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USE OF GEOSPATIAL ANALYSIS METHODS IN LAND MANAGEMENT AND CADASTRE

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Abstract
The possibilities of using the geospatial analysis methods for visualizing land monitoring data and modelling the spatial distribution of the main agrochemical soil indicators are discussed in the article. The research was conducted within the limits of land use of RUP "Uchkhoz BGSHA" (Republic of Belarus, Mogilev region, Goretsky district). The total area of the surveyed territory was 3187.0 hectares. The geospatial analysis of the spatial distribution of humus, mobile phosphorus, mobile potassium and pH_{KCl} was carried out using the Geostatistical Analyst module of the ArcGIS software. Semivariograms were used as the main tool for studying the structure of the spatial distribution of agrochemical indicators. The exponential function was identified as the best variogram model, the type of the circle was standard, the type and the number of sectors was 4 with a displacement of 450, and the lag was 200 metres. The interpolation accuracy was determined from the mean error (ME), mean square error (RMSE) and standard error (RMSS). The universal kriging method was used to perform the forecast and visualize the spatial distribution of agrochemical indicators. The multivariate analysis was performed using the functionality of the Raster Calculator tool, Principal Component analysis and Maximum Likelihood Classification. The search and determination of areas of sites with the most optimal agrochemical indicators were carried out by the multifactor analysis in the GIS environment. Calculation of the area of each circuit within the limits of working parcels was carried out using the utility "Zone Statistics".
Key words: geospatial analysis, interpolation, universal kriging.

Introduction

One of the main strategic national interests declared in the National Security Concept of the Republic of Belarus is sustainable economic development and high competitiveness of the Belarusian economy, as well as the achievement of a high level and quality of life of citizens (Ob utverzhdenii…, 2010; Myslyva et al., 2016). An effective tool for ensuring the economic well-being and food security of the country is its powerful and modern agro-industrial industry. The productive potential of the agricultural sector, especially husbandry, is determined by the quantitative and qualitative characteristics of agricultural land, the quality of which, in turn, is determined by the fertility of the soil cover (Kurakpaev, 2016; Myslyva, 2018). The economic efficiency of land use and the efficiency of agriculture generally largely depend on the quality of land resources.

Rational use of land resources is one of the most important factors in the development of the Republic of Belarus. Monitoring of the state of land becomes a reference point for public authorities for developing regulatory legal acts regarding their use, conducting territorial planning, implementing measures to protect land and reproduce soil fertility. It is necessary to use innovative means for processing and analyzing spatial information about the state of land, to master methods of appropriate solution of management problems, assessing and monitoring the dynamics of land use to solve these problems.

Methodology of research and materials

The purpose of the research was to establish the possibility of using methods of geospatial analysis to estimate the spatial distribution of humus, mobile phosphorus, mobile potassium and pH_{KCl} within the land use of RUP "Uchkhoz BGSHA" (Fig. 1), and to identify areas with the most optimal agrochemical indicators by performing multivariate analyses in the GIS environment.

The geospatial analysis of data was carried out using the Geostatistical Analyst module of the ArcGIS software version 10.2. The data obtained from the materials of the agrochemical survey of the territory of RUP "Uchkhoz BGSHA" (Republic of Belarus, Mogilev region, Goretsky district), executed in 2014 by the Mogilev Regional Design and Exploration Station of Agrochemicalization were used for the analysis. The total area of the surveyed territory is 3187.0 hectares. The soil cover of the study area is represented mainly by sod-podzolic sandy loam on water-glacial sandy loam soils and sod-podzolic loamy on loess-like loam soils.

