Use GIS for Estimation of Agricultural Suitability of the Lands (on an Example of the Agricultural Organization)

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Key words: land tenure, agricultural suitability, landscape factors, GIS

SUMMARY

Creation of sustainable, effective land tenure and protection of land resources is one of priority directions of development of Belarus. First of all it concerns to agrarian land tenure as more than half of land fund of country it is involved in an agricultural production.
The estimation and choice of directions of perfection of agrarian land tenure is necessary for carrying out on the basis of the landscape approach. The more objectively at the organization of territory landscape factors are taken into account, the agricultural production will be more effective to develop.

Questions of an estimation of suitability of the lands for agricultural use under landscape factors by means of GIS-technologies (on an example of the agricultural organization) are considered in this research. The thematic layers describing the basic landscape factors, influencing on agrarian land tenure (a relief, soils) and layers of agricultural suitability of the lands under these factors were created. Then the combination of layers of suitability was constructed by means of overlay operations. Received conditionally optimum the spatial model of territory was compared to actual structure of land tenure and recommendations on improvement of use of the lands of a study area were made.

РЕЗЮМЕ

Создание устойчивого, эффективного землепользования и охрана земельных ресурсов является одним из приоритетных направлений развития Республики Беларусь. В первую очередь это относится к аграрному землепользованию, так как более половины земельного фонда республики вовлечено в сельскохозяйственное производство.

Оценку и выбор направлений совершенствования аграрного землепользования необходимо осуществлять на основе ландшафтно-экологического подхода. Чем объективнее при организации территории учитываются ландшафтные факторы природной среды, а также пространственная дифференциация территории, тем надежнее будет обеспечено постоянное повышение эффективности сельскохозяйственного производства.

В этой статье рассматриваются вопросы оценки пригодности земель для сельскохозяйственного использования по ландшафтным факторам с помощью ГИС-технологий (на примере сельскохозяйственной организации). Созданы тематические

слои, характеризующие основные ландшафтные факторы, влияющие на аграрное землепользование (рельеф, почвы), слои агропригодности земель по этим факторам и результирующая комбинация слоев, построенная с помощью оверлейных операций. Полученная условно оптимальная пространственная модель территории сопоставлена с фактической структурой землепользования, сделаны рекомендации по улучшению использования земель хозяйства.

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1. INTRODUCTION

The modern resource and environmental problems causes necessity of optimization of agrarian land tenure, development of ecologically balanced methods of its spatial organization. Special value for sustainable agrarian land tenure has interrelation of its spatial structure with concrete landscape conditions of territory. Underestimation or ignoring of the specified interrelation results not only in essential economic costs, but also to amplification of degradation of the natural environment.

As example the region of the Belarusian Polesye can serve, one of which main problems today is degradation of the lands. It is shown in the following basic forms: water and wind soil erosion, chemical and radiating pollution of the lands (as a result of Chernobyl disaster), degradation of peat soils on the drained bogs, deterioration of soil properties as a result of long agricultural use, degradation of the lands at fires.

Unfortunately, during spatial planning of the land tenure and formation of ecological requirements and restrictions the landscape factors and geographical features of territory till now is not taken into account.

The purpose of research is to develop offers on optimization of agrarian land tenure of the agricultural organization on the basis of the complex analysis of landscape factors of territory with application of GIS-technologies.

Object of research are agricultural lands of study area.

Research tasks are:

- to estimate influence of landscape factors on agrarian land tenure;
- to reveal interrelations between landscape factors and spatial structure of land tenure;
- to analyse suitability of landscape factors for agricultural activity;
- to develop offers on optimization of land tenure.

2. STUDY AREA

The study area covered around 50 km^2, which is between 52^{o}04' and 52^{o}08' N latitudes, 26^o 12' and 26^o 23' E longitudes (Figure 2-1).

This area is a part of geographical region of Belarusian Polesye. It is located on the Polessky lowland mainly within basin of river Pripyat.

The originality and distinctive features of this territory are defined by a flat relief, presence of a plenty of bogs, riches and heterogeneity of structure of a soil cover, uniqueness of local landscapes.

The large-scale hydraulic engineering land improvement was carried out here which, unfortunately, not to the full took into account all landscape features of territory. As a result of it there was a radical change of a water and climatic mode of territory, the structure and properties of soils has changed, processes of degradation of the lands have amplified.

