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Research paper

The Geoinformation Support of the Landscapes Spatial Development

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Abstract

Under current conditions the progressively increasing anthropogenic pressure on land resources and significant changes in the structure of land tenure require the creation and immediate implementation of a system for surveillance and inspection the use and condition of lands in order to identify changes on-time, to asses them prevent and eliminate the consequences of negative processes occurring on the land tenure territory. The task of effective use of land is not properly performed due to the lack of reliable information about its condition and use. Such information can be obtained through the creation and operation of the ongoing system of the land condition state monitoring based on geoinformation technologies. This study is directed at determining the influence and correlation of the landscape spatial development with elements of the territory organization using the criterion of agricultural crops productivity with geographic information system (GIS).

The necessity of the analysis is connected with the detection of cyclicality, regularity, the influence direction of the territory organization elements on the landscape spatial development, which will make it possible to apply the most cost-effective and environmentally sound ways of using particular areas.

Keywords: *geoinformation technology, landscape, land tenure, productivity, spatial development.*

1. Introduction

Under the conditions of dynamic modern society development, the complexity of the technical and social infrastructure, the information becomes a strategic resource that determines effective land tenure. With the reliable information all managerial decisions and actions related to the rational and effective use of anthropogenic landscapes are based. Modern information technologies, especially geoinformation technologies, GPS system and Earth's remote sensing (ERS) system have become an important factor and tool of increasing land tenure efficiency. High information capacity of artificial Earth satellites observations makes it possible to quickly and objectively assess reserves of resources, crop conditions, forest lands, the origin and development of threatening natural phenomena, pollution of the natural environment, and suchlike. This allows to take measures on-time to rationally use natural resources and prevent damage from natural disasters and environmental disasters.

Over the past decades, intensive development of the agriculture has led to massive land degradation in Ukraine. This process is greatly facilitated by the development of wind and water erosion of soils, which is primarily due to the great territory ploughness. Total humus losses due to mineralization and soil erosion are increasing annually, and environmental and economic losses make a significant cost for restoring the landscape productivity. The given information shows the particular urgency of the issues of increasing use and reproduction efficiency of the agricultural lands productive potential.

Over the last years the computer technology has become more widely used as part of the landscape spatial structure study (landscape diversity).

A big attention is paid by many scientists to solving the problem of effective land use, applying the latest technologies and implementing GIS and ERS systems, such as Bulygin S.Yu., Krasovskiy G.Ya, Lyalko V.I., Medvedev V.V., Romashchenko M.I., Savin I.Yu., Tarariko O.G., Trofimchuka O.M., Ushkarenko V.O., Shevchenka A., Yakimchuka V.G. and others.

The results of their research include many aspects of this problem. However, the changes in modern land use, the dynamic application of these changes, the requirements determined by the new land regulations, the enhancement of the social, ecological and economic situation require the ongoing research to determine the directions and measures for further process implementation of improving the territory organization with the application of landscapes spatial development and impact on economic efficiency of agricultural production.

2. The study purpose

Based on the degree of relevance and problematic scientific solution, the purpose of study is to develop recommendations for establishing a connection between the economic and technological factor (the application of agricultural technology, reclamation) and location of specific working areas to improve the analysis of the territory organization with comprehensive justification for the landscape spatial development.

3. Results

The landscape is a specific territory with a single geological foundation (local geological structure), with one relief type (one morpho-sculpture, with the same climate, with soils and vegetation zonal type (within the same natural zone), specific set of natural boundaries and localities [1].

All methods of landscape researches study spatial or spatiotemporal relations. When applying mathematical methods to study the correlations between geographic phenomena, this is done implicitly. Without taking into account spatial aspects, it is impossible to implement the methods themselves, for example, cartographic method. There is an active development of special sections of one or another method specifically for the needs of the landscapes spatial development research. All methods can practically be combined with each other.

Among the means of information support for the landscape research, geoinformation systems (GIS), – an interactive systems that can collect, systematize, store, process, evaluate, display and disseminate data, take a special place as means of obtaining new information and knowledge about spatio-temporal phenomena on their basis [1].

Unlike many developed countries where GIS is used extremely widely, in our country, their importance and use of opportunities and capacities just start to develop. Any industry that has a network of production or services distributed on a certain territory becomes interested in using GIS technologies to increase the efficiency of its activities. These systems play a big part in solving various environmental problems.

