The mathematical modelling of the land resources mass evaluation in agriculture

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Abstract. The article is devoted to the development of the mathematical model of mass (cadastral) evaluation of agricultural land plots belonging to the agricultural organizations located in the Leningrad Region. On the basis of the initially selected composition of the cadastral value pricing factors, by applying the expert method of Analytic hierarchy process, the most significant ones were identified. Using the Pareto method, the factorial indicators were ranked according to the degree of their influence on the value of land. As a result of the research, the evaluative model of the cadastral value of agricultural land was constructed and tested according to the main indicators of the modeling quality.

1. Introduction
Mass (cadastral) evaluation of land in modern realities has an important economic and social value. Its results are the basis for the taxation, as well as for making sound management decisions regarding the most efficient use of the land and related real estate.

The topic of mass (cadastral) evaluation of lands and especially its methodological support has been reflected in many publications of the domestic researchers. Thus, for example, the results of applying the expert approach to mass assessment are analyzed in the works by [1,2]. The publications of [3,4] highlight the features of the statistical methods for calculating the cadastral value of land application. The article [5] contains requirements for market information used for cadastral valuation. Individual papers are devoted to the disclosure of the problems of cadastral valuation in the context of various categories and uses of land and other real estate. For example, the article [6] examines the main difficulties of cadastral evaluation of a separate category of land, the forest land.

The topic of cadastral valuation is also very relevant abroad. The main issues of concern to the representatives of the western scientific community are related to the accuracy of the generated statistical models of mass land evaluation [7], methods for determining the values of pricing factors [8,9], analysis of the specificity and possibilities of using mass and individual evaluation of objects in the conditions of the existing real estate market [10, 11].

2. Methods
The mass land evaluation model should be viewed as a mathematical interpretation of the land market behavior at a specific time in a vast geographical area (in this case, a specific market segment that is the agricultural use). The established mathematical interpretation can be applied repeatedly in the long term.
Our goal was not to substantiate the types of models fully reflecting the relationship between the studied phenomena because their definition was the subject of special scientific research, the results of which were taken into account in the present study.

The specific indicator of the cadastral value of the agricultural organizations land (y) was taken as an effective indicator. The dependence of the value of the agricultural organizations land as a way of agrarian economy on the value of pricing factors is characterized by the equation of linear multiple regression:

\[ Y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + \cdots + a_m \cdot x_m, \]  

where:

- \( Y \) is the theoretical value of the resultant mark, the specific indicator of the cadastral value of land (rubles/sq m);
- \( x_1, x_2, \ldots, x_m \) is the value of factor signs, the value of cost factors;
- \( a_0, a_1, \ldots, a_m \) are the parameters of the equation (the regression coefficients).

To make the calculation of the multiple regression equation justified and reliable, it is necessary to observe the requirement of sufficiency and representativeness of the sample. Thus, according to S.V. Gribovskiy, I.N. Anisimova, N.P. Barinov, I.I. Eliseeva and others, the number of land plots involved in the simulation should exceed the number of pricing factors by 6-7 times [12].

First, we determined the rank of the pricing factors for the agricultural organizations by analyzing the hierarchies based on the expert assessment.

At the next stage, the factorial indicators were ranked to determine their significance with the Pareto method.

Further, within the framework of this study, the evaluative models were constructed in the context of agricultural organizations using the example of the Leningrad Region not only from the point of view of cost formation but also from the point of view of the economic effect obtained with various combinations of pricing factors in order to deepen the theoretical basis of the mass evaluation of agricultural land.

In order to exclude multicollinearity, the correlation coefficients between pricing factors were calculated.

The reliability of the constructed model is usually estimated by the following characteristics: coefficient of certainty (determination), mean square error, coefficient of variation, beta coefficient, correlation coefficient, Student-Fischer test. The first three are analyzed as a measure of agreement of the constructed model reflecting the predictive accuracy of the applied statistical dependencies. The remaining indicators establish the statistical significance of individual variable models.

3. Results

At the initial stage of work, the distribution of the selected groups of factors weight coefficients within agricultural organizations based on the results of expert evaluation using the Analytic hierarchy process method showed the following results: socio-economic factors form land value by 29%, climatic factors by 34%, territorial accessibility factors by 37%. Thus, the largest share in the field of agricultural organizations is occupied by factors of territorial accessibility.

Using the Pareto method, factorial indicators were ranked and displayed as a bar graph with a cumulative curve to determine their significance (Fig. 1).
Figure 1. Ranking of factors by degree and impact on the cadastral value of land. F1 is fertility, F2 is contour, F3 is stonyness, F4 is humidity, F5 is erodedness, F6 is remoteness from the district center, F7 is remoteness from the paved road, F8 is state of the driveways, F9 road network density, F10 land provision (as a whole), F11 is land provision of the population (agricultural lands), F12 is land supply of the population (arable lands), F13 is land provision of the rural population of the region, F14 is average yield in agriculture of the region, F15 is average yield of crop production in the region, F16 is level of transport costs, F17 is investment attractiveness, F18 is environmental situation in the area being evaluated.

