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Geoenvironmental assessment of site suitability for construction purposes

Geośrodowiskowa ocena przydatności terenu do celów budowlanych

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Abstract. Among the changes that may occur in the geological environment of the built environment and the surrounding area are: landslide movements, subsidence in loess formations, deformation of the surface associated with the exploitation of raw materials, surface erosion and filtration deformation, karst phenomena, variability of geotechnical parameters associated with the loading or unloading of the subsoil, with changes in humidity, temperature, the presence of contaminants, the reaction of expansive soils (shrinkage and swelling), changes in the location of the groundwater table and its chemistry, floods and flooding. Of great importance in the spatial planning of cities and municipalities are maps of areas predisposed to the occurrence of such phenomena and the assessment of the suitability of land for development developed on their basis. The article presents a methodology for mapping the investment suitability of land based on the Van Westen method. The method of obtaining input data based on current system databases (SOPO, ISOK), geological, hydrogeological maps, local expertise is described. The final suitability map for the selected area of Rzeszow was developed
Keywords: geoenvironment; index statistical method; buildability map; Rzeszow.

Streszczenie. Do zmian, które mogą występować w środowisku geologicznym podłoża budowlanego i otaczającego go terenu należą: ruchy osuwiskowe; osiadanie zapadowe w utworach lessowych; deformacje powierzchni związane z eksploatacją surowców; erozja powierzchniowa i deformacje filtracyjne; zjawiska krasowe; zmienność parametrów geotechnicznych związana z dociążeniem lub odciążeniem podłoża, ze zmianami wilgotności, temperatury, obecnością zanieczyszczeń; reakcja gruntów ekspansywnych (skurcz i pęcznienie); zmiany położenia zwierciadła wód podziemnych i ich chemizmu; powodzie i podtopienia. Duże znaczenie w planowaniu przestrzennym miast i gmin mają mapy obszarów predysponowanych do występowania tego rodzaju zjawisk i opracowana na ich podstawie ocena przydatności terenu pod zabudowę. W artykule przedstawiono metodologię mapowania przydatności inwestycyjnej terenu na podstawie metody Van Westena. Opisano sposób pozyskiwania danych wejściowych oparty na aktualnych bazach systemowych (SOPO, ISOK), mapach geologicznych, hydrogeologicznych, lokalnej wiedzy eksperckiej. Opracowano finalną mapę przydatności dotyczącą Rzeszowa.
Słowa kluczowe: geośrodowisko; indeksowa metoda statystyczna; mapa przydatności do zabudowy; Rzeszów.

Land management should be carried out with spatial order and sustainable development. Geoenvironmental assessment of the suitability of land for construction purposes requires the development of both monitoring and mapping methods of space through the prism of spatial planning and rational land management. In line with the idea of continuous monitoring of space promoted in the European Union, it would be advisable to develop measures of „sustainable land use" and indicators and methods to support the quality of planning decisions. Indicators of sustainable development have been proposed by the European Commission with reference to already existing conditions. Considering that these indicators can be used to monitor land use processes, they should primarily be used in assessing the suitability of land for construction and rational land management. Therefore, it would be reasonable to adequately describe the scope of the conditions of the municipality's general plan and local land use plans, and promote the indicators and methods of geoenvironmental assessment as a good planning practice for assessing the suitability of land for construction purposes, which would be periodically improved and updated.

An important tool for performing analysis and qualitative mapping of land suitability is the collection and processing of spatial data in databases (ArcGIS platform). According to research in [1], ArcGIS software is a useful tool for mapping land suitability/use and performing qualitative analysis of urban, agricultural, mining and all land use projects [2, 3]. GIS analysis has also been used to assess the suitability of land for animal habitat and the cultivation of selected plant species [4],

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as well as for geographic analysis and landscape assessment and planning [5]. In addition, GIS can be used in private and public real estate planning [6].

The purpose of land suitability analysis is to determine the location within the planning area that is best suited for a particular land use, such as housing, agriculture, mining, national parks, etc. [7]. The analysis can be used for the development of land-use plans and spatial order planning [8] and by experts in various fields depending on the intended purpose of the land use. For a farmer, this would mean the suitability of the land for cultivation, animal husbandry and pasture, and for an urban planner for building houses, etc. The intended purpose that the expert formulates is, according to [9], to distinguish between the site selection problem and the search problem. The site suitability search problem arises when there is no predetermined area for suitability analysis. As recommended in [10], suitability analysis divides the study area into basic units of observation, such as polygons. According to other researchers, site search analysis also determines the spatial features of a site, including its shape and continuity [11, 12]. Thus, planning related to site suitability for development is based on spatial analysis using GIS.