Despite its widespread availability there is evidence that GIS is underused in the realm of landscape design research. Though recognized as a useful tool for mapping and planning, the potential of GIS is often still underutilized due to a lack of awareness and prejudice [2].

Geographic information systems are the most effective tools for characterizing and describing a geographical environment, including constantly changing specific landscape. These systems are used to solve many practical problems related to spatial data used to ensure environmental safety and sustainable development of landscapes. These systems can be used to analyze the monitoring data of the researchable object, create digital maps that show the current condition of the landscape territory, analyze the changes that occurred in the researchable region over a certain period of time, and predict the consequences of certain economic decisions made.

The GIS structure includes:

- data saving and searching, that allows to receive data immediately for the relevant analysis, update and correct them;
- data entry, that provides entering and / or processing of spatial data obtained from maps or any other sources of information;
- data representation (delivery) in various forms (maps, tables, images, block diagrams, digital terrain models, etc.).
- data processing and analysis, that allows to asses parameters, solve computational and analytical tasks [1].

Analyzing modern geoinformation support for characterizing the landscape spatial development, GIS advantages over other information systems were discovered, which consist in the possibility of combining dissimilar data based on the geographic (spatial) information. GIS-technologies become irreplaceable in the landscapes research, as they provide the ability to search for objects by geographic or other spatial feature, and to detect an object in the database by the values of its attributes with following determination of its location on the map-scheme.

Nowadays, GIS is an irreplaceable tool for investigating tasks related to spatially distributed information, including the entering and saving of source information, the efficient processing of spatial data, visual and geostatistical analysis, and the preparation of various output cartographic and other documents [3,4].

The development is an irreversible, directed, regular change of material and ideal objects. Only the simultaneous presence of all three of these properties identifies development processes among other changes. The reversibility of changes characterizes the functioning processes (cyclic reproduction of a constant system of functions). The absence of regularity is distinctive for random processes of catastrophic type. The absence of directionality, changes can not accumulate, and therefore the process loses its distinctive for development single, internally interconnected line [5].

Now there is a need to conduct research on the elements of the territory organization to identify the cyclical nature, the regularity, the direction of their influence on the landscapes spatial development. One of the methods of landscape research is geographical description during which they establish correlation and indicate how strong they are. Using the mathematical tool, the information theory, especially the coupling coefficient, the factor phenomenon and the integral index, or other factor can be constructed in the form of a table or a figure of the components interaction model [1, 6].

So, there is a task to express individual properties of land lots in quantitative form and determine the degree of their connection or connectedness. We propose to establish the correlation between some basic elements of the territory organization and the productivity of agricultural crops, which is an important feature of the natural complex. The productivity depends on many factors and therefore it is difficult to establish the exact level of influence of an individual factor. The climate (humidity, heat, wind, etc.), soil cover, morphological characteristics of the area the achievement of a certain economic effect are difficult to be impacted, but they are needed to be taken into account when organizing the production.

Biological factor is the biological features of different plant species, their varieties and hybrids, their ability to absorb solar radiation, moisture, various nutrients, etc. There is no obvious direct connection between a particular territory organization and the biological factor, but one of the requirements for land management in agriculture is taking into consideration the needs of plants.

For the compilation of mathematical models for calculating the size of the effect on yield, information on the structure of the interaction (type of dependence function) of all of the above factors is required. Also, a significant number of variables in the model has a certain measurement error, respectively, the models have rather low accuracy and consist of many assumptions and simplifications. While investigating this question, it was found that yields are potential, actual and biological. Biological yield is the one of all products created by photosynthesis during a growing season for one hectare of sown area, which is determined at the time of the achievement of biological maturation on stumps [7].

Statistical studies of the impact of the organization of the territory on yields are complicated by the fact that there is a difference between biological and actual crop, which depends on several main factors. If the terms for harvesting are delayed, then 4% of the grain crop is lost in consequence of technologically unregulated harvesting equipment - 4,5%, while transporting - 1,5% [8]. That is, in order to assess the effectiveness of certain elements of the organization of the territory, not monetary, but natural indicators are better suited, including not actual, but biological yield.

Indicators of landscape development, including biological productivity of crops, can be studied using satellite data and GIS. In the basis of works using GIS in landscape mapping, most scientists adhere to a single methodological approach: first using a modern remote sensing data, field research data and GIS operator knowledge, a landscape map that can be supplemented with applied content is created .