The lands of study area are used for conducting an agriculture and are part of the agricultural production organization (APO) "Lemeshevichi".

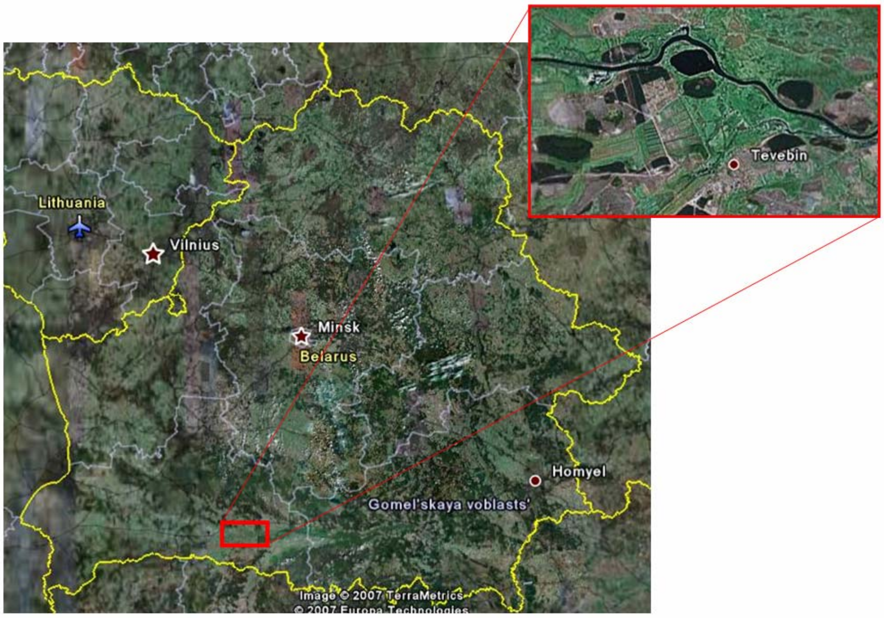

Figure 2-1: Location of the study area

3. METHODOLOGY

In modern conditions at spatial planning (including agrarian land tenure) the planners widely apply the GIS-technologies to the full taking into account landscape and other factors of differentiation of territory (Vitchenko 2004; Kalep 2005).

Use of GIS-technologies assumes creation of thematic GIS-layers under all characteristics without dependence from their territorial differentiation on this or that object. The created layers can be used and for a cadastral estimation of the lands, and for the analysis of suitability of the lands, and for optimization of spatial structure of land tenure, and for formation of rational requirements and restrictions and for other tasks of spatial planning. GIS enables the analysis of considered parameters in each point to digital model that allows to estimate both internal differentiation of any site, and influence on it of external factors. It also allows to receive the information on spatial relations between objects, to carry out spatial interface of objects and to execute the complex analysis of considered territory.

Interpolation of the data under discrete characteristics allows to refuse calculation of the average parameters, and functions of the spatial analysis automatically enable to calculate integrated surfaces, switching in calculations of weight of influence of separate factors.

Development of agrarian land tenure is influenced to the greatest degree with three landscape factors: a climate, a relief and soils. The climate determines temperature conditions of territory and forms its water mode. However it difficultly gives in to the spatial analysis, besides influence of this factor is difficult for looking after at a level of the agricultural organization. At this level it is possible to speak about influence of a microclimate, however it is determined, mainly, by a relief of territory. The relief is responsible for redistribution of heat and a moisture. At its analysis for the purposes of optimization of agrarian land tenure it is necessary to take into account slope angle, an exposition and length of slopes, features of accumulation of water and other characteristics.

The important factor influencing agrarian land tenure, undoubtedly, the soil cover is. At the analysis of soils it is necessary to take into account their typical accessory, structure of mother breeds, degree of humidifying and other qualitative characteristics.

The analysis is carried out with the help of creation of the level-by-level model containing layers of suitability of the lands under landscape factors and their resulting combinations, received with use of overlay operations. Such technology demands definition of criteria of suitability of factors, reclassification of factorial layers (assignment of parameters of suitability to all cells of a raster), calculation of weights of influence of each factor on agricultural activity and subsequent association (overlay) of factors with the purpose of creation optimum (under landscape factors) model of territory.

