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MODELING MARKET VALUE OF LAND PLOTS USING GIS

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Abstract. This work examines the regulatory framework for expert monetary valuation of land plots. Scientific research on the development and improvement of economic-statistical methods for mass monetary valuation of land plots is analyzed. The peculiarities and advantages of using GIS in the valuation procedure are considered. A structure of the valuation database is developed for the effective selection of comparable plots during valuation by comparing sales prices and market analysis. The valuation database is formed based on data on land plot sales. Price formation factors are analyzed in order to construct an economic-statistical model of market value for land plots in Rivne. Scales of indicator values are proposed for formalizing the assessment of price formation factors. Functions of the ArcGIS are used to establish indicator values. The market value of land plots is modeled using multiple regression analysis. Additionally, a surface of land plot values is constructed, which serves to determine the approximate market value. The model has been verified using GIS tools. An accuracy assessment of the developed model has been carried out.

Keywords: expert monetary valuation, lands of settlements, GIS, land plot, modeling, market value.

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1. Introduction

Land plots within populated areas are the spatial basis for ensuring the livelihood of the population and a valuable resource in the economic and social development of the country. The value of such land lies in their ability to generate additional income, which arises primarily in cities due to their convenient location and the infrastructure of adjacent territories. Therefore, modeling the expert value of such land plots should include spatial indicators and be carried out using GIS technologies.

Economic-statistical methods are considered the most accurate methods of expert monetary evaluation, so we will use the ArcGIS (2022) software package and the multiple regression method (Yanchuk et al., 2020) to build a model of the expert value of land plots.

Land valuation activities play an important role not only in the taxation of urban land but also in conducting property transactions with land and rights. Land valuation is also a mandatory component of investment processes.

The purpose of this work is to consider expert monetary valuation, economic-statistical methods, and analysis of factors affecting pricing. Formation of a land valuation model using GIS tools and multiple regression methods based on the appraisal database.

2. Analysis of research

The issue of improving the monetary valuation of land using geoinformation technologies is relevant in Ukraine and abroad. The use of GIS in this area allows for a significant acceleration of the assessment process, increases its objectivity and reliability, and enables mass land valuation, the development of new approaches to monetary valuation, and the creation of appropriate information resources. That is why many scientists are engaged in this issue, including Yu. P. Hubar, Yu. M. Palekha, A. A. Liaschenko, A. G. Martin, V. D. Shipulin, Lin Li, M. O. Mete, T. Yomralioglu, and others.

In order to reduce the impact of the subjectivity of the appraiser in calculating the value in expert monetary evaluation, scientists are developing new mathematical methods. In particular (Hubar, 2007; Vynarchyk et al., 2017), attempts have been made in the work to solve the problem of determining the market value of the real estate and adjustment coefficients using mathematical tools. In our opinion, the proposed algorithm requires an accuracy assessment and should be applied with more input data. The work confirms the need to use statistical methods for conducting a reliable expert monetary evaluation.

The problem of determining the mass value of land and real estate is very relevant and has significant scientific and practical importance (Hubar, 2012; Bamshad & Seyed, 2014). Aligning the needs of settlements with their economic capabilities can be achieved through various methods, the reasoned choice of which is impossible without conducting a mass appraisal of real estate in the structure of the cadastral survey of settlements. The methodology for applying mass appraisal of real estate for fiscal purposes has been improved in Ukraine based on its current use (Perovych & Hubar, 2016; Hubar et al., 2020).

In particular (Shipulin & Shterndok, 2017), the paper proposes the determination of geoinformation support for the integrated assessment of spatial factors of a megacity, which is characterized as a system of interacting elements that operate on the basis of using geoinformation system tools. Promising areas of further research include the development and implementation of directions for modeling spatial factors that affect the assessment and use of land in populated areas.

In particular (Shipulin & Shterndok, 2017), the paper proposes defining the geoinformation support of the integrated assessment of spatial factors of the city's land, which is characterized as a system of interacting elements that operate based on using of geoinformation system tools. Prospective directions for further research include the development and implementation of modeling approaches for spatial factors that affect the evaluation and use of lands in populated areas.