The process of creating a landscape map using GIS can be divided into several stages, such as: the preparation of primary information, that is, the processing of a topographic basis and the creation of a series of maps for component zoning, the selection and justification of GIS; the development of the map legend, the choice of the way to formalize spatial data, the importance of features in the allocation of landscape; representing spatial information in a raster image, creating a layer matrix in accordance with the weight of the features, creating a source layer that contains all the previous information and its overlay analysis; classification of natural territorial complex into landscape territorial units and allocation of landscape territorial structures [9].

Nowadays this method of creating a landscape map using GIS is widely used by Ukrainian landscape scientists. However, the active development of GIS, software differences, and the development of fundamental landscape studies cause the necessity of additional study of the applying GIS in landscape mapping problem.

According to satellite remote sensing data in different spectral ranges, factors are calculated – vegetative indexes characterizing the condition of vegetation. To calculate most of them, two stable ranges of the spectral curve of the plants reflectivity are used: the red zone of the spectrum (0.58-0.75 μm), which accounts for the maximum absorption of solar radiation by chlorophyll, and the near infrared (0.72-1, 3 μm) with maximum reflection of energy by the cellular structure of the sheet. The most commonly used is the normalized difference vegetative index (NDVI) [10].

The result of the space images analysis application is a map of changes indicators in the yield of agricultural crops in the context of various working areas of the agricultural enterprise "Roll-Pol" in the Barvenkove district of the Kharkov region. The plots selected for investigation are sown for one year with one agricultural crop (winter wheat or sunflower), and, accordingly, processed by the same agronomic means, which allows abstracting from the differences in biological factors of yield and most agriculture means. The distance between the plots can be abstracted from the climatic differences. The plots are within the same agricultural group are medium-grained loamy leached black grounds.

Thus, unlike the biological yield, the agricultural plants on the plots under investigation might be influenced by various spatial elements: field size, operating length, operating width, shape, slope steepness, exposition. The theoretical basis of the plot arrangement on the yields are:

– the exposure of the slope affects the thermal and water regime of the territory;

– slope steepness affects the water and erosion regime of the territory;

– the crop yields is less along the perimeter of the plots due to dusting from roads, shading from forest belts, soil compaction due to movement and turning spreads (which are larger in comparison with the rest of the plot) of vehicles, the overlaps and flaws areas while sowing.

Based on these factors, the southern exposure area (with sufficient moisture), the minimum steepness of the slope, the relatively large area, the parallel sides in the direction of the main processing, the minimum possible perimeter with equal other conditions should have a greater biological productivity.

For comparison and determination of more effective parameters of working areas, there are several approaches: the transfer of all parameters to one type: money, mass, energy units, etc., or use the evaluation method, where the measure of efficiency does not depend on the selected units of measurement, provided that all units of measurement coincide for all subjects of the evaluation. This approach can be implemented using the Data Envelopment Analysis (abbreviated as DEA) [11].

This technology allows to integrate technical aspects as well as economic aspects, and helps to distinguish between "effective" and "less effective" working areas DEA is a non-parametric mathematical programming approach, and factors that can not be expressed in currency units (because they will then have less representational appearance) can also be included in the assessment. The disadvantage of DEA is that natural conditions tend to differ from region to region, and even from landscape to landscape. This leads to unequal conditions of agricultural production, with the result that the effectiveness of the investigated objects is significantly variable.

According to the DEA method, the activity of the territorial organization's influence on productivity is estimated through the ratio of a certain "output" indicator (final product) to the "input" indicator (resource) that is used for its production. The final efficiency score is determined by comparing the performance of a particular working area against the assessment of all "best" (effective) working areas. For our experiment, the "best" workstations will meet the scientific guidelines.

In order to calculate the influence of the plots arrangement performance on the landscape, the can be used [11]. This DEA model can be "input-" or "output-oriented". In the "input-oriented" case, the DEA defines the limits by maximizing the proportional decrease in "input" indicators, while leaving the "output" those at a constant level. In the "outputs-oriented" case, the "input" indicators remain unchanged while the DEA tries to maximize the "outputs". The "output-oriented" CCR model will be, for certain, chosen because the primary objective of agriculture is, as a rule, to maximize the final product instead of minimizing costs.

Experimental plots were grouped into two groups by DEA index (Table 1). The first group is "effective" plots, whose spatial figures have a greater effect on yield, the second one is "less efficient" plots, spatial indicators of which have less effect on yield.