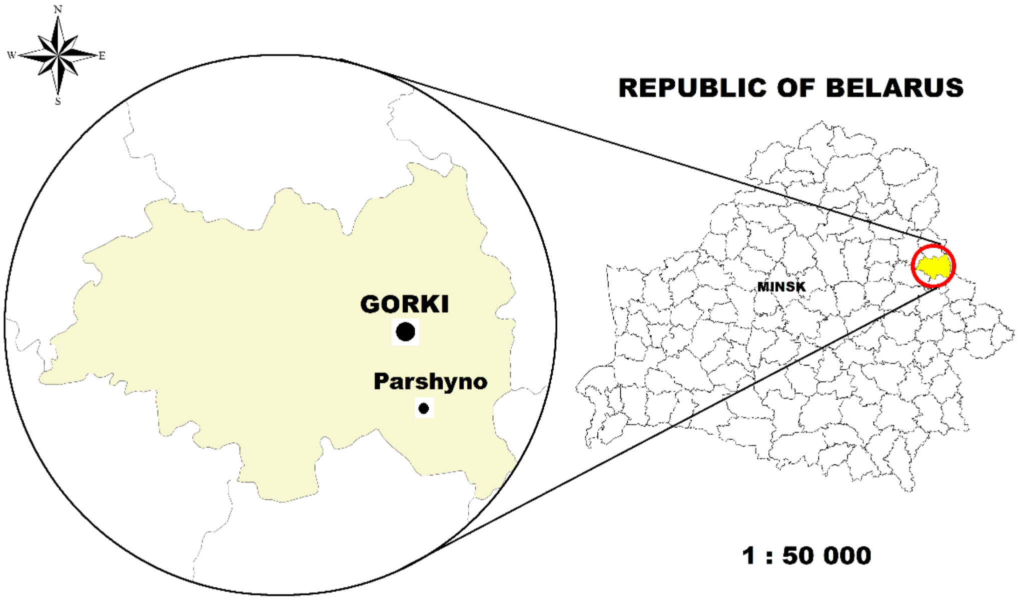


Fig. 1. The location of the studied territory

The universal kriging (Universal Kriging, UK), a geostatistical method of interpolation using the statistical properties of measured points to construct the surface, was used to perform the forecast and visualize the spatial distribution of agrochemical indicators. The universal kriging (UK) method is used when it is assumed that there is some dominant trend in the data that can be modelled using a deterministic polynomial function. It can use either variograms or covariances (mathematical forms used to express autocorrelation), apply transformations, and take into account the measurement error. The advantage of kriging is that it gives not only interpolated values, but also estimation of a possible error of these values (Myslyva et al., 2017). The interpolated value when applying universal kriging is determined by the formula (1):

$$Z(s) = \mu(s) + \varepsilon(s) \quad (1)$$

Where $\mu(s)$ denotes a deterministic function described by a polynomial of the second order,

$\varepsilon(s)$ denotes a random error that is calculated by subtracting a second-order polynomial from the original data.

Semivariograms were used as the main tool for studying the structure of the spatial distribution of agrochemical indicators. Based on the regional theory of variations and internal hypothesis (Gouri et al., 2016), the semivariogram is expressed as follows (2) (Wang, Shao, 2013):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (2)$$

Where $\gamma(h)$ denotes semi-variant,

h denotes the lag interval,

Z denotes soil property parameter,

$N(h)$ denotes the number of pairs of places separated by the distance lag h,

$z(x_i)$ and $z(x_i+h)$ denotes the values of Z at the positions x_i and $x_i + h$.

The interpolation accuracy was determined from the mean error (ME), mean square error (RMSE) and standard error RMSS (3), (4), (5):

$$\text{ME} = \frac{\sum_{i=1}^{N}(O_i - S_i)}{N} \quad (3)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)2}{N}} \quad (4)$$

$$\text{RMSS} = \frac{RMSE}{\Delta} \quad (5)$$

Where O_i denotes the observed value,

S_i denotes the predicted value,

N denotes the sample size,

Δ denotes the range equal to the difference between the maximum and minimum observable values.

Discussions and results

The application of the module "Geostatistical Analyst" for spatial modelling of distribution in soil humus, exchangeable phosphorus and potassium, as well as pH_{KCl} of soil solution provided a preliminary assessment of the initial data for their suitability for modelling purposes. As a result of the use of tools for an exploratory analysis of spatial data, a histogram of the distribution of initial data was created and the form of their distribution was investigated, and the basic statistical characteristics of the sample were calculated (Table 1).

Table 1

Statistical characteristics of a sample of data on agrochemical indicators used to construct interpolation models, n = 92

Indicator	Indicator value			Sd	Cv, %	Med	Kurtosis	Skewness
	min	max	mid					
Humus, %	1.25	3.35	1.93	0.44	22.8	1.92	4.01	0.75
P_2O_5, mg/kg	94.0	401.0	263.2	90.0	34.2	278.0	2.26	-0.29
K_2O, mg/kg	186.0	516.0	230.9	104.5	45.3	216.0	2.02	0.27
pH_{KCl}	5.2	7.0	6.07	0.4	7.76	6.05	0.34	0.04

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 modelling of the distribution surface. If the data distribution differs significantly from the normal one, you need to convert the data. In particular, if the data distribution has several peaks (extremums), that is, the data are asymmetrically distributed; the logarithmic transformation that approximates the distribution to normal is applied to such data. In our case, the conversion is suitable, since the distribution of the sample data in all cases was unimodal and close to normal, but the mean values and the median are relatively close in value.