In particular (Shipulin et al., 2015; Shulgan et al., 2017; Aydinoglu et al., 2021; Sisman et al., 2023; Droj & Droj, 2016), the monetary valuation of the land is classified as a geoinformation (spatial) analysis task, as its implementation requires consideration of the influence of various factors related to the regional, local, and zonal location of land plots in the territory of a populated area, which have spatial relations with the object of valuation. In their works, scientists examine the fundamental principles and concepts of using geographic information system technologies in land and real estate valuation.

In the research project (Li et al., 2015), seven parameters were used to determine the market value of land, namely: distance to schools, distance to roads, distance to police stations, distance to railway stations, distance to healthcare facilities, land use type, and distance to government buildings. A separate form was applied for each factor, and maps were created using data at a scale of 1:10,000, prepared by the Survey Department of Sri Lanka. Weights, which were determined through a survey and the Analytic Hierarchy Process method, were used to classify the aforementioned maps in a GIS environment. Based on the evaluation results, the territory was divided into classes of the land value and classified as zones with very low, low, moderate, high, and very high valuation levels. The disadvantage of this work, in our opinion, is the use of a survey, which introduces a certain subjectivity into the evaluation process and makes the result dependent on the opinions of the respondents.

In particular (Yomralioglu & Nisanci, 2004), a new method of assessing land value called "nominal asset land valuation" has been proposed in this work. The essence of this method is to use both qualitative and quantitative characteristics of land plots for valuation purposes. The value of the land is determined as a unit indicator that represents all price-forming factors. A land value model using GIS has been developed, with the primary goal of determining value based on the values of 28 price-forming factors, which are determined spatially.

In the research project (Mete et al., 2022b) a hybrid approach integrating GIS and machine learning was developed in this study for the mass appraisal of residential real estate. The nominal asset valuation method, based on GIS, was used to conduct proximity, terrain, and visibility analysis using Ordnance Survey and Open Street Map data, after which a land value map of the United Kingdom was created.

Using geospatial information systems (GIS) and building information modeling (BIM) technologies, a property valuation can be assessed through three-dimensional (3D) geospatial analysis and anthropogenic environmental analysis. In the study (Mete et al., 2022a), the criteria that affect property value are grouped as ecological, physical, legal, and socio-economic factors. Then, a 3D property valuation model is developed based on industry foundation classes (IFC) classes. New sets of properties and attributes, functions, and their attributes are compared with entities and data types in the IFC schema.

The research (Lemmens & Kurm, 2000) considers the non-technical issues of GIS system selection. The requirements for a GIS that meet the objectives of property assessment are identified, namely, powerful and flexible analysis tools must be available, and support for creating thematic maps.

So, summing up the research review, it should be noted that the expert monetary valuation of land plots should be based on economic and statistical methods, which will make it possible to establish a reliable value without the influence of the subjectivity of the appraiser and be carried out using GISs that will ensure the visibility of the results and automation of the valuation process.

3. Research methods

The essence of the work is to model the value of land plots for the construction and maintenance of residential buildings, utility buildings, and facilities (private plots) located in the city of Rivne. To achieve this, we propose using economic and statistical methods of evaluation, which are considered the most accurate, as well as GIS tools.

For economic and statistical modeling of value, a significant volume of reliable information is required, therefore, at the initial stage, the structure of the appraisal data was formed, and their quantitative values, parameters, and importance were established (Nikolaichuk & Shulgan, 2022b; Liashchenko et al., 2014).

The set of determining factors and their indicators has been established for this purpose, including:

- location of the land plot (cadastral number, address);
- location zone of the land plot (peripheral, intermediate, central);
- configuration of the land plot (triangular, rectangular, polygonal);
- relief of the land plot (flat, sloping, complex);
- flood zone (absent, present);
- presence of engineering networks (power supply, water supply, gas supply, sewage);
- type of driveway surface (unpaved, paved);
- distance to public transport stops (km);
- area of the land plot (m^2);
- cost of the land plot (UAH);
- price per square meter (UAH/m^2);
- distance from the center of the settlement (km);
- distance from city-forming highways (km).

When forming the appraisal base of land plots in Rivne, sales data from Internet resources for the calendar year were used, and 82 land plots were selected for housing development.

The values of the price-forming factors were determined using functions of the ArcGIS software package (ArcGIS, 2022).

