Thus, the formation of an effective land use management system will require changes in the processes, nature, management procedures, if a new "digital" decision-making system is adapted to ordered databases. Algorithms, programs, special applications will allow to automatically perform those actions that previously required countless approvals and control and supervisory procedures.

This problem is partially solved within the framework of the Unified Federal Information System on agricultural lands and lands used or provided for agriculture as part of lands of other categories. For this purpose, the system provides a solution to a number of tasks: consolidation of information about agricultural land from various sources, automation of the processes of obtaining, verification, processing, analysis of relevant information about agricultural land used or provided for agriculture as part of land of other categories, land accounting by type of agricultural land; systematic monitoring of the state and use of agricultural lands, indicators of soil fertility, development and spread of the processes of their degradation, the state of vegetation on agricultural land; visualization of the results of state monitoring of lands, including in the form of digital maps of various thematic focus; providing authorized users and stakeholders with information about agricultural lands and analytical information about their condition and use, obtained within the framework of this system.

A comprehensive digital profile of agricultural land includes both traditional information on the boundaries of land plots, cadastral numbers, owners, on the contours of fields with data on their use, etc., as well as information from soil, agrochemical, agrophysical maps, yield maps. It is necessary to ensure the binding of all data to spatial coordinates and provide the functions of geoanalytics. According to Rosreestr, half of the land plots – 29.4 million at the beginning of 2017 did not have the necessary coordinate description of the borders, the absence of which does not mean a full-fledged register of rights to land plots, and therefore their turnover.

It is quite obvious that without using the assessment of land and resource potential, registration of ownership of rural land and its arrangement, it is impossible to achieve information management (digitalization) based on "big data". The entire architecture of digitalization of rural land use should be built on this principle.

In addition, land management, its digitalization should be the main mechanism for implementing the state's agricultural policy, the main factor in increasing the competitiveness of agriculture and be embedded in the overall system of economic management.

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Forestry

The largest territories (lands) in Russia are part of the forest fund.

The fundamental strategic documents in the field of digitalization of forestry are the "Strategy for the development of the forestry complex of the Russian Federation until 2030", the goals of which are declared: achievement of sustainable forest management, effective and innovative development of the use, protection and reproduction of forests, ensuring outstripping growth rates of the forestry sector, ecological and social security of the country, fulfillment of accepted international obligations on forests; increasing the long-term competitiveness of the forest industry and increasing the contribution of the forestry complex to the social and economic development of Russia.

Within the framework of the National Project "Digital Economy", a number of measures are envisaged for the development and implementation of digital technologies in forestry. This implies assistance in the modernization of existing and creation of new systems of data on forest resources, a set of documented information about forests, their use, protection and reproduction in order to develop a single digital platform for information and analytical support of management decisions made by officials in the field of forest relations.

A problematic issue is the ratio of the norms of the Forestry and Land Codes on the categories of forest lands. Article 7 of the Land Code [2001] defines the categories of land in the Russian Federation, which include forest land (forest land and non-forest land), the composition of which is established by forest legislation. By virtue of Part 1 of Art. 8 of the Forest Code, forest areas within the forest fund lands are in federal ownership. The transfer of federal property is carried out by the Government of the Russian Federation (Part 1 of Art. 8 of the Land Code [2001]).

Since the implementation of the transfer of forest lands to lands of other categories entails a change in the legal regime of land use (exploitation, circulation, protection), the legislator has established certain features of the legal regulation of the procedure under consideration.

At the moment, the introduction of digital technologies in forest management is being actively carried out, but in a decentralized manner. In the regions of the Russian Federation, different approaches to the digitalization of forestry are used, starting with the use of specialized software products and ending with the use of certain general-purpose software products. However, none of the ongoing projects solves the problem of creating a unified information automated system that allows collecting, receiving, storing, processing and using information on the state of forests, their qualitative and quantitative characteristics, their use, protection and reproduction, or partially solves it. In addition, to date, Russia does not have a legal framework regulating the creation and use of digital technologies on the territory of the country that comprehensively automate all stages and elements of the activities of all subjects of forest relations.

