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Application of spatial analysis tools in the ArcGIS environment for the analysis of urban settlement networks (in the example of the Ivano-Frankivsk region of Ukraine)

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SUMMARY

The article demonstrates the use of the Spatial Analyst Tools module in ArcGIS for analyzing urban settlement networks on the example of Ivano-Frankivsk region. Using the density tools, we have created road density maps of the region, calculated the Euclidean distance from the main roads and urban settlements of the region. Also, the maps of population density and urbanization level of the region were developed.

Keywords: spatial analysis, GIS, network of settlements, Ivano-Frankivsk region

Introduction

Geographic information systems have long been an integral part of geographical research, where they serve as a means of collecting, analyzing, interpreting and visualizing spatial information. Among the branches of geography in which GIS are particularly useful is geo-urban studies (urban geography, urban geography), a science closely related to practice, in particular, urban and regional planning.

In geo-urban studies, spatial and attribute data analysis are most often used in ArcGIS applications. Spatial analysis focuses on the relative location of objects in space and the relationship between their different types. Attribute analysis mostly involves operations with quantitative characteristics (e.g., measuring distances, directions, area, density, etc.). The analysis of quantitative indicators characterizing the state of the network of cities in different regions of Ukraine is relevant given the administrative and territorial reform that took place in the country in 2020. It has led to the need to update a wide variety of data, including cartographic data. In addition, as a result of Russia's armed aggression against Ukraine, the problem of rebuilding urban settlements that were under occupation or near the combat zone and suffered significant damage has arisen.

The purpose of the article is to summarize the possibilities of using Spatial Analyst Tools in the ArcGIS environment to analyze urban settlement networks on the example of Ivano-Frankivsk region of Ukraine

Theory and research methods

The publication is based on the previous experience of foreign scientists in the use of GIS in geo-urban studies (Shi, Goodchild, Batty et al., 2022; Goodchild, 2021) and GIS analysis techniques (Lansley, de Smith, Goodchild, Longley, 2018). Ukrainian scientists also study the spatial organization of settlement systems and issues of spatial development using GIS analysis tools (Niemets et al., 2020; Zastavetska et al., 2019; Kostrikov et al., 2018; Pidgrushnyi, 2017; Andreychuk & Yamelinets, 2013).

The main tool for spatial analysis in ArcMap 10.6.1 is the Spatial Analyst Tools module. In particular, it uses the Density block of operations to determine the density of point or line objects (Point Density and Line Density functions, respectively). The algorithm for calculating the density for each cell includes adding points and lines and dividing by the area of the search area. Another tool, Kernel Density, superimposes a smoothly curved surface on each line. Its value is highest on the line and decreases with distance from it, reaching zero at a given radius (ESRI, n.d.).

Euclidean Distance tools are used to determine distances. They allow you to describe the relationship of each cell to a source or group of sources based on a straight-line distance. This block contains three tools:

1. *Euclidean Distance* shows the distance from each cell in the image to the nearest source. An example of use is to determine the distance from an object to the nearest city or other settlement.
2. *Euclidean Direction* shows the direction from each cell to the nearest source.
3. *Euclidean Allocation* defines the cells that should be distributed to the source based on the closest proximity.

Results

The network of settlements in any region is characterized by quantitative indicators, the most important of which are the number of total populations, density of settlements, average distance between settlements, etc. To display them, the method of qualitative background is usually used, as well as pie or bar charts.

To analyze the population settlement based on statistical data, a map of the population density of the region by administrative districts was developed (Fig. 1). Ivano-Frankivsk district is the most densely populated, with the lowest values in Verkhovyna district.