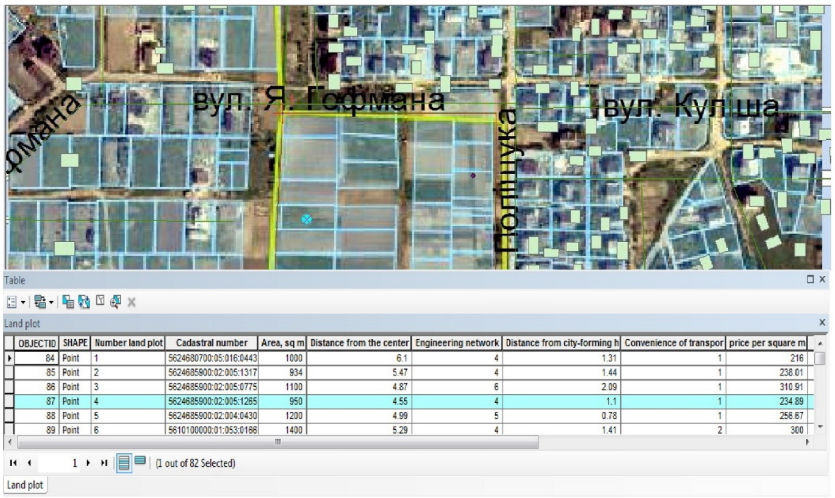
The public cadastral map was connected to the digital map of the city of Rivne using a WMS server. Then, a layer "Land plot" was formed including a list of defined parameters. The location of the land plots was identified for each by the cadastral number (Figure 1).

The following information was included in the valuation base for each land plot: cadastral number, plot address, and location zone within the settlement (peripheral, intermediate, central). It was established that out of the entered plots, sixty-nine – are in the peripheral zone, thirteen – are in the intermediate zone, and two plots are in the central zone. This distribution is due to the high density of buildings in the central part of the settlement, therefore, the model constructed in this area will not be sufficiently reliable. The intermediate and peripheral zones contain a sufficient number of land plots for statistical processing and model building.

The shape of the land plots was determined graphically. The vast majority of plots have a rectangular shape, with only a few having a polygonal shape.

The territory of Rivne city usually does not have sharp slopes or lowlands, so the relief can be considered flat. Only in the areas of the Bus Station, Zoo, and North, can a more hilly relief be observed. The Google Earth Pro program was used for a more detailed check of the relief (Shulgan & Nikolaichuk, 2022a) (Figure 2).

Based on the information's analysis, about the location of the plot relative to hydrographic objects and the altitude above sea level in Google Earth Pro, the risk of flooding was determined (Shulgan & Nikolaichuk, 2022a).



OBJECTID	SHAPE	Number land plot	Cadastral number	Area, sq m	Distance from the center	Engineering network	Distance from city-forming h	Convenience of transpor	price per square m
84	Point	1	5624680700:05:016:0443	1000	6.1	4	1.31	1	216
85	Point	2	5624685600:02:005:1317	934	5.47	4	1.44	1	238.61
86	Point	3	5624685600:02:005:0775	1100	4.87	6	2.09	1	310.91
87	Point	4	5624685600:02:005:1285	950	4.55	4	1.1	1	234.89
88	Point	5	5624685600:02:004:0430	1200	4.99	5	0.78	1	258.67
89	Point	6	5610100000:01:053:0186	1400	5.29	4	1.41	2	300

Figure 1. Layer "Land plot" with attribute table

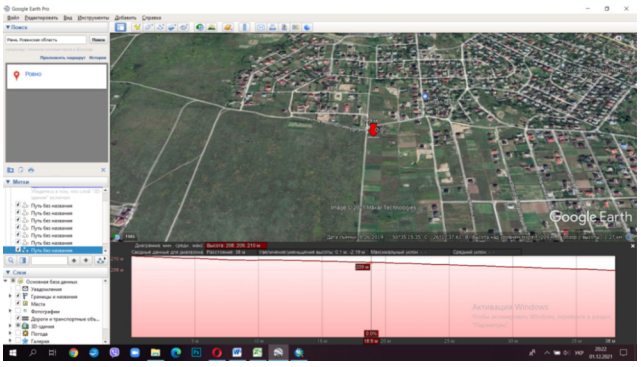


Figure 2. Determination of land plot relief

To formalize the values reflecting the appraisal factor of engineering communications, the following indicator values were applied: on-site, nearby, and remote. Each value was assigned a corresponding score in points (Table 1).