The procedures for generating factors maps follow the major functionality of GIS. The relevant data are acquired and stored in a GIS database, and then the data are manipulated and analyzed to obtained information on a particular evaluation criterion for multicriteria spatial decision making. In a sense the factors maps can be considered as output of GIS-based data processing and analysis to generate factors maps (Malczewski 1999).

Analytical Hierarchy Process (AHP) method (Saaty 1980) was used for computation of the factors weights. It is developed to select the best from a number of alternatives with respect to several factors. AHP allows for both the inconsistency in the decision and provide the means to improve the consistency. Here the user will perform simple Pairwise Comparison i.e. he/she will compare two elements at a time. The values of the Pairwise Comparison are determined according to the scale introduced by Saaty. The available values for the comparison are the member of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}, 9 representing absolute importance and 1/9 the absolute triviality.

The tool "Raster calculator" of ArcGIS v. 9.2 was used for overlay of factors taking into account weights of their influence on agricultural activity with the purpose of creation optimum (under landscape factors) model of territory.

The received model is compared to actual structure of land tenure and is taken into account at definition of actions for change of use of the lands: to their improvement, transformations, to a conclusion from an agricultural revolution, to modes of use.

4. DATA AND ITS PROCESSING

As the initial information for the analysis are used:

- Land information system of Pinsky district;
- Topographical map of study area with 1:10000 scale;
- Aerial photographs with 1:10000 scale;
- Soil map with 1:10000 scale;
- The data about agro-chemical parameters of soils.

In this study, ArcGIS v.9.2 and ArcView v.3.2 GIS software was used to produce thematic layers “contour lines of relief” and “soils”. On the basis of a layer of “contour lines of relief” with use of tools of module Spatial Analyst are automatically constructed TIN and GRID of study area. Further on the basis of TIN with the help of module Spatial Analyst layers “slope of relief” and “exposition of slopes” and on a basis GRID and special module HydroTools v.1.0 the layer “flow accumulation” were produced.

4.1 Slope angle

One of the major characteristics of a relief of territory is **slope angle** on which size the degree of danger of erosion depends. Erosive processes start to develop at value of slope angle 2^o and more. This value is an original threshold after which it is possible to speak about intensity of a relief (Ivlev 2004). However it is necessary to note, that erosion in one case can be observed at value of slope angle $0,5^o$ and even $0,3^o$, and in the other case erosion can start to be shown at much more slope angle values. The analysis of slope angles of study area has shown, that 92 % of territory have values from 0^o up to 2^o and 8 % are characterized more than 2^o. Slopes with value less than 2^o are referred to more suitable for agricultural use, and slopes with value more than 2^o to less suitable (Figure 4-1).

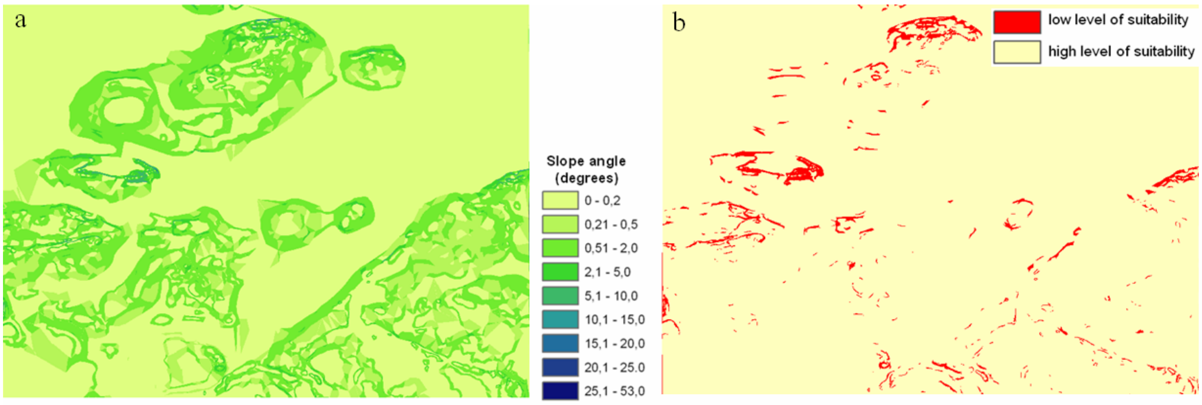

Figure 4-1: Fragment of a thematic layer "slope of relief" (a) and classification of slopes on suitability for agricultural use (b)