Within the framework of the Program "Digital Economy of Russia" in forestry, the formation of a federal state information system "Information system for remote monitoring of the Federal Forestry Agency" is being implemented, including the Unified State Automated Information System for recording timber and transactions with it, as well as the creation of the following new systems:

1. Departmental fund of spatial data.
2. Automated system "Control over the reliability of forest pathological survey reports".
3. The situation center of the Federal Forestry Agency.
4. Unified automated information system.

In our opinion, the "digitalization" of the forestry industry can significantly reduce costs, make all transactions and forest use "transparent", exclude illegal logging, illegal seizure of forest areas, and increase the profitability of the entire industry. The main direction of the development of informatization in forestry should be the creation of a unified automated information system as a unified Internet platform to provide information and analytical support for the activities of economic agents, officials in the field of forest relations.

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Lands for industry and other special purposes

Digitalization of land use in the category "Lands of industry and other special purposes" is carried out depending on the nature of special tasks for the solution of which they are used or intended [Land Code, 2001].

The main difficulty in digitalizing land use in industry and settlements (cities) is the zoning of territories. According to the current legislation, the types of zones with special conditions for the use of territories [Land Code, 2001] can be established: zones of protection of cultural heritage objects; security zone of electric power facilities, security zone of railways; security zone of communication lines and structures; protected zone of a specially protected natural area (state nature reserve, national park, natural monument); network and state gravimetric network; protective zone of a hydropower facility, etc.

Judicial practice

The possibilities and practical use of digitalization is manifested in a decrease in the number of court cases in the field of land use. Analysis of judicial statistics shows a large number of land disputes that are considered by courts annually. According to the report on the work of the courts of general jurisdiction on the consideration of civil, administrative cases at first instance for 12 months of 2017 in the courts of general jurisdiction, 179,830 disputes related to land use were considered on the merits, with a total of 231,345 applications for such categories of cases. For comparison: the courts of general jurisdiction, considering land disputes as a court of first instance, in 2015 received 104,022 cases related to the application of land legislation [Umerenko, 2018].

Which aspects of land use the digitalization of land use can solve: disputes over the formation of land plots, disputes over the acquisition of rights to land plots, disputes over rights to land plots and termination of rights; disputes about the determination of the procedure for the use of land plots; disputes over payment for land plots; disputes about inheritance of land plots.

This list is conditional and can be criticized due to the intersection of the subject of the dispute.

It is important to note that participation in international organizations allows Russia to integrate the most successful experience in cadastral registration in Western countries. For example, in Spain, the inventory (cadastre) is divided into urban and rural. It contains information about changes of a physical, economic and legal nature. The first includes changes related to the physical appearance of the object: new construction; extension, reconstruction, partial or complete demolition or demolition of existing buildings; in the rural cadastre – a change in the structure of cultivated areas or forms of land use. Changes of an economic nature are associated primarily with a change in the type of use of the property or its purpose. Changes such as the transfer of ownership or the emergence of a right are considered legal; allocation of a part of a real estate object, its division or merging with other objects.

Negatively affected lands

The management of negatively affected land resources is an important issue.

First, the extensive use of land resources has led to the disruption of the ecological balance in nature and the degradation of large areas of agricultural land. On the territory of the Russian Federation, there are practically no lands left that would not experience anthropogenic impact of a predominantly negative nature. Thus, the area of territories undisturbed by economic activity is estimated to be at least 65%, while undisturbed areas on all continents of the Earth make up 27%. This is largely due to the transition to industrial and intensive technologies, the use of high doses of mineral fertilizers and chemical plant protection products, which are accompanied by soil pollution with ballast substances, the accumulation of toxic chemicals in the soil and subsoil waters.

