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GEOSTATISTICAL SIMULATION OF THE RESULTS OF AGROECOLOGICAL SOIL MONITORING IN KYIV REGION

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Key words: agro-ecological monitoring of soil, geostatistics, kriging.

The problem formulation

Intensive management (growth of industrial and agricultural pressure on natural systems, improper waste disposal) causes a significant technogenic soil transformation, which sometimes exceeds the rate of soil-deposition process.

Monitoring carried out to detect changes in soil surface and determine the danger of excessive pollution is an expensive process. Risk evaluation of the contamination in areas where no soil sampling was conducted, is essential to draw a line between clean and contaminated areas. However, the accuracy of risk assessment depends on many factors, including the technique applied. Therefore, the application of geostatistical methods proved successful for the soil monitoring data analysis for this purpose [7, 8, 9, 10, 11].

Geostatistics is a type of statistics used to analyze and predict the spatial or spatiotemporal events. It is based on the theory of zoned variables [9], which are placed in space (i.e., have spatial coordinates) and shows spatial autocorrelation so that points that are close to each other in space are more similar to each other than those being distant.

Geostatistics provides advanced methods to facilitate quantification of the spatial features of soil parameters and to make it possible to interpolate them spatially [3, 6].

Analysis of recent research and publications involved in the problem solution and referred to by the authors

Many foreign scientists, including T. Burges, R. Webster, A. Dobermann, C. Carlon, D. McGrass, A. Stein, K. S. Chan etc., have been engaged in the study and application of geostatistical methods for soil monitoring.

In Ukraine the problems of soil monitoring, assessment, management, protection and regeneration have been studied by O. F. Balatskii, G. D. Hutsuliak, A. S. Danilenko, D. S. Dobriak , S. M. Iliashenko, V. V. Medvedev, L. H. Melnyk, L. V. Melnyk, V. Y. Mesel-Veseliak, A. M. Tretiak, M. M. Fedorov, S. D. Cheriomushkin, A.V. Chupis, etc.

In Ukraine the specialists of the State Scientific and Technological Center for soil fertility (Tsentr-derzhrodiuchist), subordinate to the Ministry of Agrarian Policy and Food of Ukraine are involved in the determination of agro-chemical and physico-chemical parameters, heavy metals and trace elements on monitoring control plots. They determine the soil fertility and its changes and develop agro-measures to protect from soil degradation.

Unsolved aspects of the problem emphasizing

Penetrating study of the problem of application of geographic information and geostatistical methods for soil monitoring modeling at the regional level in Ukraine have not been conducted.

The article purpose formulation (problem setting)

The purpose of this article is to investigate theoretical foundations and practical application of geostatistics techniques in data analysis of agro-ecological soil monitoring, and *its content* is geostatistical modeling to estimate parameters of the soils of the Kyiv region of Ukraine.

The main subject matter of research

Since, one of the objectives of agro-ecological monitoring is to study the changes in soil, it is necessary to apply geo-statistical analysis and modeling to display them.

The input data of the 12 control sites network, created by Tsentrderzhrodiuchist specifically for permanent agro-ecological monitoring are applied for the geostatistical soil modelling. The network covers the territory of Kyiv region in uneven manner: unfortunately, it covers not all natural and economic zones, soil types, leaves unconsidered local landscape features, level of degradation processes and land pollution [2]. This factor has a negative impact on the construction of geo-statistical model and on its representativeness. But this will be mentioned further when describing the input data and the other stages of modelling.

Control sites being a square of size 100 × 100 m are bound to local landmarks and coordinate system.

In 2006-2010, a study of soil samples at 12 sites was conducted. The survey was carried out in one stage or round. [1] The following indicators of soil quality were determined: physico-chemical: pH salt extraction, exchangeable calcium, exchangeable magnesium; agrochemical: humus, ammonia nitrogen, mobile phosphorus, exchangeable potassium; trace elements: manganese, boron; radioactive and heavy metals, pesticides: cesium (Cs-137), strontium (Sr-90), lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), DDT and HCH.

As an example, the manganese concentration change was investigated (because it is the element that was normalized by the Box-Cox transformation) in soil according to soil monitoring data of 2009-2010 [3].

The surfaces of the spatial distribution of manganese and changes in its concentration were built by universal kriging, because this kind of kriging displays optimally such case according to the results of

" cross-check " (options implemented in Geostatistical Analyst ArGIS 9.2): an average error close to zero, small root mean square prediction error, an average standard error similar to the root mean square prediction error, a standardized mean prediction error near 1 (see Table 1.) [5]. This is illustrated in Fig.1.