4.2 Slope exposition

The following characteristic of a relief of territory is **the exposition** of slopes which represents a direction of surfaces concerning the sides of light. Depending on a direction (on the south, on the north, on the west, on the east), slopes receive various dozes of a solar energy that influences a mode of humidity of soils and temperature of air, that actually determines the microclimate of territory, that finally is reflected in productivity of agricultural crops. Researches show, that slopes of southern expositions are characterized by more comfortable conditions for agricultural crops (Kalichkin 2002).

Also the exposition of slopes determines a potential opportunity of origin and development of processes of water erosion of soils. On slopes of northern and northwest expositions, land, as a rule, are not exposed (or are exposed in a small degree) erosion, and on slopes of southern expositions the erosion is shown more intensively. For the purposes of classification it was not taken into account, as the probability of display of water erosion in researched territory in the greater degree is determined by slope angle.

The analysis of expositions of slopes has shown, that 63,2 % of study area are flat, 18 % concerns to slopes of southern expositions, 11,3 % - to slopes of northern expositions, 3,3 % - to slopes of east exposition and 4,2 % - to slopes of the western exposition. Flat territories, and also slopes of southern, south-west, south-east and western expositions are referred to more suitable for agricultural activity, and slopes of northern, north-east, north-west and east expositions - to less suitable (Figure 4-2).

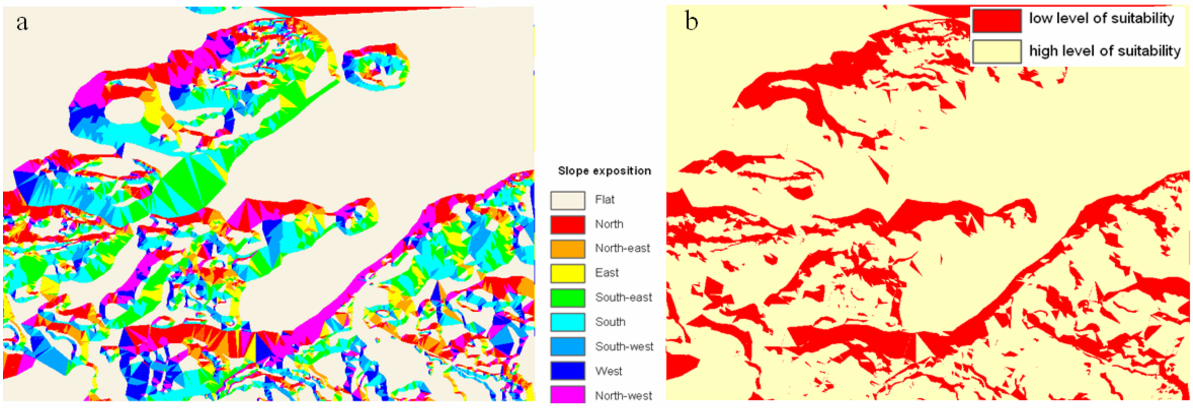

Figure 4-2: Fragment of a thematic layer "exposition of slopes" (a) and its classification on suitability for agricultural use (b)

4.3 Flow accumulation

One more important characteristic of a relief of territory from the point of view of its influence on agrarian land tenure are features of flow accumulation of water. This characteristic in a combination to the analysis of other factors is used, in particular, for the analysis of a water mode of territory, a substantiation of construction and reconstruction of a meliorative network. The layer "flow accumulation" shows movement of water in everyone cell of digital model of a relief, and also quantity of this water stream before full drying. The closed sites of dark color represent downturns of a relief in which water stands that results in oppression and destruction of agricultural crops on these sites. To more suitable territories for agricultural use sites with an average level of flow accumulation, providing optimum supply of agricultural plants by water are referred. To less suitable sites with the maximal and minimal flow accumulation (surplus or lack of a moisture for plants), and also downturns are referred (Figure 4-3).