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 with 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 all the investigated agrochemical indicators 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 interpolating as well as apply the trend removal option for constructing models using the universal kriging method.

The experimental anisotropic variograms were calculated to determine the possible spatial structure of humus content, mobile phosphorus and potassium, and the pH of the soil solution. The exponential function was identified as the best variograms model, the type of the circle was standard, the type and the number of sectors was 4 with a displacement of 450, and the lag was 200 meters. The results of estimating the predictive models generated by the universal kriging method are presented in Table. 2.

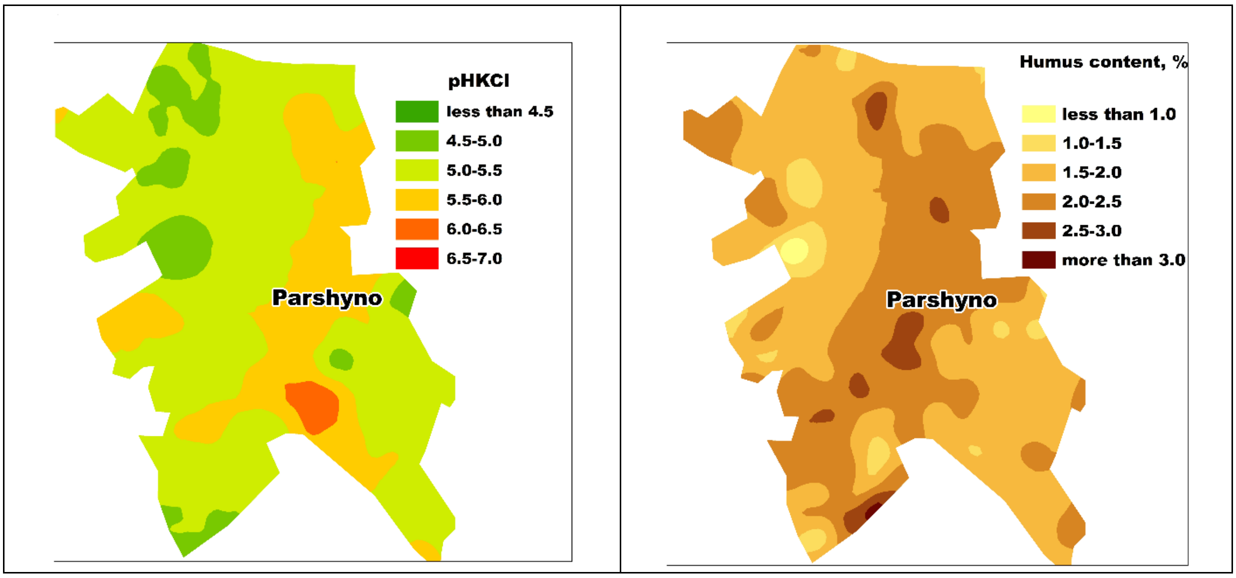
Table 2

Results of interpolation accuracy estimation

Semivariogram model	ME	RMSE	RMSS
Humus content, %	0.0015	0.38	1.03
Mobile phosphorus content, mg/kg	0.25	71.09	1.01
Mobile potassium content, mg/kg	0.85	84.20	1.03
pH_{KCl} of the soil solution	0.0049	0.81	1.08

By the accuracy of the interpolation, the predicted models of the spatial distribution of agrochemical indicators created using geospatial analysis methods are located in the following descending series: humus > phosphorus> potassium > pH_{KCl}. This is explained by the fact that there is a close correlation (r = 0.97) between the content of humus and phosphorus in the soil, but the pH of the soil solution, unlike other indices, does not undergo any dramatic changes within the study area (Cv = 7.76). In the case of sharp changes in the index, interpolation by the kriging method gives results that are more accurate.

Fig. 2 presents the results of visualization of the spatial distribution of the studied data (the classification was performed by the method of manual intervals).