Geostatistical methods make it possible to reconcile the various observations on the state of the soil to produce integrated assessments. It is advisable to apply integrated index that combines all available indicators of soil for the analysis of agro-ecological condition of soil in Kiev Region [4].

Table 1

Comparison of interpolation errors identified as a result of cross-checking among ArcGIS 9.2

Errors	The kinds of kriging			
	Ordinary	Disjunctive	Simple	Universal
An average error	0,011	0,036	0,036	0,006
A small root mean square prediction error	0,541	0,537	0,537	0,528
An average standard error	0,009	0,0581	0,058	0,006
The root mean square prediction error	0,900	0,994	0,994	1,088
A standardized mean prediction error	0,611	0,555	0,555	0,497

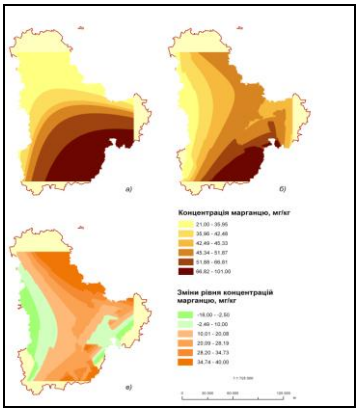

Fig. 1. The manganese concentration changes in the soils of the Kyiv region according to agro-ecological monitoring in 2009-2010: the manganese concentration in 2009 (a) and 2010 (b), the difference between the years (c)

However, this kind of kriging better reflects only this case, the construction of models for other indicators may require other types of kriging.

The integrated index of the soil is calculated for each control area applying a set of measured parameters. Measurement results of the quantity of substances present in the soil have been transformed to point system with application of different methods developed by soil scientists. Thus, the points to assess the concentration of the measured parameters in the soil have been determined by Kornfild methods for ammonia nitrogen, Turin method for humus, Chirikov method for potassium, etc. For example, according to the Kornfild method if the amount of ammonia nitrogen in the soil is less than 100 mg/kg, the result of measurement is assigned a score of 1, from 100,01 to 150 mg/kg, the result is 2, from 150,01 to 200 mg/kg – 3, and if the value is above 200, – 4. The results of other measurements have been transformed similarly. Dependence of the points on measurement values of concentration of specific components of the soil are presented in Table 2. Transformation results during the period of 2010 year are presented in Table 3.

Table 2

Transformation of the measurement results into points

Component/substance soil	Concentration	Mark
Ammonia nitrogen, mg/ kg	<100	1
	100,01-150	2
	150,01-200	3
	>200	4
Humus, %	<1,0	1
	1,01-2,0	2
	2,01-3,0	3
	3,01-4,0	4
	4,01-5,0	5
	>5,0	6
Exchangeable potassium, mg/kg	<20	1
	21-40	2
	41-80	3
	81-120	4
	121-180	5
	>180	6
Mobile phosphorus, mg/ kg	<20	1
	21-50	2
	51-100	3
	101-150	4
	151-200	5
	>200	6
pH salt extraction, Xe	<4,1	1
	4,1-4,5	2
	4,6-5,0	3
	5,1-5,5	4
	5,6-6,0	5
	6,1-7,0	6
	7,1-7,5	7
	7,6-8,0	8
	8,1-8,5	9
	>8,5	10
Manganese, mg/kg	<15	1

	15,01-20	2
	20,01-30	3
	30,1-45	4
	45,01-70	5
	>70	6
Boron, mg/kg	<0,15	1
	0,16-0,22	2
	0,23-0,33	3
	0,34-0,50	4
	0,51-0,70	5
	>0,70	6
Lead, mg/kg	<0,2	1
	0,2-0,5	2
	0,5-1,5	3
	1,5-5,0	4
Cadmium, mg/kg	<0,02	1
	0,02-0,05	2
	0,05-0,1	3
	0,1-0,5	4
Zinc, mg/kg	<1	1
	1-2	2
	2-5	3
	5-20	4
Copper, mg/kg	<0,2	1
	0,2-0,5	2
	0,5-2,0	3
	2,0-5,0	4
Cesium-137 kBq/m^2	<37	1
	37-185	2
	185-555	3
	555-1480	4
	>1480	5
Strontium-90, kBq/m^2	<6	1
	6-111	2
	111-1480	3
	>1480	4

The same operation is done with data during the period 2006-2009.