Table 1: Calculation results by DEA for investigated working sites Kharkiv region Barvenkove district of JV ROLPOL in 2015-2017 by the method

Working sites	Input indicators					Outputs	Assessment	Groups by DEA (1-effective, 2-less)
	Area, hectares	Perimeter indicator	Correlation of working length and width	Steepness of the slope indicator	Degree exposure (Mid-angle from north)	Biological productivity (NDIV) Sum of coefficients	Values of efficiency indicators by the DEA method	
1	32.8	2348.9	1.63	2.03	69.3	57.9	0.35	2
2	7.4	1166.5	2.14	2.55	82.6	17.4	1.00	1
3	59.5	3580.1	2.98	1.73	98.6	90.4	0.67	2
4	48.8	3549.7	0.23	1.88	105.0	79.0	1.00	1
5	11.1	1446.5	2.11	2.48	32.7	12.3	0.48	2
6	30.1	2912.1	4.91	4.14	30.8	57.6	0.84	2
7	55.6	3014.0	1.41	2.14	65.4	92.8	0.78	2
8	48.6	2848.7	1.02	1.84	54.6	106.1	1.00	1
9	66.8	3918.1	2.52	2.14	65.2	150.9	1.00	1
10	20.7	1956.8	2.14	3.03	41.0	45.0	0.95	1
11	31.4	2841.9	1.57	2.15	101.8	45.9	0.64	2
12	31.4	3250.8	6.15	2.43	44.2	66.6	0.93	1
13	41.7	3165.5	2.25	1.99	109.7	74.0	0.78	2
14	78.9	3930.9	2.82	2.01	71.4	115.3	0.69	2
15	155.0	5487.9	2.72	1.53	53.3	250.6	1.00	1
16	47.8	3280.7	0.87	1.05	81.2	99.7	0.99	1
17	104.4	4340.3	1.93	1.29	90.8	202.7	1.00	1
18	30.7	2331.0	1.72	2.11	119.7	50.1	0.72	2
19	64.5	3267.8	0.94	2.25	116.7	94.6	0.85	1
20	102.1	4673.6	2.23	1.89	76.5	144.4	0.79	2
"Etalon"	400	10733.1	5	0.1	180	946.8	1.0	1
U test Mann Whitney	41		38		45	33		

Note: statistically significant at p <0.05

The basis of the DEA method is to construct a curve based on "successful" (effective) workstations (plots) by linear optimization. The following is needed to be solved by linear programming for each operation plot:

$$max_{\phi,\lambda}\ (\phi); -\phi y_i + Y\lambda \geq 0 \quad (1)$$

Under the constraint system:

$$x_i + X\lambda \geq 0;\ \lambda \in R_+ \quad (2)$$

where – □□is a scalar, □ is *Nx*1 vector of weights, *X* is *NxK* is a matrix of "input" indicators for all working plots *N*, *Y* is *NxM* is a matrix of "output" indicators for all *N* working plots, x_i is *Kx*1 is a vector of " input" indicators for *i*-th plot and y_i is *Mx*1 is a vector of "output" indicators for *i* -th plot. The technical efficiency used in this paper is defined as *1* / □□[11].

"Output" indicator (the result), which is the level of biological productivity, is expressed through NDIV gained due to LandSat-8, an Earth satellite pictures project. Resolution 30×30 m. The satellite photos were taken for 2015-2017 before harvesting.

In the "effective" group the area is 25.7% larger than in the "less effective" group, the perimeter is 9.3%, biological productivity (NDIV) is 50.2%. Other indicators are larger in "less effective" group.

Input indicators:

– area, ha – the larger the area, the fewer blank races and turns, and, other things being equal, the greater yield;

– reverse perimeter value the smaller the perimeter, the fewer – blank races and turns, and, other things being equal, the greater yield;

– correlation of working length and width – the longer the length, the fewer blank races and turns, and, other things being equal, the greater yield;

– reverse steepness of the slope value – the lower the steepness of the slope, the better the water regime and, other things being equal, the greater yield (calculated from the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data);

- slope exposure, deg – the southern slope, with sufficient moisture, forms the best thermal and water regime and, other things being equal, a greater yield (north – 0 °, south – 180 °) (calculated from Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data).

These parameters are calculated with use of ArcGIS (a family of geo-information software's by ESRI company).

The relationship between the specific indices of the working sites and the values calculated by DEA are shown in Fig. 1-5.

As it can be seen from Figures 1-5, there is a certain correlation between the spatial indicators of the plot arrangement and DEA assessment, but there is no any clear functional format.