Secondly, natural and man-made emergencies are a serious source of pollution. Land use issues in the affected territories are regulated by a large number

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of legal acts. So, according to Art. 14 of the Land Code [2001], lands that have been exposed to radioactive and chemical contamination and where the production of products that meet the requirements established by law is not ensured, are subject to restriction in use, exclusion from the category of agricultural land, and can also be transferred to reserve lands for their conservation. The production and cultivation of agricultural products is not allowed on contaminated lands. The procedure for the use of such lands is regulated by the Decree of the Government of Russia dated February 27, 2004 No. 112 "On the use of lands exposed to radioactive and chemical contamination, carrying out reclamation and cultural and technical works on them, establishing protective zones and preserving objects located on these lands". Land use in areas affected by the accident at the Chernobyl nuclear power plant is regulated, among other things, by the Law of 15.05.1991 No. 1244-1 "On social protection of citizens exposed to radiation as a result of the disaster at the Chernobyl nuclear power plant".

The issues of preventing and responding to oil and oil products spills on the territory of Russia are regulated by the Decree of the Government of the Russian Federation of December 31, 2020 No. 2451.

The use of lands exposed to radioactive and chemical contamination is carried out depending on the danger to human life and other organisms. Lands can be divided into three categories:

1. Contamination of the territory is within acceptable limits and such a site can be used without restrictions.
2. Land of medium pollution, which can be cultivated with conditions for preliminary sanitation (cleaning measures).
3. Territory with life-threatening pollution. The site is subject to conservation for a certain period until the re-analysis of soil and air.

The complete restriction on the use of land applies only to areas with a dangerous degree of pollution. Other territories can be exploited with certain restrictions. On the contrary, it is recommended to use some agricultural land with a low degree of pollution for sowing forage crops, which, in the process of growth, process impurities of heavy radioactive metals in the soil, which contributes to the fastest cleansing.

Other lands unsuitable for use are subject to cleaning, rehabilitation or conservation measures. The principles of the rational use of such territories are determined by legislative acts on the basis of the norms of state environmental monitoring.

All this necessitates the development of qualitatively new approaches to land use and nature management, in which the main place should be occupied by the harmonization of compromise relations between society and the biosphere, nature and man, ecology and economy. Moreover, greening should be a priority, since not only the economic effect of the measures taken, but also the prevention of negative manifestations in nature depends on minimizing environmental miscalculations in practice [Petrova & Stepkin, 2020].

Digital technologies will make it possible to implement an effective and rational set of measures for the greening of land use.

At present, several directions of this activity are being considered.

First of all, this is the creation of an integrated system for remote monitoring of the region, which will allow monitoring the state of the forest fund, agricultural lands, waste management, subsoil use, etc. In addition, the accumulated problems can be quickly and massively solved using modern information and communication technologies.

In addition, an experiment is currently being prepared in Russia to create a single information resource on land and real estate. The project will allow to combine disparate information resources on land of state and municipal authorities to improve the efficiency and quality of service delivery.

The World Land Management Survey prepared by the United Nations Economic Commission for Europe stated that "...the level of civilization of a society is determined by the level of development of land management and land use". It was also emphasized there that "…due to insufficient land management in Russia, millions of hectares of previously cultivated agricultural land are empty". The data of the

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National Union of Land Surveyors of Russia show that more than 60 million hectares of land, consisting of 6.2 million plots, can be involved in agricultural use.

An important and promising direction of digitalization of land use in Russia is the implementation of technologies of the "Smart Region" project. Of course, a state program for the integrated development of rural areas based on digital management should be introduced. A tool should appear that will help to see the strengths and weaknesses of each region in terms of different indicators. Without analyzing this, it will be difficult to make decisions and move on.

CONCLUSION

Thus, as a result of the research, the following can be distinguished. The consistent introduction of digital technologies in the land use of the country will not only allow for a new leap in scientific and technological progress in this area, but will also contribute to successful socio-economic development. The potential for digitalization of land management is aimed, first of all, at the development of specific proposals for the efficient and comprehensive use of land, substantiation of all possible ways to improve and develop the use of territories, as well as to logically accelerate the formation of a rational model of land use of the near future.

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