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THE USE OF GEOINFORMATION SYSTEMS IN TERRITORIAL PLANNING FOR THE LOCATION OF WASTEWATER TREATMENT PLANTS IN POLAND

Abstract. *This paper investigates in detail the possibilities of using geographic information systems (GIS) as an effective tool for spatial planning, in particular in the field of selecting optimal locations for sewage treatment plants in Poland. Considerable attention is paid to the analysis of key spatial, environmental and socio-economic factors that determine the feasibility of selecting specific locations. These factors include the terrain, availability and accessibility of transport infrastructure, possible impact on the natural environment, including water resources, soil and biodiversity, as well as social aspects related to the reaction of the local population to the location of treatment facilities. The methodological basis of the study was a multi-criteria analysis (MCA), which allowed for a comprehensive assessment of various spatial factors and the identification of the three most suitable sites for the construction of the treatment plant. The use of GIS in combination with MCA enabled the integration and systematisation of heterogeneous spatial data, which allowed for the consideration of complex interrelationships between environmental, economic and social factors. The analysis identified the three most suitable sites for the construction of the wastewater treatment plant. Site № 1 was chosen as the most optimal: the area is 2 783,1 hectares; the shape coefficient is 0,05 (close to a regular square); the distance from built-up areas is the maximum among the studied sites; transport accessibility is the availability of high-quality access roads. The results of the study confirm the high efficiency of geographic information systems in the field of territorial planning, especially for tasks requiring consideration of multifactorial criteria. The findings indicate the expediency of active implementation of GIS for making strategic decisions in the field of environmental and spatial planning. The application of this approach allows to minimise potential negative impacts on the environment and local communities, as well as to increase the efficiency of natural resource management.*

Key words: *Geographic Information Systems, territorial planning, wastewater treatment plants, environmental optimization, spatial analysis.*

Олексюк Іванна, Касіянчук Дмитро. Застосування геоінформаційних систем у територіальному плануванні для місць розташування очисних споруд у Польщі

Анотація. *У роботі детально досліджено можливості застосування геоінформаційних систем (ГІС) як ефективного інструменту для територіального планування, зокрема у сфері вибору оптимальних місць для розташування очисних споруд на території Польщі. Значна увага приділена аналізу ключових просторових, екологічних і соціально-економічних чинників, які визначають доцільність вибору конкретних локацій. Серед*

таких чинників ураховано рельєф місцевості, наявність і доступність транспортної інфраструктури, можливий вплив на природне середовище, зокрема на водні ресурси, ґрунти та біорозмаїття, а також соціальні аспекти, пов'язані з реакцією місцевого населення на розміщення очисних споруд. Методологічною основою дослідження став багатокритеріальний аналіз (MCA), що дозволив здійснити комплексне оцінювання різних просторових чинників і визначити три найбільш придатні ділянки для будівництва очисних споруд. Використання геоінформаційних систем у поєднанні з багатокритеріальним аналізом забезпечило інтеграцію та систематизацію різнорідних просторових даних, що дало змогу врахувати складні взаємозв'язки між екологічними, економічними та соціальними чинниками. У процесі аналізу було визначено три найбільш придатні ділянки для будівництва очисних споруд. За оптимальну була вибрана Ділянка № 1: площа – 2 783,1 ар.; коефіцієнт форми – 0,05 (близький до правильного квадрата); віддаленість від забудованих територій максимальна серед досліджених; транспортна доступність – наявність під'їзних доріг високої якості. Результати дослідження підтверджують високу ефективність геоінформаційних систем у сфері територіального планування, особливо для завдань, що потребують урахування багатофакторних критеріїв. Отримані висновки свідчать про доцільність активного впровадження геоінформаційних систем для ухвалення стратегічних рішень у галузі екологічного та просторового планування. Застосування цього підходу дозволяє мінімізувати потенційні негативні наслідки для навколишнього середовища та місцевих громад, а також підвищити ефективність управління природними ресурсами.