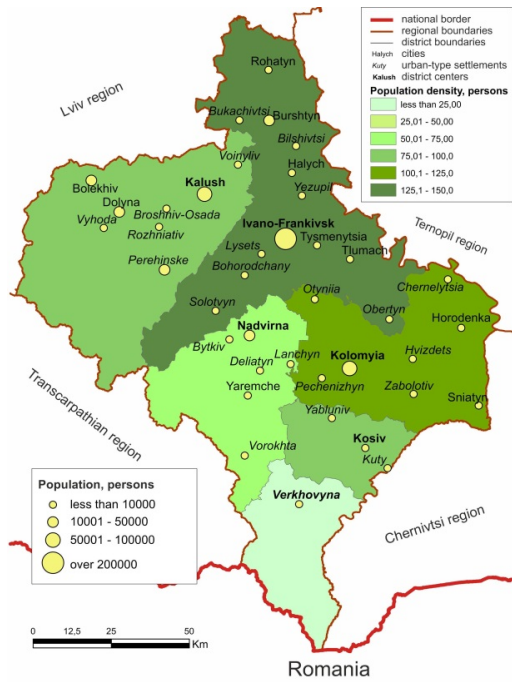


Figure 1 Network of urban settlements in Ivano-Frankivsk region and total population density by administrative districts

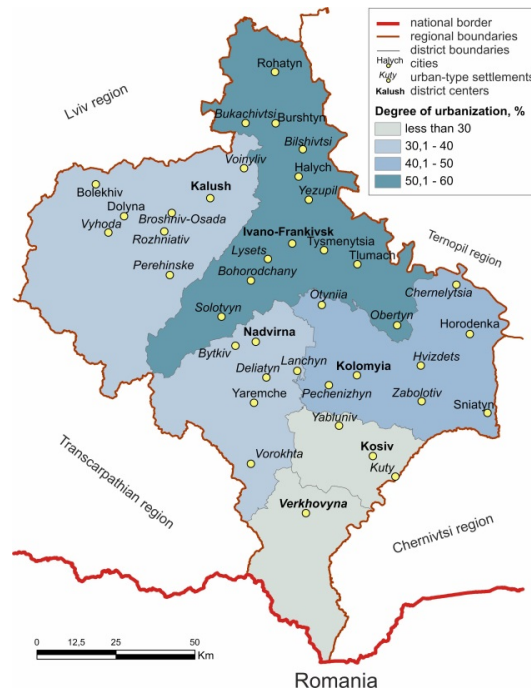


Figure 2 Degree of urbanization in Ivano-Frankivsk region by administrative districts

The degree of urbanization in Ivano-Frankivsk region is 44.6% (beginning of 2022). The map (Fig. 2) shows this indicator by administrative district. Kosiv and Verkhovyna districts are the least urbanized (17% and 19%, respectively). Ivano-Frankivsk district has the highest degree of urbanization (55%).

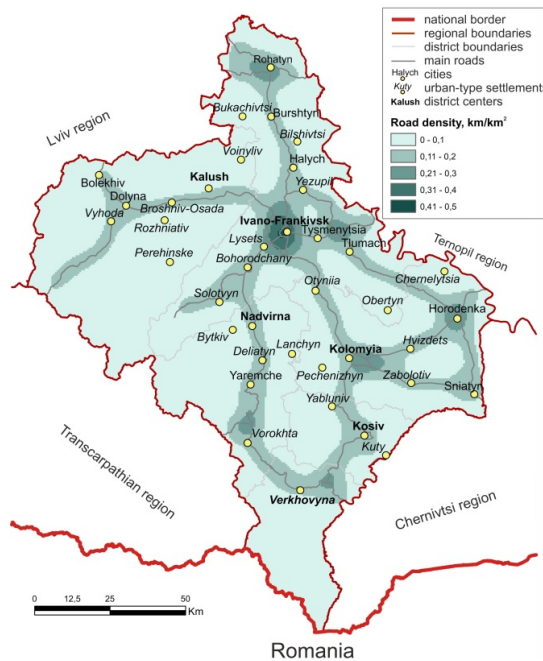


Figure 3 Road density in Ivano-Frankivsk region

In addition to the aforementioned indicators, the state of the city network characterizes the degree of development of the region's infrastructure. Fig. 3 shows a map of road density by administrative district. The roads of the "primary" and "trunk" classes (according to the OSM classification) which correspond to roads of national and regional importance (P and N according to the state classification), were selected for display.