Analysis of site suitability for development

Geoenvironmental assessment of site suitability requires the use of geospatial technologies through a geographic information system (GIS), which will provide the ability to analyze, interpret and model the suitability of land for construction purposes. In this modeling, all environmental factors will be weighted based on their level of influence using a multi-criteria assessment to create a land suitability map. Land mapping land for construction purposes is therefore essential to locate and assess which areas are highly or lowly suitable. Land suitability mappingusing GIS provides a classification of areas into zones/categories, each of which has a different probability of investment suitability. Such maps are essential for urban-oriented land use planning.

The purpose of this study was to develop a suitability map using a Multi-Criteria Evaluation (MCE) approach and GIS using the Van Westen method to identify spatial development opportunities in the municipality of Rzeszow.

The method

A baseline spatial analysis of the Rzeszow municipality was carried out using ArcGIS v.10.2 software. The study area is located in the Subcarpathian region of southeastern Poland. A characteristic feature of Rzeszów – the capital of the Podkarpackie Voivodeship – has been the expansion of its boundaries since the beginning of the 20th century, resulting in the expansion of buildable land [13]. Intense expansion of Rzeszow's boundaries began in 2006, and since then, almost every year, the city's area has been expanding with the addition of rural areas (Figure 1). Currently, developer urbanization is underway, i.e. action within the administrative boundaries of the city aimed at maximizing profit while

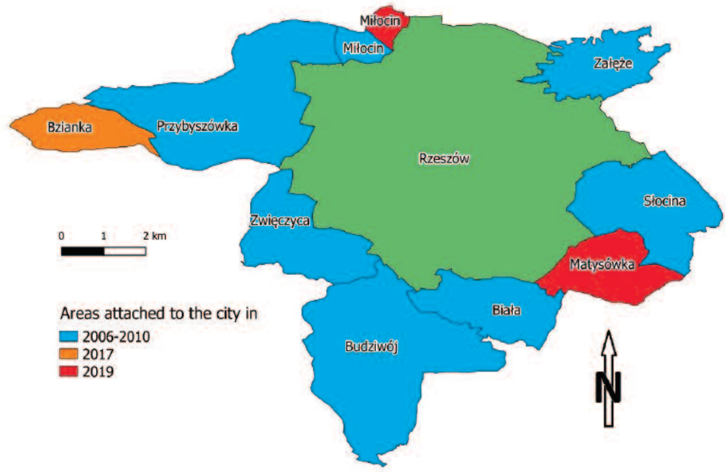
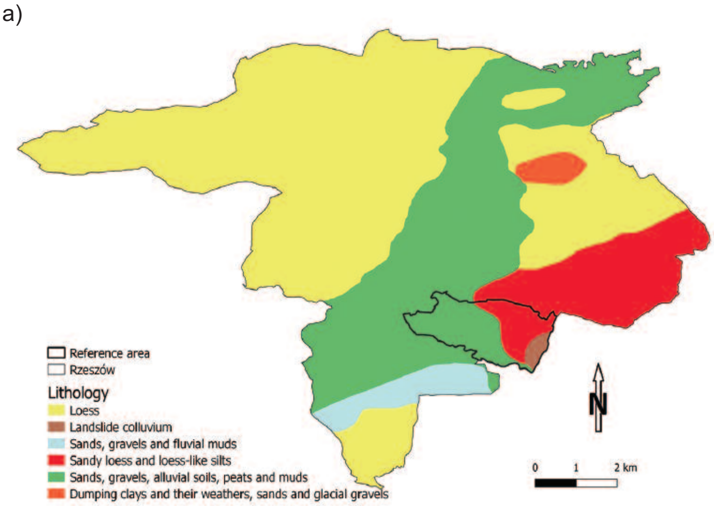


Fig. 1. Map of annexed areas – expansion of Rzeszow's borders
Rys. 1. Mapa przyłączanych terenów – rozszerzanie granic Rzeszowa

minimizing costs. Planning decisions are the result of pressure from both physical and legal investors. The result of such an interpretation of the city's development goals is a program directed at investment activity at any cost with disregard for natural conditions, including geotechnical ones. Such a program of development of a settlement unit is fraught with many errors, generating potential problems in the rational management of space in the realities of a market economy [14].