As a number of investigated objects (worksites) is 20 (*n* <50), the Shapiro-Vilka criterion [12] was applied as a criterion for distribution normality verification. The result is the abnormal distribution, so the non-parametric statistical criterion, U-Mann-Whitney's criterion [12] was determined as the method of verification.

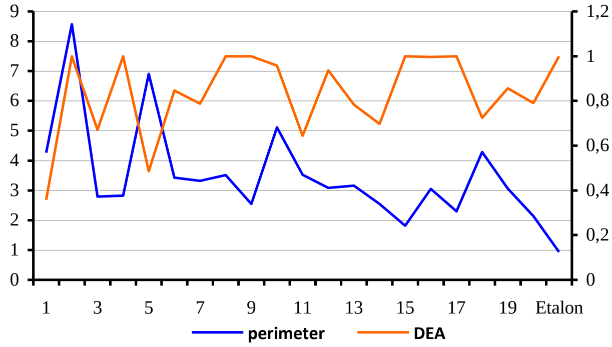

Fig. 1: Perimeter index and DEA value dependency graph

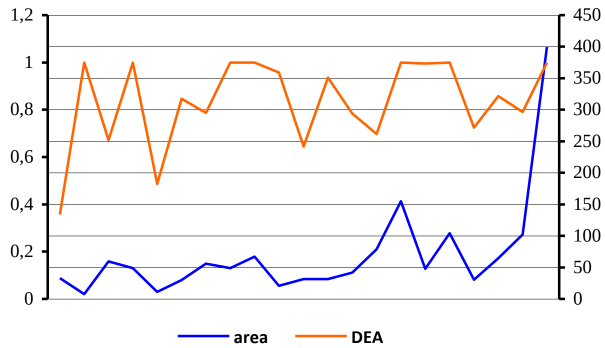

Fig. 2: The graph of the relationship between operating length and width of working plots and DEA value

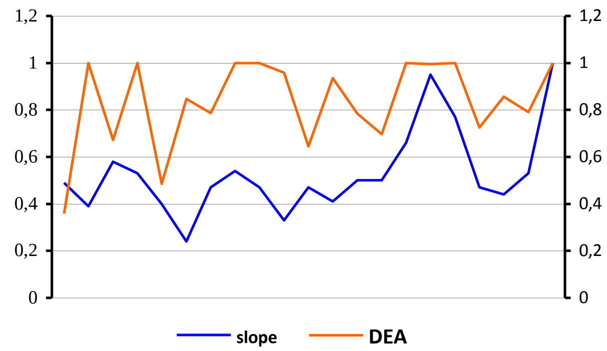

Fig. 3: NDIV dependency and DEA value graph

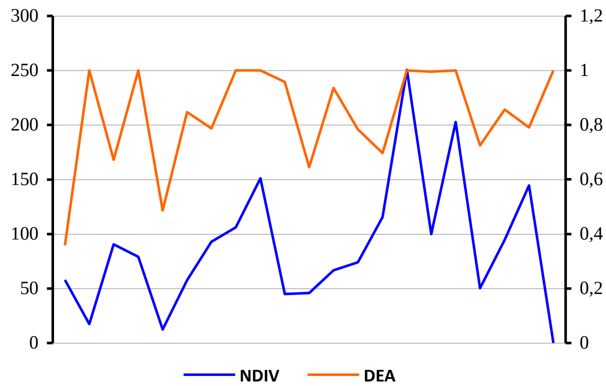

Fig. 4: Exposure and DEA values dependency graph

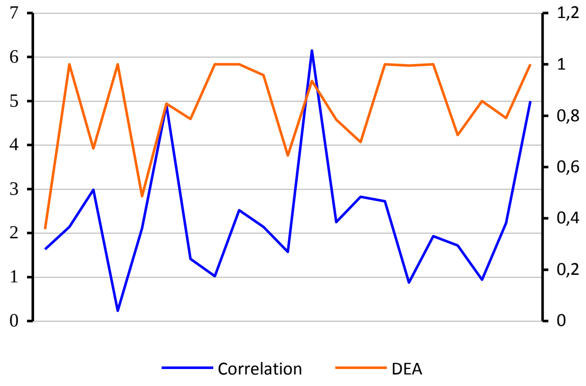

Fig. 5: Aspect ratio and DEA value dependency graph

As we see from the table, for every parameter the statistical criteria are above the critical value of Ukr (0.05) = 27 and, therefore, the differences in the levels of the samples can be considered as insignificant.