Table 1. Distribution of points based on the presence of engineering networks

Placement of communications	Power supply	Gas supply	Water supply	Sewerage	Total
On the plot	3	3	3	3	12
Nearby	2	2	2	2	8
Remotely	1	1	1	1	4

The determined score regarding the availability of engineering communications was recorded in the attribute table for each land plot in the ArcMap software package.

Another factor by which scores were assigned was the type of coverage of access roads. In combination with the distance to public transport stops, these two indicators were combined into the convenience of transportation communications. The type of coverage of access roads was determined using Google Earth Pro images (Shulgan & Nikolaichuk, 2022a). The distance from public transport stops was evaluated according to the following criteria: "near" and "far". A stop that is "near" is considered within walking distance, which is 500 meters in the city. Anything further than this distance was indicated as "far". The evaluation criteria are summarized in Table 2.

Table 2. Distribution of points by type of road surface and distance to stops

Driveways	Public transport stops	Convenience of transport communications
Hard coating	Nearby	3
Hard coating	Remotely	2
Without a hard coating	Nearby	
Without a hard coating	Remotely	1

The database contains information about the land plot, such as area, land value, and value per square meter. The areas of the land plots were transferred from the public cadastral map, while the land value was transferred from the assessment base.

However, all these factors are interrelated and may depend on each other. The database indicated the area of the land plots, which, on average, was about 1000 square meters. The value of the entire land plot and the value per square meter were also indicated.

The distance from the center of the settlement was determined in the ArcMap program. Two new fields, CentroidX and CentroidY, were added to the attribute table. They were calculated using the "Calculate Geometry" function, applying X and Y coordinates. After that, the coordinates of the city center were determined using the same principle of finding CentroidX and CentroidY. The next step was to insert the found coordinates into the attribute table of the land plots in the new fields Centr_centroidX and Centr_centroidY. The distance to the center was then calculated using the Field Calculator according to the formula presented in Figures 3 and 4.

Similarly, the distance indicator from the center was measured for the distance to major roads of urban significance.

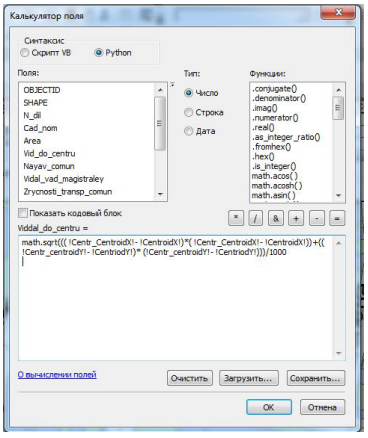


Figure 4. Calculation of the distance from the center of Rivne to the land plot in the Field Calculator

According to the methodology of expert monetary evaluation, all the factors considered can be used to determine the value of land plots for construction (Postanovoiu Kabinetu Ministriv Ukrainy, 2002). The constructed database can serve as a basis for selecting information on the sale of analogous plots when using traditional evaluation

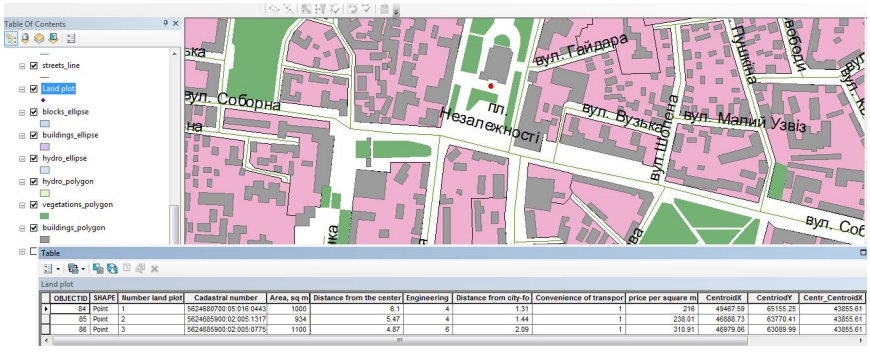


Figure 3. Coordinates of centroids of land plots and the center of Rivne city

methods. When developing an expert value model, the number of factors and evaluation indicators should be reduced or grouped and reduced to those that are most important for a given settlement. After analyzing the proposed factors for building the model, we will choose the following value-generating indicators: the cost of the land plot per 1 square meter, the area of the plot, the distance from the city center, the presence of communications, the distance from the city-forming highways, and the convenience of transport communications. These indicators provide the most detailed description of the location of plots and are formalized using various scales.