The area of the Rzeszow agglomeration has a hilly and flatland character. It is located within the southern edge of a large geological unit, the so-called Carpathian Foredeep. The older bedrock of the Carpathian Foredeep is filled with marine sediments of the Miocene, developed in the form of silty clay and siltstone of the Krakowiec fraction. Directly overlying the Miocene top are sediments of fluvial accumulation developed initially by a sand and gravel series, followed by fluvial muds represented by various types of clays and silts, as well as watershed soils composed of organic and clayey silts. The thickness of the package of Quaternary sediments varies depending on their location and is 16 – 18 m. At this level, the top of the Tertiary Krakowiec clays appears. Thus, lithologically, this is a very diverse area. Such topographic attributes as slope and exposure were calculated directly from the digital elevation model. The analyses used the Van Westen method [15], so in the first stage of the study, thematic maps of three factors – passive: geological structure; slope; and active: floodplains (Figure 2).

Topographic attributes (in this case, slope) calculated directly from the digital elevation model represent continuous variables, so they were converted to interval (categorized) form. The geological map was developed based on the reinterpretation of earlier geological maps of the area and the detailed Geological Map of Poland. It shows the main complexes that make up the Carpathian flysch, distinguishing lithostratigraphic units. Based on this map, thematic layers on geological structure were established. Aggregation of digital a)



b)

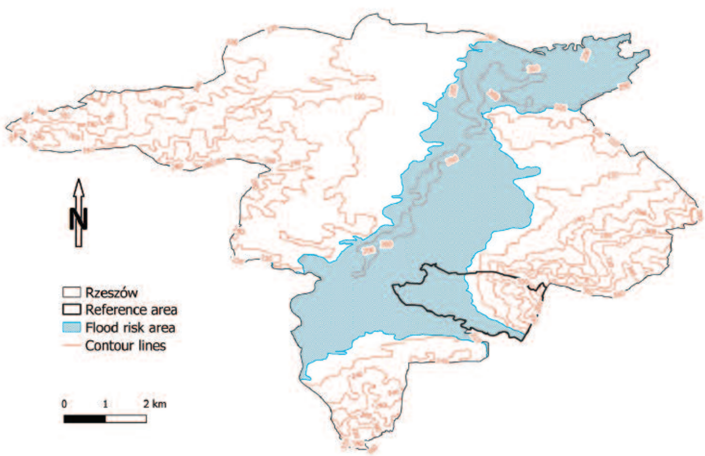


Fig. 2. Example maps for selected passive factors: a) lithology; b) flood risk area

Rys. 2. Przykładowe mapy dla wybranych czynników pasywnych: a) budowa geologiczna; b) tereny zalewowe

data was also carried out for land cover. Data acquired during field work and three maps visualizing environmental and geological factors were used to produce a map of land suitability for construction purposes at a scale of 1:10000 by means of the index statistical method WoE (Weights of Evidence) – Van Westen, using formula (1):

where:

$$W_i = \ln\left(\frac{\text{Dens clas}}{\text{Dens map}}\right) = \ln\left(\frac{\dfrac{\text{Npix}(S_i)}{\text{Npix}(N_i)}}{\dfrac{\sum \text{Npix}(S_1)}{\sum \text{Npix}(N_1)}}\right) \quad (1)$$

W_i – landslide susceptibility coefficient assigned to a given class of thematic map;

Dens clas – landslide density in a given class of thematic map;

Dens map – landslide density covered by the map;

$\text{Npix}(S_i)$ – number of raster cells with landslides within a given class of thematic map;

$\text{Npix}(N_i)$ – number of raster cells within a given class of thematic map.

The WoE method is a log-linear version of general Bayes theory [7]. The main idea of this method is to "cross" the landslide map with individual thematic maps. This makes it possible to calculate the landslide density of the thematic maps and relate it to the landslide density of the entire map area. Based on the logarithmized magnitudes, the so-called association indicators W+ and W- , or Weights of Evidence, are calculated. The magnitude of the weights is a measure of the relationship between the area unsuitable for development (landslide) and each class of variables adopted for prediction (passive factors). A positive value of the logarithm of W_i indicates a class favorable to landslide formation, while a negative value indicates unfavorable conditions (table).

