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SPATIAL ANALYSIS OF SOIL ACIDITY USING GEOSTATISTICAL MODELS BASED ON GIS

T. Myslyva[1)], O. Kutsaeva[2)]

[1)]Belarussian State Agricultural Academy, Gorki, Belarus, byrty41@yahoo.com
[2)]Belarussian State Agricultural Academy, Gorki, Belarus, alexa-1982@bk.ru

The main objective of this study is to review and evaluate three common interpolation methods namely: Inverse Distance Weighting (IDW), Radial Basis Function (RBF) and Ordinary Kriging (OK), and generate maps of soil pH using these methods. Studies were conducted within the limits of land use of RUP "Uchkhoz BGSHA" (Republic of Belarus, Mogilev region, Goretsky district). Based on cross-validation results, a polynomial function was identified as the best variogram model. In terms of interpolation accuracy, the investigated deterministic and geostatistical methods are located in the next descending row: RBF> IDW> OK.

Key words: geospatial analysis; pH_{KCl} of soil solution; interpolation; spatial distribution.

Introduction. The economic efficiency of land use and the efficiency of agriculture generally largely depend on the quality of land resources the quality of which, in turn, is determined by the fertility of their soil cover. Indicators-constants, to which the pH of the soil solution belongs, are the main source of information on basic ecological permanent soil. Therefore, it is extremely important to predict the spatial distribution of soil pH for assessing the state of the soil system and planning measures for the rational use of land resources and the reproduction of soil fertility.

Geostatistics is an effective method for studying the spatial distribution of soil characteristics and their inconsistencies [1, p. 56]. A number of researchers have used Geospatial methods and the comparison of their effectiveness in assessing the spatial relationship of the agrochemical properties of soils and the geographic variability of soil characteristics [2 –7]. However, in the scientific literature there is not enough information about the development of this area of research in the territory of Belarus.

Discussions and results. The purpose of this study was to compare the effectiveness of various interpolation methods – the Inverse Weighted Distance method

(IDW), the Radial Basis Function method (RBF) and Ordinary Kriging (OK) to estimate the spatial distribution of soil pH within the land use of RUP “Uchkhoz BGSHA” (Republic of Belarus, Mogilev region, Goretsky district), and estimate the use of cross-validation to assess the accuracy of spatial modeling and identification the most suitable method. The total area of the surveyed territory is 3197.89 hectares. The soil cover of the study area is represented mainly by sod-podzolic sandy loams on water-glacial sandy loams soils and sod-podzolic loamy on loesslike loams soils.

Table 1

Statistical characteristics of a sample of data on pH of the soil solution used to construct interpolation models, n = 70

Indicator name	Indicator value			Sd	Cv, %	Med	Kurtosis	Skewness
	min	max	mid					
pH_{KCl}	3.50	7.30	5.93	0.79	13.4	6.10	0.68	-1.03

The application of the module “Geostatistical Analyst” for spatial modeling of distribution pH_{KCl} of soil solution provides a preliminary assessment of the initial data for their suitability for modeling purposes. As a result of the use of tools for exploratory analysis of spatial data, a histogram of the distribution of initial data is created and the form of their distribution is investigated, as well as the basic statistical characteristics of the sample are calculated (Table 1).

Note: Sd is the standard deviation; Cv is the coefficient of variation; Med is the median.

Preliminary evaluation of the data makes it possible to establish the necessity of carrying out their transformation with the subsequent modeling of the distribution surface. If the data distribution differs significantly from the normal one, you need to convert them. In particular, if the data is asymmetrically distributed, the logarithmic transformation that approximates the distribution to normal is applied to such data. In our case, although the variation coefficient of 13.4 % indicates that the data sample is quantitatively homogeneous, the distribution of data is not normal and requires a logarithmic transformation. In particular, this is evidenced by the values of the Kolmogorov-Smirnov coefficient and the Pearson's acceptance criterion. Moreover, the magnitude of the coefficient of kurtosis less than zero indicates the flatness of the actual distribution of data compared to normal as well as the value of the coefficient of asymmetry -1.03 indicates the skewness of the distribution of data to the left.

The Trend Analysis tool of the Geostatistical Analysis module allows to display data in a three-dimensional perspective. The locations of the reference points, which in our case are the locations of the selection of soil samples for agrochemical analysis, are plotted on the x, y plane. A unique feature of this tool is that the values are projected onto the perpendicular planes x-z and y-z in the shape of dispersion diagrams. Then, polynomials are fitted by using scattering diagrams on the projected planes. The line of the best fit (polynomial), drawn through the projected points, shows the trends of data changes in certain directions. In our case, a certain trend for soil pH level is observed both in the direction of the west-east and in the direction of the north-south. Since the trend is U-shaped, it is advisable to use a second-order polynomial as a global trend model for performing interpolation as well as apply the trend removal option for constructing models using the ordinary kriging method.