To establish the spatial distribution of the value of land plots in Rivne based on the developed database, we will build a spatial model. To do this, we will use the inverse distance weighting (IDW) tool. IDW is a tool that calculates the surface of a raster based on point values using the inverse distance weighting method. This method finds the average value, taking into account the distances to reference points. The best results can be obtained if the network of reference points is dense enough to locally reflect the data that needs to be modeled. Therefore, a spatial model called Surface of land plot values was created. Figure 5 shows the distribution of the value of land plots from the lowest to the highest divided into seven ranges (Nikolaichuk & Shulgan, 2022).

Using the developed spatial model, it is possible to estimate the approximate value of a land plot within the limits of Rivne city. For a more accurate assessment, we will apply the multiple regression method. The ArcGIS software package does not have tools for regression analysis, so we will export the attribute table from the "Land plot" layer to Excel.

For a reliable expert assessment, as previously mentioned, it is worth using economic and statistical methods. Based on the selected and exported data using the multiple regression method, we will build a model of the market value of land plots. The linear multiple regression model has the following general form:

$$y = a_0 + a_1x_1 + a_2x_2 + ... + a_nx_n, \quad (1)$$

where y – the average value of the dependent variable; x_1, x_2... x_n – independent variables that affect the value of y; a_0 – intercept; a_1, a_2 ... a_n – coefficients that show how the value of y increases with a one-unit increase in x (Yanchuk et al., 2020).

To calculate the unknown values of coefficients, the "LINEST" function was used in the Excel software package. As a result, the model will take the following form (Shulgan & Nikolaichuk, 2022c):

$$y = 728.262464 + 0.050468x_1 - 161.358432x_2 - 62.685863x_3 - 8.412778x_4 + 2.417709x_5, \quad (2)$$

where y – the market value of the land plot; x_1 – the area in square meters; x_2 – distance from the city center in kilometers; x_3 – availability of utilities, rated on a scale; x_4 – distance from major city highways in kilometers; x_5 – the convenience of transportation, rated on a scale.

The developed economic-statistical model allows for determining the expert value of land plots for residential development in the territory of the city of Rivne.

4. The results of the research

To test the accuracy of the developed model, a land plot with a value of 312 UAH/m^2 was selected. The plot has the following characteristics:

- Intended use – for the construction and maintenance of residential buildings, utility buildings, and structures.
- Located in the Chervonyi Hory district.
- Area of 600 m^2.

The rest of the indicators were determined from a digital map using GIS tools. After evaluating the available

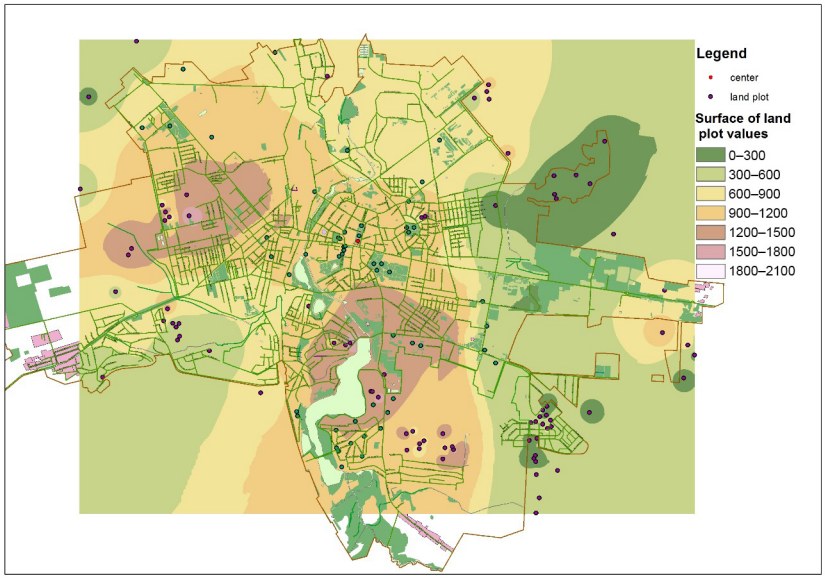


Figure 5. Surface of land plot values in Rivne city

communications and transportation connections and measuring the distances from the city center and highways, a new layer called “Land Valuation” was created for automation purposes. The coefficients of the developed economic-statistical model of value (2) were entered into the attribute table of this layer. These coefficients are fixed and transferred without changes when we switch to the editing mode in a new row.