Ключові слова: *геоінформаційні системи, територіальне планування, очисні споруди, екологічна оптимізація, просторовий аналіз.*

Introduction. Ensuring the rational use of natural resources and minimising environmental impact are among the main challenges of modern spatial planning. Urbanisation, population growth and climate change create new challenges in environmental management, especially in the context of the construction of wastewater treatment facilities. The importance of locating such facilities is driven by the need to ensure effective wastewater treatment and the preservation of aquatic ecosystems.

Spatial planning requires consideration of a complex set of natural, social and technical factors, which makes it difficult to make optimal decisions. The use of GIS allows for the integration of various spatial data, their analysis and visualisation, which significantly increases the accuracy and validity of decisions.

The relevance of GIS in this area is not only due to their ability to process large amounts of data, but also to the possibility of conducting multi-criteria analysis. This ensures that aspects such as terrain features, accessibility of transport infrastructure, environmental impact and socio-economic consequences are taken into account.

According to the National Statistical Office of Poland, in 2023, the country's population was approximately 37,6 million, with deaths exceeding births, leading to a population decline [1], and forecasts indicate a further decline in population to 30,9 million in 2060 [2]. These demographic changes are affecting the structure and functioning of urbanised areas, which in turn requires the adaptation of infrastructure, including wastewater treatment systems.

Study area. The study was conducted on the territory of two communes in Poland (Fig. 1) – Pierzchnica and Chmielnik, located in the Kielce County, a region of significant environmental and socio-economic importance.

The main reason for selecting these gminas was the need to improve wastewater management due to the growing burden on local infrastructure and the risk of water pollution, and to modernise water treatment systems.

In addition to the Pierzchnica and Chmielnik communes, the analysis was extended to neighbouring districts, which include:

1) protected areas – areas with limited human intervention, which are important for the preservation of ecosystems;

2) transport infrastructure – major roads, railway junctions and transport corridors that provide logistical advantages;

3) water bodies and hydrographic objects – rivers, lakes and other water resources that influence the choice of location for treatment facilities due to the need to comply with environmental standards.

The integrated approach allowed us to take into account aspects such as social impact, access to resources and environmental protection. For

Fig. 1. The study area

example, determining the safe distance from water bodies (in accordance with regulations) was a key factor in excluding some areas from further analysis. Taking into account transport infrastructure allowed us to identify areas that are most convenient for construction and operation logistics. This expansion of the study area helped to create a more accurate and reasonable set of potential locations for the construction of wastewater treatment plants and to take into account the socio-economic context.

Materials and methods. A wide range of materials and methods were used to conduct the study. The main sources of data were geospatial data obtained from open sources (OpenStreetMap (OSM) [3], European Data Portal [4], INSPIRE Geoportal [5]) and created by processing in QGIS.

In [6], an innovative indicator system based on the analysis of remote sensing and GIS data is proposed. Its purpose is to identify the optimal locations for the placement of sewage treatment plants in Phnom Penh. This helps to avoid deterioration of the aquatic environment and reduce risks to human health. Paper [7] presented an integrated approach to the formation of databases necessary for design, developed stages of information processing and analysis, and created a feasibility study for the use of land plots for urban planning projects based on GIS technologies. The authors of [8] applied multi-criteria decision analysis using GIS to optimise the location of sewage treatment plants. As a result, they created a series of mapping models that take into account the criteria important for site selection using an analytical hierarchy of weights for each factor.

The study [9; 10] was based on hydrological analysis using a digital elevation model (DEM), which allowed to define the boundaries of catchment areas and the drainage network. Suitable areas for the installation of drainage systems were identified, taking into account the slope of the terrain, types of land use and proximity to water bodies. In [11], innovative techniques were developed, including a combination of GIS analysis and direct current resistivity (DCR), to detect wastewater leaks in semi-arid urban areas. This data is critical for further planning and management of water resources. The issue of the impact of hazardous geological processes on the environment and their consideration within certain cadastral zones has been studied in [12].

The location of treatment facilities is a key element of their efficiency. As noted in [2; 13], this process requires taking into account such factors as population density, water availability and transport infrastructure. GIS was used to conduct a spatial analysis of these factors. According to the materials of the GeoTerrace-2024 conference [14], modern technologies such as GIS open up new opportunities for spatial analysis and decision-making in territorial planning. The analysis took into account terrain, water resources, transport infrastructure and socio-economic factors.