Based on the obtained results, we will form a list of significant factors that will participate in further research in order to build an estimated cadastral value model (in descending order of importance): Remoteness from the district center, Fertility, Remoteness from the paved road, Environmental situation in the area being evaluated, Investment attractiveness, Contour and Erodedness.

In order to form evaluation models in the context of agricultural organizations of the Leningrad Region, the minimum number of proposals in the cluster has been determined. For the agro-climatic zone of the Leningrad region, it should be about 42-49 plots of land with the agricultural type of permitted use.

The initial stage is the formation of the initial sample, which includes the values of the offer price (market price) and pricing factors. Finding the values of pricing factors identified as a result of expert synthesis was carried out through the use of various sources of information, namely:

- Real Estate Market Monitoring Rosreestr automated information system;
- specialized publications on real estate (“Zagorodny Dom”, “Bulleten Nedvizhimosti”, “Zagorodnoe Obozrenie”, “Iz Ruk v Ruki”);
- Internet sites of real estate agencies (chance.ru; piter-realtor.ru; avito.ru);
- the soil map of the Leningrad Region and a rating scale of soil varieties;
- the ecological map of the Leningrad region;
- the public cadastral map;
- the official reports and reports of the executive regional authorities on the state and use of land resources;
- the national atlas of soils of the Russian Federation;
- the space images;
- the electronic maps;
- the results of previously conducted land evaluation works;
- the various types of zoning (land-evaluating, agro-climatic).


| #  | Y   | X1  | X2  | X3  | X4  | X5  | X6  | X7  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | 18.8| 16000| 45.5| 33  | 0.5 | 1   | 3   | 1   |
| 2  | 22.9| 35000| 25  | 33  | 0.2 | 1   | 3   | 1   |
| 3  | 31.6| 31600| 25  | 33  | 0   | 1   | 3   | 1   |
| 4  | 31.7| 12000| 37.1| 33  | 0.03| 1   | 3   | 1   |
| 5  | 20.0| 30000| 42.4| 33  | 0.7 | 1   | 3   | 1   |
| 6  | 20.8| 1200 | 37.1| 33  | 0.4 | 1   | 3   | 1   |
| 7  | 22.6| 23000| 30.6| 33  | 0   | 1   | 3   | 1   |
| 8  | 30.0| 500000| 31.5| 33  | 0.5 | 1   | 3   | 3   |
| 9  | 31.6| 190000| 31.5| 33  | 4   | 1   | 3   | 2   |
| 10 | 115.5| 55400| 12.6| 37  | 0.2 | 1   | 3   | 1   |
| 11 | 134.1| 41000| 15.3| 37  | 0.5 | 1   | 3   | 1   |
| 12 | 107.1| 28000| 11  | 37  | 0.2 | 1   | 3   | 1   |
| 13 | 133.1| 26300| 10  | 37  | 0.1 | 1   | 3   | 1   |
| 14 | 119.0| 42000| 24  | 37  | 0.7 | 1   | 3   | 1   |
| 15 | 126.7| 30000| 15  | 37  | 0   | 1   | 3   | 1   |
| 16 | 125.0| 32000| 10  | 37  | 1   | 1   | 3   | 1   |
| 17 | 124.6| 56200| 22.6| 37  | 0   | 1   | 3   | 2   |
| 18 | 150.0| 10000| 11  | 37  | 0.1 | 1   | 3   | 1   |
| 19 | 220.6| 68000| 20  | 43  | 0   | 1   | 2   | 2   |
| 20 | 231.2| 67000| 23  | 43  | 0   | 3   | 2   | 2   |
| 21 | 200.0| 50000| 20  | 43  | 0.1 | 1   | 2   | 2   |
| 22 | 216.7| 12000| 20  | 43  | 0   | 1   | 2   | 1   |
| 23 | 216.7| 12000| 8   | 43  | 0.5 | 1   | 2   | 1   |
| 24 | 233.3| 30000| 15  | 45  | 1   | 3   | 2   | 1   |
| 25 | 252.6| 146500| 16 | 45  | 0   | 3   | 2   | 2   |
| 26 | 256.7| 77900| 13  | 45  | 0   | 3   | 2   | 2   |
| 27 | 258.3| 60000| 15  | 45  | 0   | 3   | 2   | 2   |
| 28 | 236.5| 29600| 12  | 47  | 0   | 3   | 2   | 1   |
| 29 | 270.0| 10000| 10  | 49  | 0.1 | 1   | 2   | 1   |
| 30 | 254.5| 27500| 21  | 49  | 0   | 1   | 2   | 1   |
| 31 | 240.0| 20000| 10  | 49  | 0.1 | 1   | 2   | 1   |
| 32 | 308.6| 97200| 18  | 50  | 0.1 | 1   | 2   | 2   |
| 33 | 369.0| 420000| 14 | 50  | 0.1 | 1   | 2   | 2   |
| 34 | 280.0| 250000| 14 | 50  | 0.09| 1   | 2   | 3   |
| 35 | 294.1| 170000| 14 | 50  | 0.08| 1   | 2   | 2   |
| 36 | 333.3| 30000| 10  | 50  | 0.1 | 3   | 2   | 1   |
| 37 | 247.5| 40000| 15  | 50  | 0.15| 1   | 2   | 1   |
| 38 | 292.7| 41000| 15  | 50  | 1.5 | 1   | 2   | 1   |
| 39 | 361.1| 18000| 8   | 50  | 1   | 1   | 2   | 1   |
| 40 | 366.7| 60000| 7   | 50  | 0.1 | 1   | 2   | 2   |
| 41 | 300.0| 30000| 7   | 50  | 0.1 | 1   | 2   | 1   |
| 42 | 307.7| 26000| 8   | 50  | 0.1 | 1   | 3   | 1   |