To automate the calculation of value, the assessed plot is added to the map with a conditional symbol. The values of price-forming indicators, such as area, scores for communications and convenience of transportation, and distance to the center and highways of city-forming importance, are established in the attribute table using GIS tools.

Using the field calculator and the developed economic-statistical model, the value per square meter of the plot, represented on the market, was determined (Figure 6).

The result of the expert value of the land plot calculated in ArcGIS based on the constructed model is 271.2 UAH/sq.m (Figure 7).

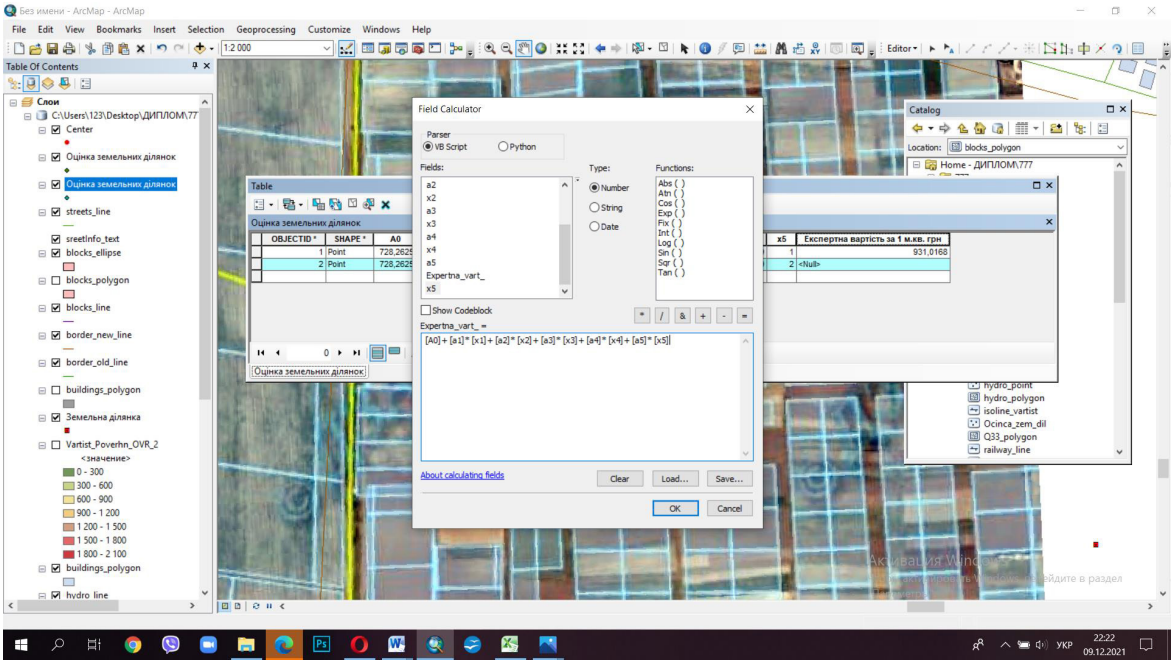


Figure 6. Calculation of expert value of land plot based on the economic-statistical model in the Field Calculator