The experimental anisotropic variograms were calculated to determine the possible spatial structure of pH of the soil solution. The polynomial kernel function and spherical semivariogram model were identified as the best, the type of the circle was standard, the type and the number of sectors was 4 with a displacement of 45^0, and the lag was 100 meters. The best model was chosen based on five criteria: mean error (ME), mean square error (RMSE), mean square normalized error (RMSS), mean standard error (ASE) and the difference between RMSE and ASE. In this study, the spherical variogram model in most cases meets the requirements for the best model.

Table 2

Parameters of interpolation methods used to create soil pH forecast maps (type of search area – standard; sector type – 4 sectors with a displacement of 45^0; angle – 90^0)

Inverse Distanse Weighting (IDW)	Radial Basis Functions (RBF)	Ordinary Kriging (OK)
Power parameter: 2.5335 Search area: min = 10; max = 15	Search area: min = 10; max = 15 Kernel function: spline with tension; kernel parameter: 0.0806	Search area: min = 2; max = 15 Kernel function: polynomial; semivariogram model – spherical

The interpolation methods under study were implemented to estimate the values of the unmeasured data on the pH of the soil solution and to create surfaces from the predicted points. The parameters used in the interpolation models and used to create soil pH prediction maps are presented in Table 2, and the visualization of the prediction results is shown in Fig. 1.

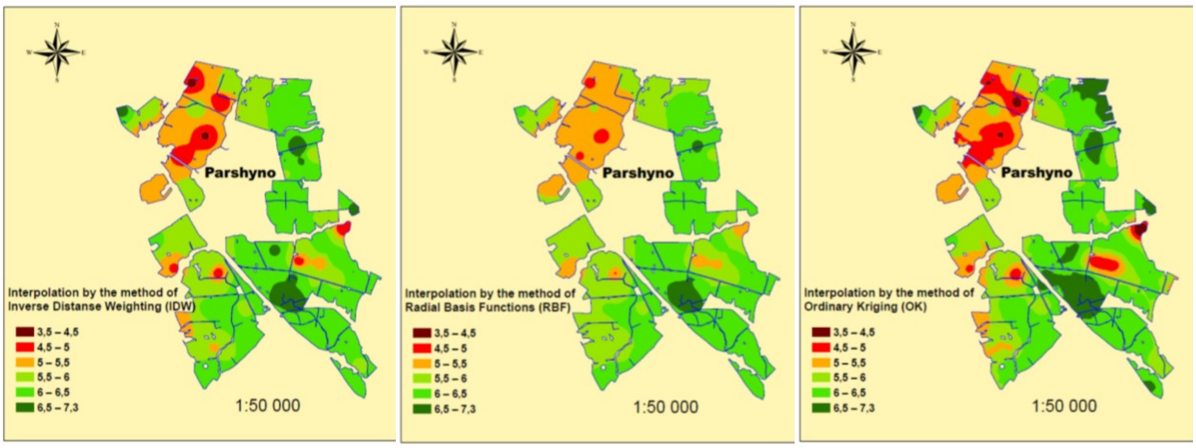

Fig.1. Prediction maps of soil pH distribution

Because of the interpolation methods of RBF and IDW during the cross-validation procedure only two criteria are defined – the average error (ME) and the mean square error (RMSE), the comparison of the effectiveness of the methods for soil pH prediction was carried out by these indicators. The most suitable for forecasting purposes was the model created by the method of radial basis functions, the value of the root-mean-square error of which was 0.763. (Fig. 2).