Then all indicators of soil quality were broken up into groups of indicated above: physico-chemical parameters (pH salt extraction), agrochemical parameters (humus, ammonia nitrogen, mobile phosphorus, exchangeable potassium), trace elements (manganese, boron) and heavy metals (cesium-137, strontium-90, lead, cadmium, copper, zinc). According to the formula of the arithmetic mean for each group of indicators was found the average score is presented in Table 4.

The integrated index was calculated using the formula:

$$I_s = \frac{i_1 + i_2 + i_3 + i_4}{4},$$

де i_1 – index of physic-chemical structure, i_2 – index of agrochemical composition, i_3 – index of trace element content, i_4 – index of heavy metals contamination. The results of calculation of the integral index are presented in Table 5.

Table 3

The transformed measurement indicators

Code district [1]	Code location [2]	pH salt extraction	Humus	Ammonia nitrogen	Mobile phosphorus	Exchangeable potassium	Manganese	Boron	Cesium-137	Strontium-90	Lead	Cadmium	Copper	Zinc
2010														
1	1	7	4	3	6	4	5	6	1	1	4	1	3	3
2	2	7	3	1	3	4	5	6	1	1	4	3	3	3
3	3	6	3	2	5	4	5	4	1	1	4	2	3	3
4	4	6	4	2	6	6	5	6	1	1	4	2	3	3
5	5	6	3	1	5	5	6	6	1	1	4	2	4	3
6	6	7	2	1	6	5	6	5	1	1	4	2	4	3
7	7	4	3	1	6	5	5	5	1	1	4	3	4	3
8	8	6	3	2	6	6	6	5	1	1	4	2	3	4
9	9	6	2	1	6	4	5	5	1	1	4	1	2	3
10	10	3	3	2	4	2	6	4	1	1	4	1	4	4
11	11	4	1	1	3	1	3	3	1	1	3	1	4	4
12	12	2	2	1	2	2	4	3	1	1	3	1	1	3

The results of geostatistical modeling of the integral index of soil in Kyiv region is built using universal kriging and are shown in Fig. 2. The accuracy of the constructed models are sufficient: the average error is 0,028, a small root mean square prediction error – 0,417, an average standard error – 0,056, a root mean square prediction error – 1,522, a standardized mean prediction error – 0,291.

[1] Code district: 1 – Bilotserkivskiy; 2 – Volodarskiy; 3 – Zgurivskiy; 4 – Perejaslav-Khmelnitsky; 5 – Stavysche; 6 – Tarashchansky; 7 – Tetiivskyi; 8 – Baryshivka; 9 – Brovarskyi; 10 – Borodyanskyi; 11 – Ivankovskiy; 12 – Poliskyi.

[2] Code location: 1 – Glushki; 2 – Volodarka; 3 – Zgurivka; 4 – Zhovtneve; 5 – Vynarivka; 6 – Potoki; 7 – Tetiiv; 8 – Peremoga; 9 – Krasylivka; 10 – Zagaltsy; 11 – Oliva; 12 – Yablunka.

This index is constructed in such a way that its lower value means better soil condition, and higher value means worse one (Table 6).

Table 4

The average scores for groups of soil indicators

Code district[3]	Code location[4]	Physical and chemical indicators	Agrochemical indicators	Microelements	Heavy metals
2010					
1	1	7	4,25	5,5	2,166667
2	2	7	2,75	5,5	2,5
3	3	6	3,5	4,5	2,333333
4	4	6	4,5	5,5	2,333333
5	5	6	3,5	6	2,5
6	6	7	3,5	5,5	2,5
7	7	4	3,75	5	2,666667
8	8	6	4,25	5,5	2,5
9	9	6	3,25	5	2
10	10	3	2,75	5	2,5
11	11	4	1,5	3	2,333333
12	12	2	1,75	3,5	1,666667

Table 5

The integral index of agroecological condition from the period 2006-2010

№	Location	The integral indicator				
		2006	2007	2008	2009	2010
1	Glushki	4,479	4,604	4,542	4,542	4,729
2	Volodarka	4,479	4,521	4,208	4,208	4,438
3	Zgurivka	4,708	4,063	4,000	4,000	4,083
4	Zhovtneve	4,813	4,938	4,708	4,708	4,583
5	Vynarivka	4,208	4,458	3,542	3,542	4,500
6	Potoki	4,583	4,208	4,604	4,604	4,625
7	Tetiiv	4,521	3,708	4,333	4,333	3,854
8	Peremoga	4,042	4,104	4,042	4,042	4,563
9	Krasylivka	3,708	4,333	4,042	4,042	4,063
10	Zagaltsy	3,354	3,438	3,188	3,188	3,313
11	Oliva	3,542	3,417	2,771	2,771	2,708
12	Yablunka	3,021	2,438	2,563	2,563	2,229