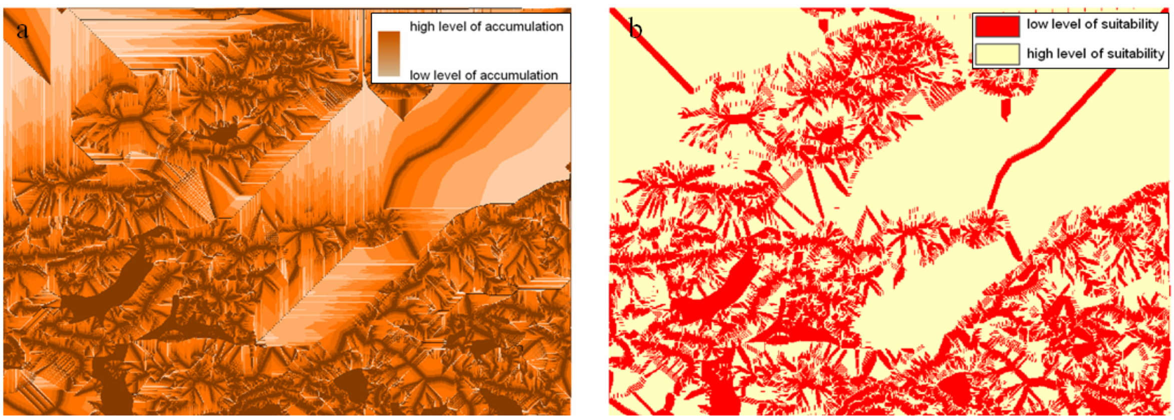

Figure 4-3: Fragment of a thematic layer "flow accumulation" (a) and its classification on suitability for agricultural use (b)

4.4 Soil data

The information on type of soil, its genesis, structure, degree of humidifying is brought in the attributive table of a theme of “soils”.

For the analysis of a soil cover of study area except for a polygonal theme of “soils” the point theme showing a spatial site of soil cuts also was created (Figure 4-4). In the attributive table of this theme the information about agro-chemical characteristics of soils is brought.

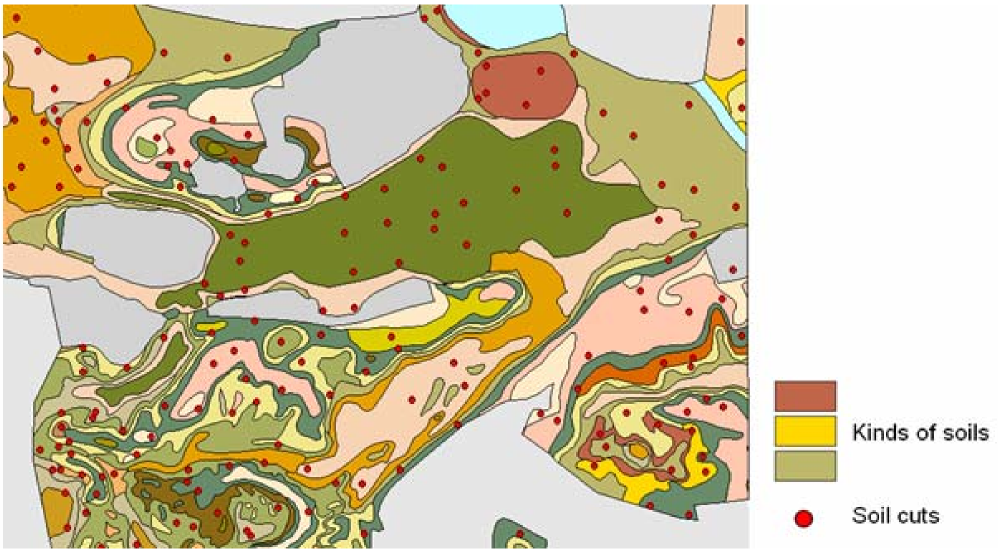

Figure 4-4: Soils and soil cuts of study area

Then these discrete values by interpolation method were automatically transformed into the grid-surfaces reflecting parameters of soils. It has allowed to refuse calculation of the average parameters and to take into account these data during overlay operations at construction of integrated layers. The similar technique of the analysis of the discrete data allows to estimate concentration (or absent-mindedness), connectivity (or randomness) of parameters.