As it can be seen from the table, the geometric parameters of the working plots do not significantly affect to biological yield. Calculation of links between the elements of the plot arrangement and yields gives the reasons to conclude that although everything in nature is interconnected and interdependent, these connections are not rigid, and there is a certain range of fluctuations of factors and integral indicators. At the same time, properly arranged working plots have been noted by investigators [13] as reducing the cost of fuel and lubricants, equipment depreciation and the working time expenses.

Further direction of investigations: use of images of greater resolution made from space, application in calculations of indicators of landscape structure mosaic and groundwater occurrence level (Fig. 6-7).

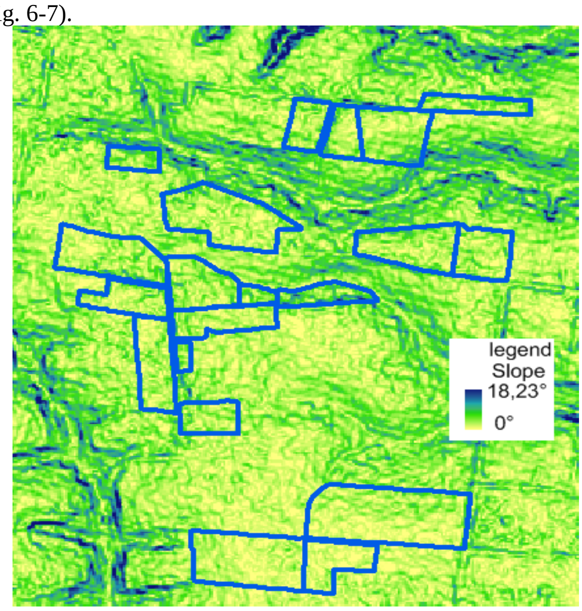

Fig. 6: The use of GIS-technologies for the mapping of steep slopes, degrees (calculated on the basis of Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data)

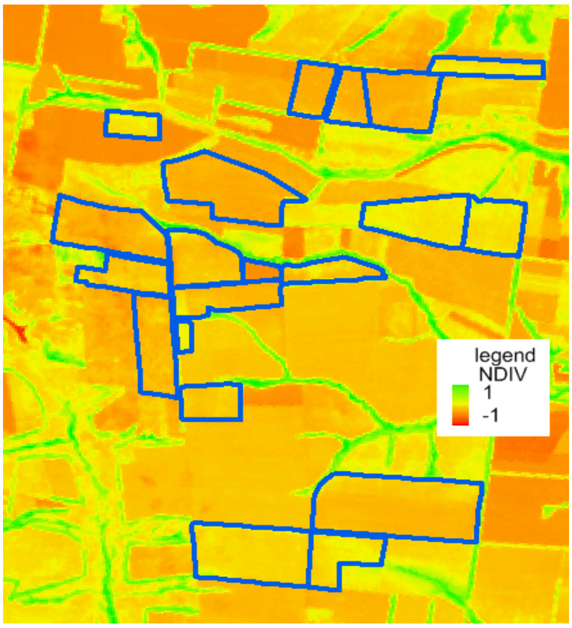

Fig. 7: The use of GIS-technologies for the compilation of NDVI cartograms

So, scientists [1] point out that the analysis of the connections of the four main factors (geomorphological, hydrothermal, biotic and soil) will enable to construct a model of the interaction of individual factors with the elements of the landscape.

4. Conclusions

The main tasks to solve with use of GIS (geo- information systems) creation include assessment, zoning and planning of landscapes development. The spatial approach provided by GIS enables to use complex multidimensional and multicriteria models while investigating the land use processes and the assessing the negative effects of anthropogenic impact. The current state of society requires modern approaches in collecting, storing, analyzing and forecasting the state of landscapes, which can be provided with a modern geoinformational approach to the solution of the tasks. The level of development of science and technology allows us to widely use GIS technology to study the spatial development of landscapes. With the help of space images, it is possible to establish the spatial characteristics of the organization of the territory and determine the vegetation indices.

Within the investigated farm, in the Barvinckove district of the Kharkiv region of Ukraine for the period 2015-2017, the nature of the impact of the organization of the territory on biological yield is not significant. But using data obtained from research, it is possible to evaluate and control the quality production of agricultural products in ways that ensure the restoration of land fertility, methods that exclude or limit the negative impact of environmental activities; implement standards, norms, rules and regulations for agrotechnical, agrochemical, reclamation, phytosanitary and anti-erosion measures.

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