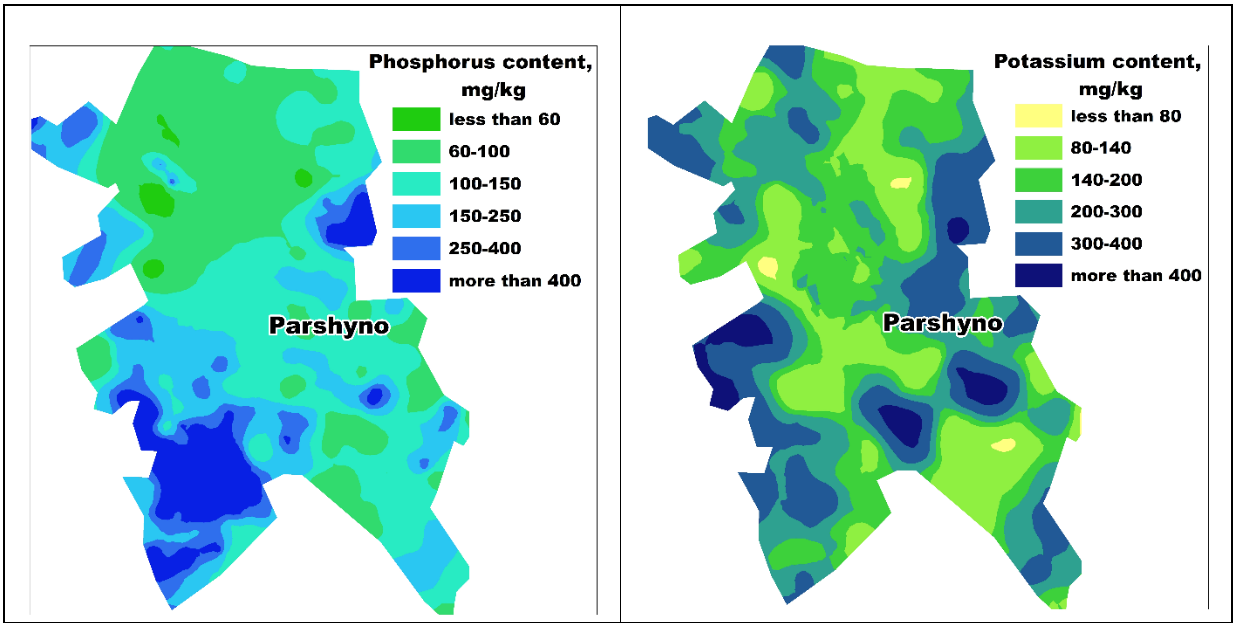


Fig. 2. The spatial distribution of agrochemical indicators in a 0-20 cm layer of soil, modelled by the method of universal kriging

It is necessary to note that the implementation of multifactor analysis, when based on the analysis of several interpolated rasters simultaneously drawing conclusions about the qualitative state of the territory and its suitability for various purposes of use, is quite frequent in solving problems through spatial analysis. The main task of our studies was to analyze the interpolated surfaces in order to find the sites the most favorable for the complex of basic agrochemical indicators. To perform this kind of analysis, the toolkit of the ArcToolbox module was used. Before starting the analysis, you need to reclassify the interpolated surfaces using the Reclassification utility from the Spatial Analyst toolbox. This tool changes the values of the raster to the corresponding values of the class specified by the user.

Multifactor analysis for searching the optimal agrochemical land parcels was carried out in three ways:

- Method 1: analysis using the functionality of the Raster Calculator tool of the “Map Algebra” utility;
- Method 2: analysis using the tool “Principal Components” of the utility “Multidimensionality”, in the application of which one resulting multichannel raster is created from several rasters;
- Method 3 - Maximum Likelihood Classification, using classification with training.

As a result of multifactor analysis, three resulting images were obtained by the methods described above. If we compare the maps obtained by different classification methods, we can see that the most qualitative sites have the same spatial localization. This indicates the possibility of using the proposed approaches for the search (localization) of the most valuable areas (Fig. 3).

The next step was to use the functionality of the raster calculator and create the resulting raster surface based on the rasters obtained in three different ways, where localization of the sites with low, satisfactory, good and excellent quality was noted.

Due to the advantages of visualizing the results of spatial analysis, more valuable from the practical point of view is to determine the areas of parcels or land masses belonging to a particular quality group. This option is especially important for an introduction of precision farming systems based on the concept of the existence of heterogeneities of factors that determine the fertility of the soil within a single field.

This feature is also provided in the functionality of the ArcToolbox module. Calculation of the area of each circuit within the limits of each working area was performed using the tools of the “Zonal Statistics As Table” tool of the utility “Zonal Statistics”. Zonal operations allow to perform analysis, the output data of which is the result of calculations performed on all cells belonging to each input zone. A zone can be defined as one area of the specific value, but it can also consist of several detached elements, or regions, all of which have a single value. Zones can be specified by raster or sets of object classes.