Classification of characteristics of soils on suitability for conducting an agriculture (Figure 4-5) was carried out with use of optimum quantitative parameters of each characteristic (Smejan 1989): acidity of soil (Ph in KCl) 5,6 - 6,5; the contents of humus 2,0 - 3,2 %; contents of phosphorus 5 - 32 mg / 100 g; contents of potassium 15 - 32 mg / 100 g.

a)

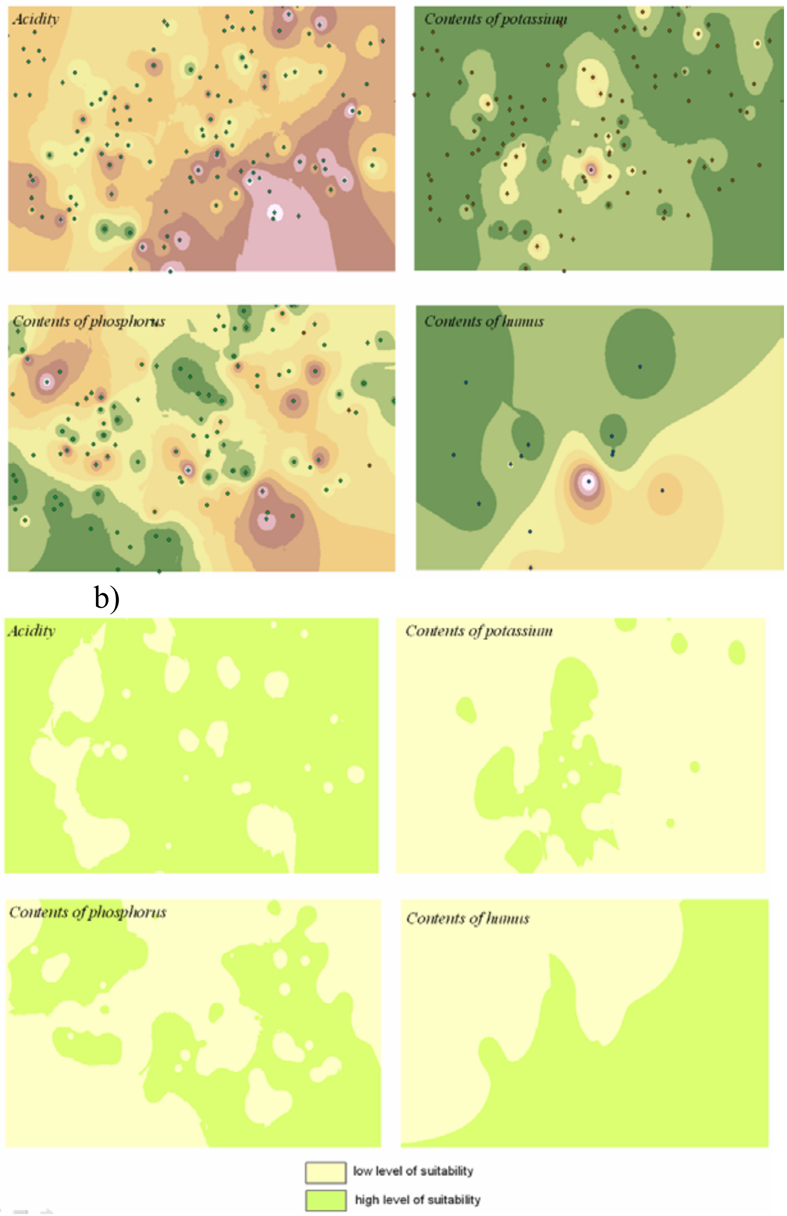

Figure 4-5: Agro-chemical parameters of soils and their classification on suitability for agricultural use

4.5 Computation of the factors weights

Saaty proposes a simple method for this task, known as averaging over normalized columns, that involves the following steps: I) calculate the sum of the values in each column of the pairwise comparison matrix; II) divide each element in the matrix by its column sum; III) compute the average of the elements in each row of the normalized matrix, that is, divide the sum by the number of factors. These averages provide an estimate of the relative weights of the factors being compared (Table 4-1).