GIS allows combining and analysing different spatial data, which ensures the accuracy and validity of decisions. This study aims to identify the optimal locations for the construction of wastewater treatment plants in the communities of Pierzchnica and Chmielnik, Republic of Poland, using geographic information systems. This process is multifactorial and takes into account geographical, environmental, economic and social aspects.

The following tasks were performed to achieve this goal.

Collecting and analysing spatial data: defining the boundaries of the study areas; analysing the terrain, taking into account slopes, heights and natural barriers; collecting information on water resources (rivers, lakes, ponds, etc.); studying transport infrastructure (roads, railways, main routes); analysing existing buildings and their impact on the choice of location.

Determination of site selection criteria: selection of sites with a minimum slope to ensure the stability of structures; establishing a safe distance from water bodies to avoid pollution; assessment of the availability of transport infrastructure for construction and operation; consideration of social factors such as distance from residential areas.

Spatial analysis: integration and processing of data using GIS tools; creation of thematic maps showing the main aspects of the territories; execution of queries to identify sites that meet the established criteria.

Evaluation of results: comparison of options by criteria; analysis of risks and benefits of each of the proposed locations.

The research methodology is divided into three key stages (Fig. 2):

1) preliminary processing of cartographic data;

2) spatial analysis and creation of models based on SRTM data;

3) interpretation of the results and drawing conclusions.

Disscussion. The study identified three potentially suitable sites for the construction of wastewater treatment facilities. The analysis was based on a multi-criteria approach, including environmental, social, geographical and economic indicators.

The research process consisted of several key stages, each of which was based on the use of specialised tools and analysis methods. This helped to ensure data integrity and avoid measurement errors.

The study used geographic information analysis to identify the optimal locations for wastewater treatment plants in two Polish communes. The GIS software QGIS was used to process, integrate and analyse the spatial data.

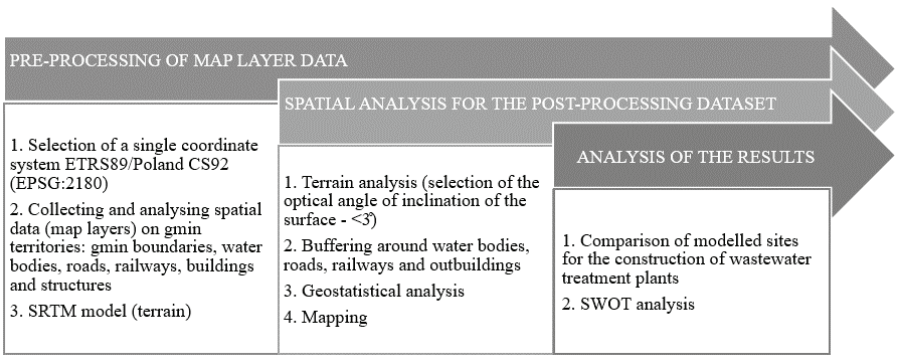

Fig. 2. Structure of the methodology [14]

I. Preparation of input geodata.

At the first stage, spatial data was collected and processed (Fig. 3): digital elevation model (DEM) – used to calculate the slopes of the territory; transport infrastructure – obtained from OpenStreetMap (OSM) and containing layers of roads, railways and access roads; hydrography – including rivers, lakes and water protection zones; settlements – vector layers showing the boundaries of built-up areas; cadastral data – land plot boundaries to assess legal restrictions.

All layers were converted to a single ETRS89/ Poland CS92 coordinate system (EPSG:2180) to avoid spatial distortions.

II. Geoprocessing and spatial analysis:

1) cropping of the study area – the Clip tool was used to cut off unnecessary data outside the study area;

2) slope analysis – performed using Terrain Analysis → Slope, which allowed creating a slope layer. Areas with a slope of more than 3° were excluded as unsuitable;