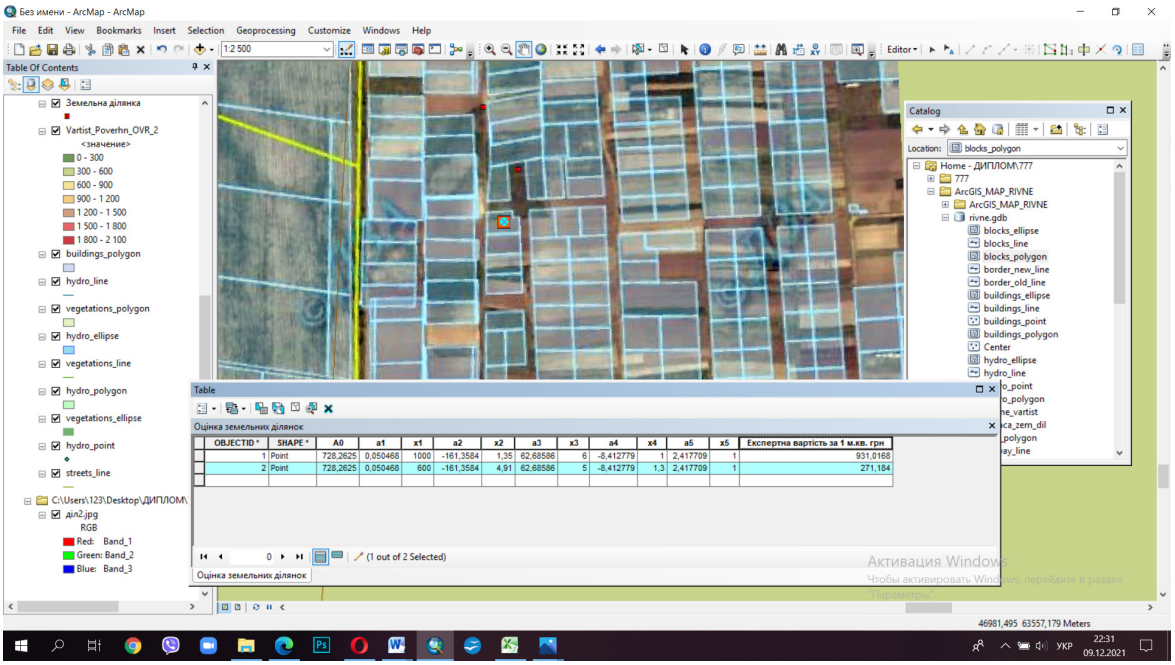


Figure 7. The result of calculating the expert value of the land plot in ArcGIS

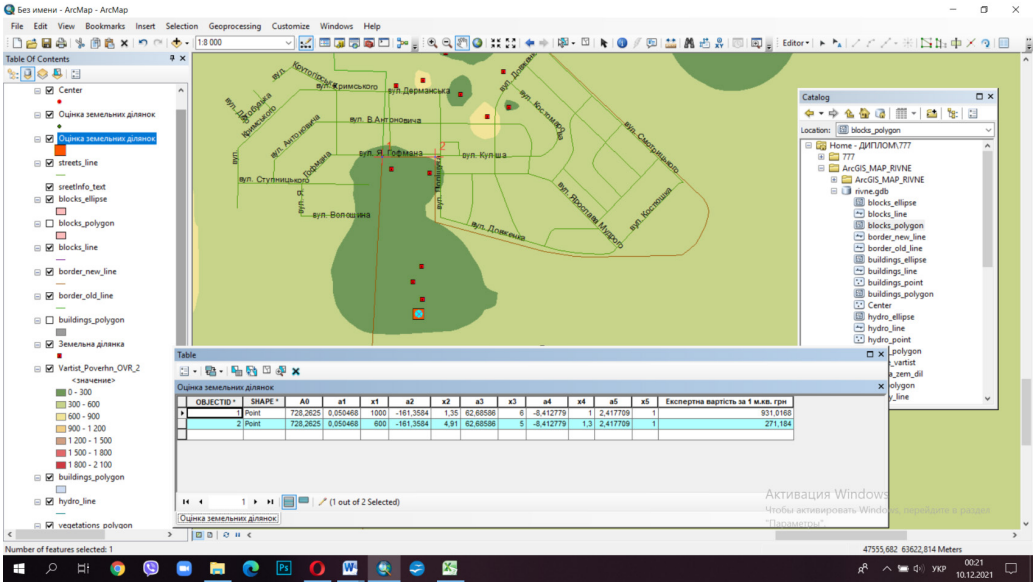


Figure 8. The location of the land plot on the surface of value

According to the constructed surface of value, the land plot falls within the range of 0 to 300 (green color) (Figure 8).