Table 4-1 Determining the Relative Factors Weights

Step I								
Factors	SA	SE	FA	KS	Hum	Pot	Ph	Acid
Slope angle (SA)	1	2	2	0,25	0,25	2	2	2
Slope exposition (SE)	0,5	1	2	0,25	0,25	2	2	2
Flow accumulation (FA)	0,5	0,5	1	0,25	0,25	2	2	2
Kinds of soils (KS)	4	4	4	1	2	2	2	2
Contents of humus (Hum)	4	4	4	0,5	1	2	2	2
Contents of potassium (Pot)	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5
Contents of phosphoru (Ph)	0,5	0,5	0,5	0,5	0,5	2	1	0,5
Soil acidity (Acid)	0,5	0,5	0,5	0,5	0,5	2	2	1
Sum	**11,5**	**13**	**14,5**	**3,75**	**5,25**	**15**	**13,5**	**12**
Step II								
Factors	SA	SE	FA	KS	Hum	Pot	Ph	Acid
Slope angle (SA)	0,087	0,154	0,138	0,067	0,048	0,133	0,148	0,167
Slope exposition (SE)	0,043	0,077	0,138	0,067	0,048	0,133	0,148	0,167
Flow accumulation (FA)	0,043	0,038	0,069	0,067	0,048	0,133	0,148	0,167
Kinds of soils (KS)	0,348	0,308	0,276	0,267	0,381	0,133	0,148	0,167
Contents of humus (Hum)	0,348	0,308	0,276	0,133	0,190	0,133	0,148	0,167
Contents of potassium (Pot)	0,043	0,038	0,034	0,133	0,095	0,067	0,037	0,042
Contents of phosphorus (Ph)	0,043	0,038	0,034	0,133	0,095	0,133	0,074	0,042
Soil acidity (Acid)	0,043	0,038	0,034	0,133	0,095	0,133	0,148	0,083
Sum	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Step III								
Factors	**Weight**							
Slope angle (SA)	(0,087+0,154+0,138+0,067+0,048+0,133+0,148+0,167)/8 = **0,118**							
Slope exposition (SE)	(0,043+0,077+0,138+0,067+0,048+0,133+0,148+0,167)/8 = **0,103**							
Flow accumulation (FA)	(0,043+0,038+0,069+0,067+0,048+0,133+0,148+0,167)/8 = **0,089**							
Kinds of soils (KS)	(0,348+0,308+0,276+0,267+0,381+0,133+0,148+0,167)/8 = **0,253**							
Contents of humus (Hum)	(0,348+0,308+0,276+0,133+0.190+0,133+0,148+0,167)/8 = **0,213**							
Contents of potassium (Pot)	(0,043+0,038+0,034+0,133+0,095+0,067+0,037+0,042)/8 = **0,061**							
Contents of phosphorus (Ph)	(0,043+0,038+0,034+0,133+0,095+0,133+0,074+0,042)/8 = **0,074**							
Soil acidity (Acid)	(0,043+0,038+0,034+0,133+0,095+0,133+0,148+0,083)/8 = **0,089**							
Sum	**1,000**							

5. RESULTS AND DISCUSSIONS

Thus, characteristics of a relief and soils were classified according to criteria of suitability for agricultural use. Further with the help of the tool "Raster calculator" of ArcGIS v.9.2 was received the resulting layer which is taking into account all these characteristics and weights of their influence on agricultural activity.

Conditionally "optimum" model of territory received as a result of the GIS-analysis of characteristics of a relief and soils, is compared to actual spatial accommodation of

agricultural lands of study area (Figure 5-1). In the figure and in the table 5-1 sites of the lands which actual use does not correspond to a degree of their suitability are shown.
As a result of the analysis the recommendations for change of land use are produced due to transformation of the lands or substantial increase of fertility of soils (application of fertilizers, especially organic, restoration and reconstruction of a drying network etc.).