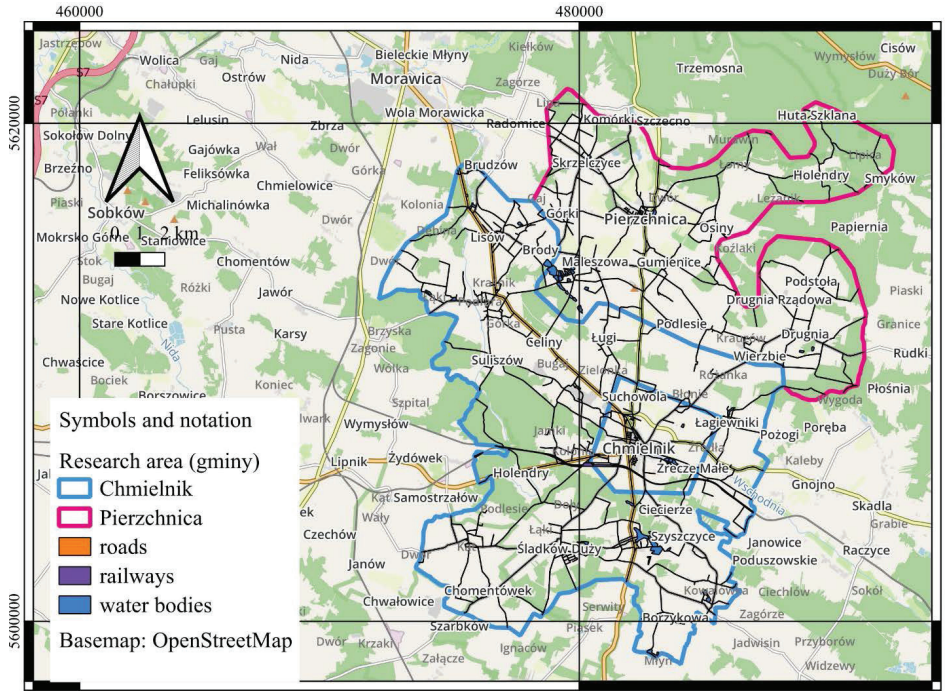

Fig. 3. Map layers

3) buffer analysis – buffer zones around water bodies (300 m), settlements (500 m) and transport network (1000 m) were determined using Buffer Tool; only those areas that meet environmental and sanitary standards were selected;

4) cross-analysis of factors – Raster Calculator tool was used to combine all the constraints and criteria, which allowed to create a map of the suitability of the territories.

III. Multi-criteria analysis (MCA) in QGIS.

The method of analytical hierarchy of processes (AHP) is used to weight the following criteria: relief (20%); transport accessibility (30%); remoteness from water resources (25%); remoteness from settlements (25%).

IV. Identification of optimal sites.

Thus, the operations performed made it possible to create a prepared set of spatial data that meets the technical requirements for further stages of analysis and decision-making.

The use of GIS spatial analysis tools ensured the integration of all collected data and allowed for a detailed analysis based on the defined criteria. Based on the integration and analysis of the data, a final map was created showing the proposed locations for the construction of the wastewater treatment plant (Figure 4).