According to the announcement, the cost of the researched land plot is 312 UAH/sq.m. Typically, the cost of land plots in announcements is overstated, so it is necessary to take into account the average discount for bidding, which is typically 10%. With the discount for bidding taken into account, the cost of the researched plot will be 280.8 UAH/m^2. In this case, the deviation of the plot's cost from the expert valuation established by the developed model is 3.5%.

The developed expert monetary valuation model allows for automated calculation of the market value of a land plot based on real indicator values. To assess the accuracy of the model, it is not sufficient to use the results for just one plot, so it was executed based on the number of plots required to ensure reliable results. The value of 25 land plots with known sale prices was assessed. Based on this data, the average square error (Table 3) was calculated to be 97.46 UAH/m^2 with an average value of land plots at 685.72 UAH/m^2.

The relative error of the calculated market value based on the constructed model is 14.21%. The average deviation of the market value from the values obtained by professional appraisers using standard methods does not exceed 15–20% (Postanovoiu Kabinetu Ministriv Ukrainy, 2002). The developed model allows for the assessment of plots with an accuracy that satisfies the procedure of expert monetary valuation of land plots.

This result indicates that the constructed model allows for reliably determining the expert valuation of land plots for the construction and maintenance of residential buildings, economic buildings, and facilities in the city of Rivne. This model can be used for mass appraisal of land plots. Furthermore, when using the ArcGIS software package, allows for automating the process of establishing cost indicators and the entire process of determining the expert valuation of land plots.

Table 3. Accuracy assessment of value calculation using the developed model

№ pp	The value of the land plot calculated using a model, Y, UAH/m^2	Nominal value of the land plot, Yn, UAH/m^2	ΔY, UAH/m^2	|ΔY|, UAH/m^2	ΔY^2, UAH/m^2
1	514.58	686.42	–171.843	171.8433	29530.1312
2	230.63	238.01	–7.379	7.3791	54.4518
3	262.10	310.91	–48.813	48.8131	2382.7167
4	223.08	247.00	–23.919	23.9187	572.1030
5	239.29	266.00	–26.708	26.7079	713.3118
6	814.87	696.42	118.448	118.4480	14029.9395
7	848.12	722.91	125.214	125.2141	15678.5700
8	539.69	653.20	–113.510	113.5104	12884.6154
9	723.26	710.00	13.260	13.2600	175.8276
10	507.97	526.33	–18.363	18.3635	337.2179
11	1025.12	1117.07	–91.949	91.9492	8454.6471
12	807.30	816.86	–9.564	9.5645	91.4791
13	974.02	1124.14	–150.117	150.1168	22535.0451
14	939.66	1062.55	–122.891	122.8912	15102.2463
15	988.79	980.33	8.460	8.4600	71.5713
16	987.30	990.50	–3.200	3.2000	10.2400
17	723.94	532.83	191.115	191.1146	36524.7940
18	728.70	639.39	89.310	89.3100	7976.2761
19	562.91	671.18	–108.266	108.2660	11721.5323
20	490.90	554.68	–63.780	63.7800	4067.8884
21	535.72	474.83	60.890	60.8900	3707.5937
22	490.90	554.68	–63.780	63.7800	4067.8875
23	859.64	939.70	–80.060	80.0600	6409.6056
24	818.17	721.26	96.910	96.9100	9391.5462
25	759.27	905.80	–146.530	146.5300	21471.0409
Sum		17143.00	–547.07	1954.28	227962.28
Average valuation, grn/m^2		685.72	Mean squared deviation, grn/m^2		97.46
Relative error, %		14.21			

5. Conclusions

The paper proposes a structure and establishes an appraisal database for the city of Rivne, which allows for selecting analogous plots and conducting a market analysis of land plots. A surface of land plot values for approximate appraisal has been constructed.

Based on information on 82 land plots obtained using GIS, an economic-statistical model of the value of land plots in the city of Rivne has been developed and verified, which enables expert monetary appraisal of land plots.

An algorithm for using this model in combination with GIS tools for automated and mass appraisal of land plots has been proposed.

The accuracy of the constructed model was evaluated and it was found that the relative error in calculating the market value is 14.21%. This model can be used in the appraisal activity for quick and reliable determination of the market value of a land plot in the city of Rivne.

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