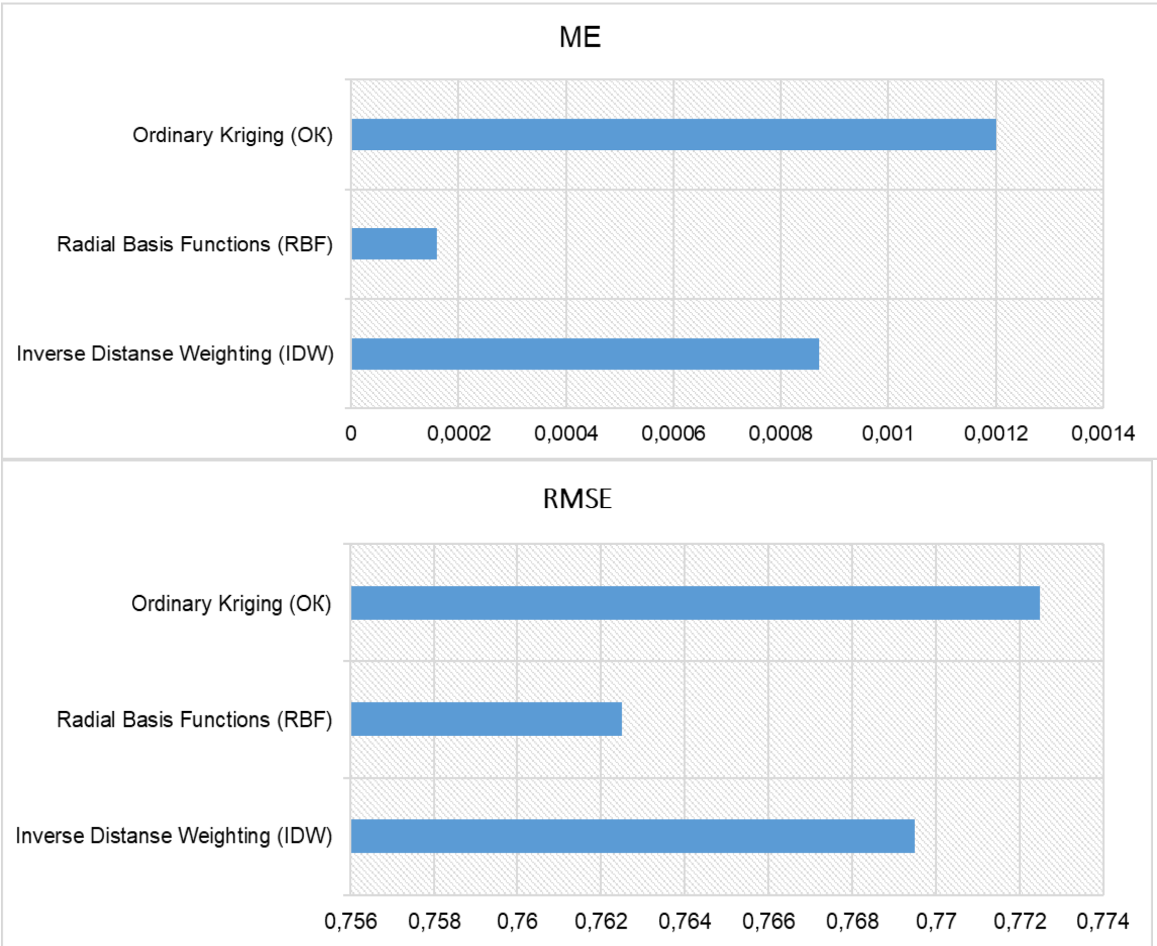

Fig.2. Results of cross-validation of predictive models of the pH of the soil solution

In terms of interpolation accuracy, the investigated deterministic and geostatistical methods are located in the next descending series RBF> IDW> OK. The IDW method interpolates the surface with sufficient accuracy if the sampling points are relatively normally distributed and the surface is uniform. In our case, none of these conditions is fulfilled: the sampling points are unevenly distributed, clustering takes place, and the steepness of the slopes of the study area varies from 0.5 to 10.0 degrees. Therefore, this method is not suitable enough to predict the spatial distribution of the pH of the soil solution. Kriging is the optimal interpolation method if the data meets certain conditions: normally distributed, stationary and no trends. Since, in our case, the data are not normally distributed and their transformation is required as well as the presence of a trend in their spatial distribution is established, the use of the ordinary kriging method to predict the spatial distribution of the pH of the soil solution is also impractical. The RBF method approaches the construction of a surface through measured values while minimizing the total curvature of the surface and is ineffective when an abrupt change in values occurs over short distances. This phenomenon is absent in our case, and the change in the studied indicator is rather smooth, which causes the high efficiency of the RBF method for interpolation.

Conclusion. Among the interpolation methods that have been studied, the most optimal method for predicting and mapping the spatial distribution of soil pH is the radial basis function method, which provides the root-mean-square error of the average predicted values at 0.763. Both the interpolation method IDW and the RBF method require adjusting the power parameter and determining the optimal search radius to improve the prediction accuracy.

Although the IDW method is relatively easy to use and does not provide for the calculation of standard interpolation errors, in our case it provided higher accuracy in predicting the spatial distribution of soil pH compared to ordinary kriging. The choice and use of the most optimal interpolation method for predicting the spatial distribution of soil pH largely depends on the characteristics of a particular set of experimental data as well as on the spatial characteristics of the territory for which the prediction is performed. Consequently, in each particular case, the selection of the optimal interpolation method should be performed, according to the specific conditions and characteristics of the data, and the definition of a single universal interpolation method is not possible.

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