The Kernel Density (KDE) tool is used to determine the density of linear or point objects as a factor of influence on animal habitats, the density of utility networks or roads in certain cities. The "population" field allows you to assign more weight to some objects depending on their importance, as well as to represent several dimensions with one point. Determining the density of roads (km/km²) is important not only for planning infrastructure development in the region. This indicator, estimated with KDE, also allows us to find out the nature of land use and effectively predict the impact of roads on landscape fragmentation (Cai, Wu, & Cheng, 2013). To determine the density of a river or railroad network, it is advisable to use the Line Density tool.

The Euclidean Distance tool is often used independently when it is necessary to determine the distance to the nearest object (regional or district centre, other settlement, etc.). Determining the distance from urban settlements to main roads is important for spatial planning and development of settlements in the region.

The map (Fig. 4) shows the distance from the main highways of Ivano-Frankivsk region (30 km was chosen as the maximum distance). The example below (Fig. 5) shows the Euclidean distance of points. These points are urban settlements of the region, so the distance with a maximum radius of 30 km was determined. Given the natural conditions of the territory, namely a combination of flat and mountainous landscapes, this type of information is useful for planning various types of land use. It also makes it possible to predict the development of agglomerations.

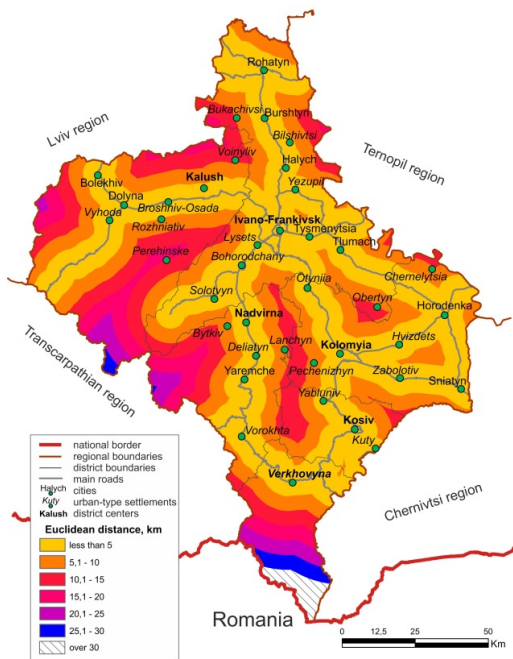


Figure 4 Euclidean distance from the main roads of Ivano-Frankivsk region

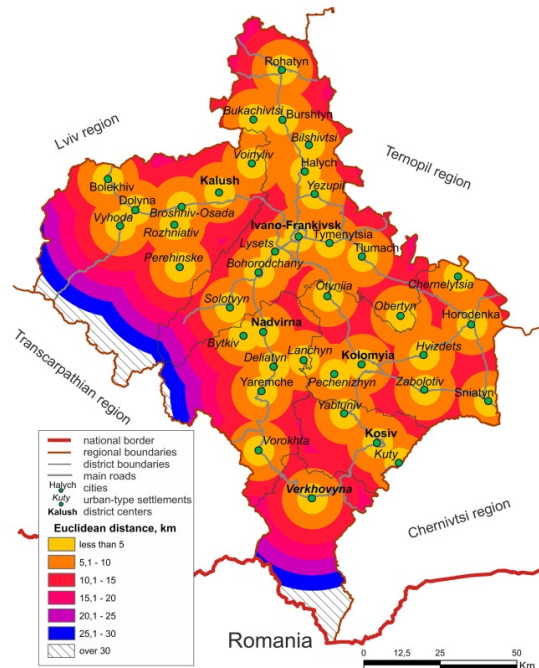


Figure 5 Euclidean distance from urban settlements of Ivano-Frankivsk region

Conclusions

The use of modern spatial analysis tools is essential for geo-urban studies. Various tools in the ArcGIS environment allow not only to visualize spatial information but also to analyze the relationships between objects and phenomena. Operations with attribute data of objects make it possible to display and evaluate quantitative and qualitative indicators of the city network: population density, distances between settlements, and distance from main highways, railways, etc. This is important in determining the peculiarities of the functioning of cities in the region, determining the prospects for their development, and solving spatial planning problems.

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