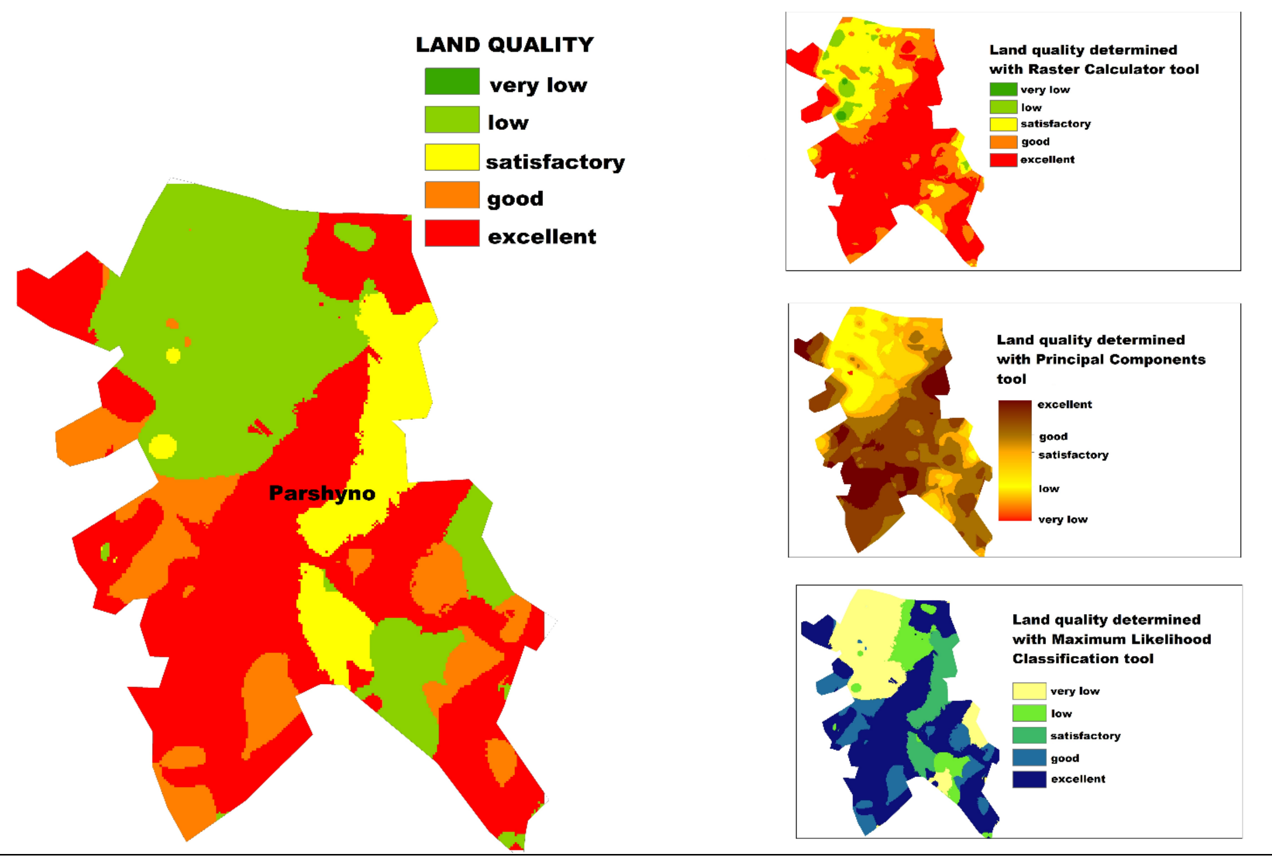


Fig. 3. The spatial distribution of agrochemical indicators in a 0-20 cm layer of soil, modelled by the method of universal kriging

As a result of the performed actions, a table is created in which the fields FID 0, FID 1 .... FID N – have ordinal numbers of working areas. The values in each field are the area of the contour of land within the limits of each specific plot, corresponding to one or another class of quality. The contents of this table can be exported to an Excel spreadsheet as well as analyzed with calculating the descriptive statistics of the resulting raster. As a result of the performed calculations, it was established that out of 3187.0 ha of the surveyed land area of RUP “Uchkhoz BGSHA”, the quality of 1469.3 ha is excellent, the quality of 430.2 ha is good, the quality of 390.1 ha is satisfactory and the quality of 897.4 ha is low.

Conclusions and proposals

The functional advantages of geospatial analysis provide visualization of monitoring data of the qualitative state of land, as well as ensure the search for individual land parcels according to the specified optimal parameters. It is the most expedient to use the universal kriging method to perform forecast and visualization of the spatial distribution of agrochemical indicators, the data having some dominant trend, which can be modelled using a deterministic polynomial function. An exponential function with the standard type of a circle and a lag size of 200 m is proposed as the best semivariogram model for determining the possible spatial structure of agrochemical soil indices. It is advisable to use the resultant raster surface based on the rasters obtained by three different multifactor analysis methods to have the most accurate establishment of localization of land parcels with low, satisfactory, good and excellent quality.

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