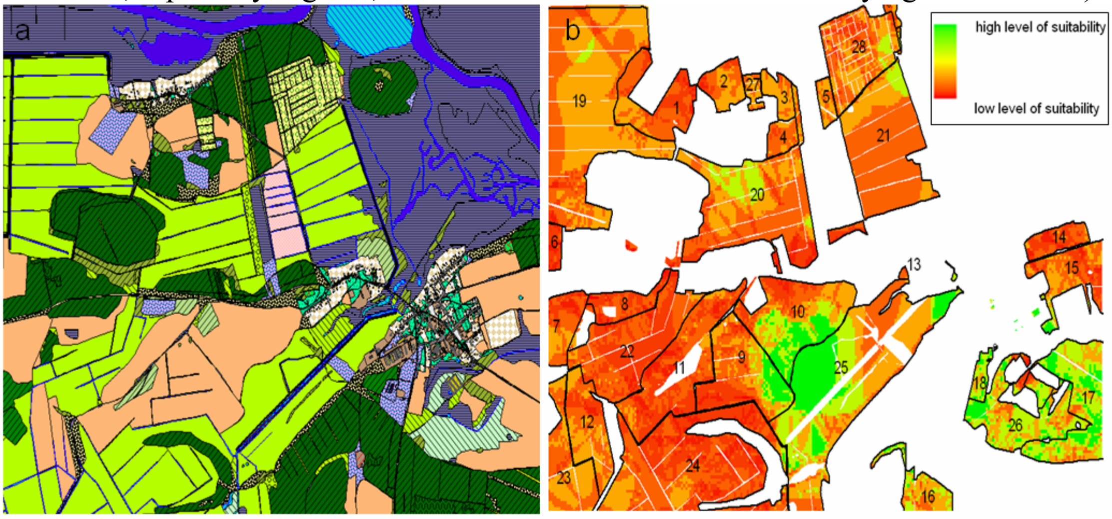

Figure 5-1: Fragment of study area: actual use of the lands (a) and "optimum" model (under landscape factors) (b)

These recommendations have conditional enough character because in the analysis only landscape factors influencing agrarian land tenure (a relief and soils) were taken into account. For their specification it is necessary to take into account requirement of the considered agricultural organization for concrete kinds of the lands and ecological consequences of offered changes.

Nevertheless, from the geographical point of view the results have the practical value consisting in the account and the analysis of landscape factors at the organization of use of the agricultural lands that allows to avoid mistakes in economic activities. Use thus of GIS-technologies effectively and quickly enables to analyse lanscape factors and to present results of the analysis in the integrated form.

Table 5-1 Comparison of a level of suitability and actual use of the lands

Number on the map*	Actual use of the lands	Level of suitability	Offers on the organization of the lands
1	Arable	Low	Translation in wood or substantial increase of fertility
2	Arable	Below average	Increase of fertilizers
4	Arable	Low	Translation in wood or increase of fertility
6	Arable	Low	Translation in wood or meadow
7	Arable	Average	Increase of fertility
8	Arable	Low	Translation in wood
9	Arable	Average	East part without changes, western translation in meadow or wood

Number on the map*	Actual use of the lands	Level of suitability	Offers on the organization of the lands
10	Arable	Above average	Northern part - translation in wood, the rest without changes
11	Arable	Low	Translation in meadow or wood
12	Arable	Average	Increase of fertility
13	Arable	Low	Translation in wood
14	Arable	Low	Translation in wood
19	Meadow	Above average	Part under arable in view of water-security zones of the rivers and channels
20	Meadow	Average	Northern part under arable
21	Meadow	Low	Northern part under long-term plants
25	Meadow	High	Under arable in view of a water-security zone of channels

*Those sites on which changes are offered are given the table only, other files of the lands remain without changes

It is very important also, that the constructed "optimum" model of the agricultural organization is not static and can vary in process of change of analyzed factors. Use GIS allows to automate this process and to carry out actualization of the information for maximum short terms.

6. CONCLUSIONS

This paper describes how GIS can help to spatial planners to optimize land tenure of the agricultural organization. With use of GIS-tools the thematic layers for all landscape factors influencing agrarian land tenure are created. Then these layers are classified according to suitability for agricultural use. The resulting layer of suitability of landscape factors which is compared to existing use of the lands is created. Further on the basis of that offers on change of land use are developed. The similar technique maximum allows to take into account all landscape conditions of concrete territory during spatial planning, optimization of land tenure, formation of ecological requirements and restrictions. It will allow to use land resources effectively and to resist degradation of the lands that is especially actual for region of the Belarusian Polesye.

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BIOGRAPHICAL NOTES

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