a The specific indicator of the cadastral value of land (rubles/sq m).

b Area (sq m).

c The remoteness from the district center (km).

d The fertility.
e The remoteness from the paved road (km).
f The environmental situation in the area being evaluated.
g The investment attractiveness.
h The contour.

Table 1. Baseline data on deals (prices of offers) with the land plots (type of permitted use is the agricultural use).
Further, as a result of the initial selection, one factor (degree of erodedness) was found to be insignificant due to its absence for all selected evaluating areas. Table 1 provides information about the offers for the land plots for sale with the agricultural use of the Leningrad Region in three agro-climatic zones type of permitted use.

The results of the factors testing for multicollinearity showed that there was a high degree of interdependence between the “Contour” and “Area” factors, as well as the “Investment Attractiveness” and “Fertility”. In both cases, the correlation coefficient exceeds the value of 0.7 (0.74 and -0.92, respectively). On the basis of the obtained results, the factors “Contour” and “Investment Attractiveness” are excluded, since they have less influence on the resultant attribute and are more strongly associated with other factors under study.

After elimination of multicollinear factors, as well as the factors with the insignificant calculated coefficients of the regression equation according to the results of the test by the Student’s criterion, the final regression equation of the form (2) was formed:

$$Y = -374.67 - 1.74 * X1 + 14.12 * X2,$$

where:

- $Y$ is the specific indicator of the cadastral value of land (rubles/sq.m);
- $X1$ is the distance from the district center (km);
- $X2$ is the fertility (quality index).

The results of the quality evaluation of the constructed evaluation model and its coefficients are presented in Tables 2-4.

**Table 2. Regression Statistics Parameters**

| Parameter          | Value |
|--------------------|-------|
| Plural R           | 0.97  |
| R-squared          | 0.95  |
| Normalized $R^2$   | 0.95  |
| Mean square error  | 25.88 |
| Observations       | 42    |

**Table 3. Analysis of Variance**

| Analysis of Variance | df | SS          | MS          | F           | F Value       |
|----------------------|----|-------------|-------------|-------------|---------------|
| Regression           | 2  | 475537.75   | 237768.88   | 354.86      | 9.4728E-26    |
| Remainder            | 39 | 26131.22    | 670.03      |             |               |
| Total                | 41 | 501668.97   |             |             |               |

**Table 4. Model Coefficients and Their Basic Parameters**

| Coefficients  | Mean square error | t-statistics | P Value |
|---------------|-------------------|--------------|---------|
| Y intersection| -374.67           | 42.16        | -8.89   | 0.000   |
| X 1 Variable  | -1.74             | 0.56         | -3.10   | 0.004   |
| X 2 Variable  | 14.12             | 0.81         | 17.34   | 0.000   |

Based on the analysis of the data presented it should be concluded that the developed model and its coefficients are statistically significant which allows it to be used to calculate specific indicators of the cadastral value of the Leningrad Region agricultural land plots.

**4. Conclusion**

The paper touches upon the topic relevant in modern conditions and associated with mathematical modeling of mass (cadastral) evaluation of the agricultural land.
It is known that a huge number of factors affect the market and accordingly cadastral value of land. The task of the evaluator is to identify and justify the most significant most determining the value of land factors.

As a result of the work on the basis of statistical data, the evaluating model of the agricultural land cadastral value was designed and tested on the main indicators of the modeling quality. It can be used to calculate the cadastral value of agricultural land.

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