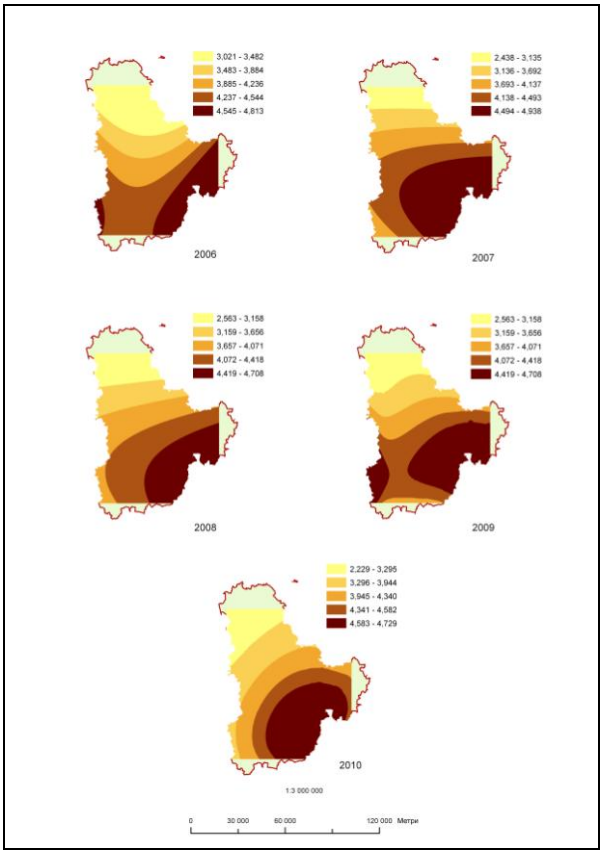

Fig. 2. Spatial distribution of the integral index of agroecological condition of soils Kyiv region

Table 6

The scale for assessment of agro-ecological condition of soils by integral indicator

Mark	The integral indicator, mark	Agroecological condition
1	1,0 – 1,7	good
2	1,8 – 2,5	satisfactory
3	2,6 – 3,3	unsatisfactory
4	3,4 – 4,2	critical
5	4,3 – 5,0	crisis

[3] Code district: 1 – Bilotserkivskiy; 2 – Volodarskiy; 3 – Zgurivskiy; 4 – Perejaslav-Khmelnitsky; 5 – Stavysche; 6 – Tarashchansky; 7 – Tetiivskyi; 8 – Baryshivka; 9 – Brovarskyi; 10 – Borodyanskyi; 11 – Ivankovskiy; 12 – Poliskyi.

[4] Code location: 1 – Glushki; 2 – Volodarka; 3 – Zgurivka; 4 – Zhovtneve; 5 – Vynarivka; 6 – Potoki; 7 – Tetiiv; 8 – Peremoga; 9 – Krasylivka; 10 – Zagaltsy; 11 – Oliva; 12 – Yablunka.

Thus, according to the results of geostatistical modeling of spatial distribution of the integral index over a five year period (2006 to 2010), agro-ecological soil condition is noted for some stability, which ranges from satisfactory and unsatisfactory to the critical one from north to south and south-east of Kyiv region accordingly.

Conclusions

GIS and geostatistical analysis techniques greatly facilitate the evaluation of soil parameters that are obtained by agro-ecological monitoring.

Geostatistical methods operate on the dependent variables, which are correlated in space or time with the degree of correlation between points (in this case between control sites of agroecological soil monitoring) being inversely proportional and dependent on the distance between them. These methods make it possible not only to interpolate values at locations where no soil samples were selected, to construct the surface of spatial distribution of soil parameters but also to evaluate the deviation of geostatistical models.

Modeling of the spatial distribution of the integral index of agroecological soil condition according to observations from 2006 to 2010 by GIS and geostatistical methods showed that the soil condition varies from north to south and south-east of Kyiv region from satisfactory and unsatisfactory to the critical one.

Geostatistical methods proposed in the article can be used to simulate and assess the condition and changes in other components of natural systems when solving problems of environmental monitoring and information obtained can be used in risk analysis and in decision-making.

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Geostatistical simulation of the results of agroecological soil monitoring in Kyiv region

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The theory and the practice application of GIS and geostatistical methods is describes for data analysis of agroecological monitoring of soils of Kyiv region. As a result of geostatistical simulation concludes that the condition is characterized by a certain stability of soil. Soil quality of the Kyiv region ranges from satisfactory (in the north) to the crisis (in the south and south-east).