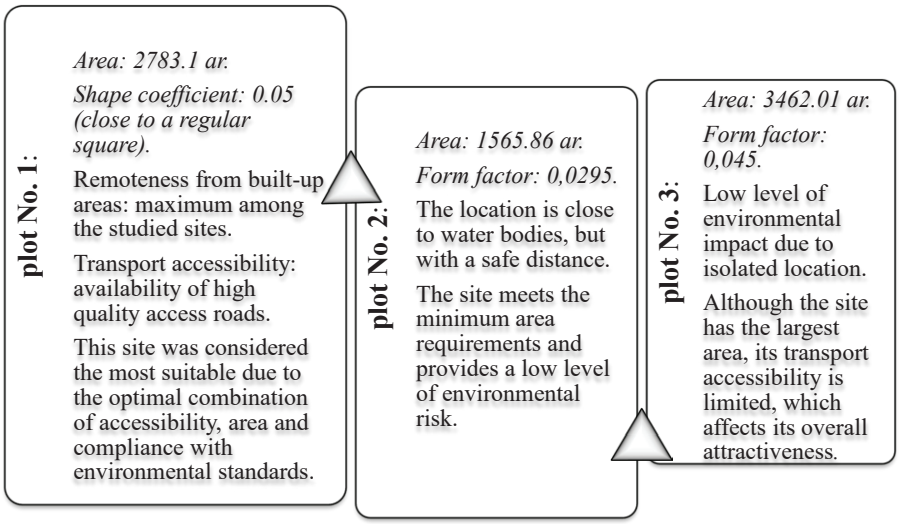

Fig. 4. Comparative scheme of sites based on selection indicators

The GIS analysis allowed us to objectively evaluate the territories, taking into account more than 10 criteria, including area, shape, transport accessibility and environmental safety. Figure 5 shows the final map with the proposed sites for the treatment plant. Out of the three plots, plot № 1 was found to be the most suitable for the project. It meets all the established criteria and minimises the environmental impact, ensuring the economic feasibility of construction.

Results. The results of the study confirmed that the use of GIS in spatial planning allows taking into account various factors, including natural constraints, technical requirements and socio-economic aspects. The multi-criteria assessment method ensured objective selection and minimised the risks of environmental impact.

The use of GIS allows for a comprehensive analysis to select the best sites for the construction of infrastructure facilities. The selected sites

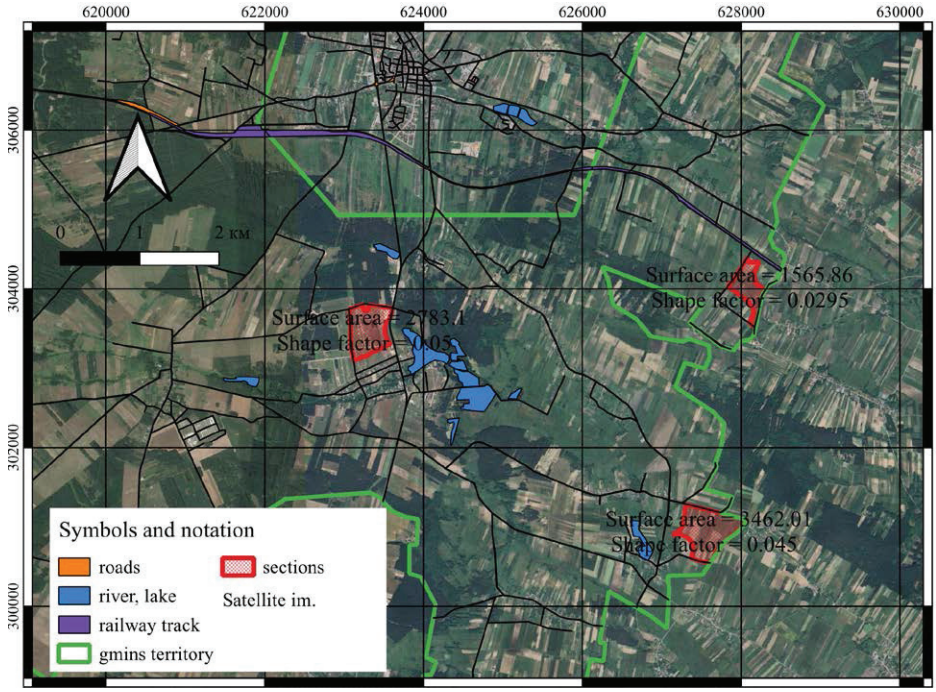

Fig. 5. Map of the proposed sites for the construction of wastewater treatment plants

meet environmental, technical and social criteria, which ensures the sustainability of the decisions made. The study was conducted using the QGIS geographic information system to identify the optimal locations for the construction of wastewater treatment plants in the communities of Pierzchnica and Chmielnik in the Republic of Poland. This task is multifactorial and requires consideration of geographical, environmental, economic and social aspects.

The analysis identified the three most suitable sites for the construction of the treatment plant. The selected locations met the criteria of safety, accessibility and efficient use of land resources. In particular, the analysis took into account the slope of the terrain, distance from water resources, accessibility of transport infrastructure, and minimisation of impact on the environment and local residents. Among the identified sites, Site 1 was assessed as the most optimal for construction, as it meets the established criteria to the maximum extent possible and ensures the efficiency of the future operation of the treatment plant.

The results obtained can serve as a basis for further feasibility studies and decision-making on the implementation of projects in these communities. The methodology can be used to plan similar facilities in other regions of Poland and Europe.

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