Van Wasten method calculations for the adopted factors for the selected area

Obliczenia metodą Van Wastena w odniesieniu do czynników przyjętych dla wybranego obszaru

Feature	Rzeszów [C]	Biała [A]	Śród-mieście [B]	Biała + Śródmieście		Biała	
				ratio [A+B/C]	Wi	ratio [A/C]	Wi
Area	126602946	6058617	5815111	0,094	0,048		
Floodplain area	38722683	3121478	2621104	0,148	0,458	0,081	0,521
Geology: sands, gravels, fluvial muds	38291160	3528018	2647709	0,161	0,542	0,092	0,655
Geology: sandy loesses and loess-like silts	13786526	2059739	0	0,149	0,466	0,149	1,138
Geology: loesses	68468657	0,1	3167402	0,046	-0,707	0,000	-17,305
Geology: landslide colluvia	470860	470860	0	1,000	2,367	1,000	3,040
Slope of 8 degrees	2280911	375545	0	0,165	0,563	0,165	1,236

In the original research, Van Westen applied equation (1) to analyses related to the assessment of a site's susceptibility to landslides. The authors of this article adapted the method to a multi-criteria, geoenvironmental assessment of site suitability for construction purposes. Vulnerability coefficients (W_i weights) were determined relative to a reference site considered the least predisposed for construction purposes, taking into account many of the passive and active factors listed in the table. In the first stage of analysis, two variants of calculations were considered. Variant one, which uses the Biała and Śródmieście as the reference area, and variant two, which includes the Biała district. The area of this district is characterized in particular by unfavorable landform, a high degree of landslides, as well as high groundwater levels and flood risk. Śródmieście, on the other hand, is distinguished by subsoil with weaker bearing capacity and an increased risk of flooding. Formula (1) was used to determine the W_i weights of each feature in relation to its density of occurrence expressed in map pixels. The extent of occurrence of a given feature within the various areas considered is included in the table in columns A, B and C. In turn, subsequent columns of the table contain the values of the determined weights.

After summing the calculated indicators for all passive factors, a map of land suitability for construction purposes in the municipality of Rzeszow was obtained (Figure 3), with intervals selected by analyzing the histogram showing the density of index values [16].

Despite the fact that different reference areas were adopted for the analyses and different values of weights were obtained, the maps of land suitability for construction purposes generated on their basis converged, and the area ranges in each class overlapped. For this reason, the map of land suitability for construction purposes (Figure 3) is limited to the case of the Biała reference area.

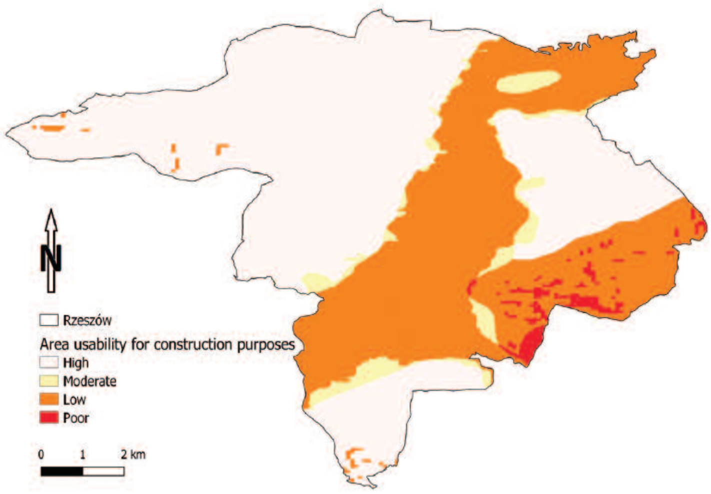


Fig. 3. Map of land suitability for construction purposes
Rys. 3. Mapa przydatności terenów do celów budowlanych

Summary

Optimal and sustainable land use planning is paramount in rational land management. Assessing land suitability is one of the basic challenges facing decision-makers and land users. The results of the conducted study showed that GIS analysis and development of a land suitability map can be used to develop a land use plan.

The presented case study shows that GIS-based methods can be applied to urban land use planning. Areas of high and moderate suitability for building purposes in the municipality of Rzeszow were identified. The results of the land suitability assessment in the current study showed that 75% of the total area of currently developed land was in an area classified as very suitable. The analysis can be modified and improved when used in conjunction with other methods, such as Saaty's AHP. The result of the study is a process for identifying the suitability of land for specific purposes, such as improving urban planning.

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