The Geoinformation Technology for Multicriteria Evaluation of Agricultural Lands

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Abstract

The article considers the geoinformation technology which allows to solve a set of problems associated with evaluating the condition of agricultural lands. The technology is based on the ontology of evaluating the agroeconomic capacity of lands. The technology is adjusted to parameters of a specific task. The setting is carried out by organizing the search on taxonomy of agricultural lands' indicators, developing a decisive tree and selection of weight coefficients of indicators. The development of both static and dynamic estimates of the condition of the fields is possible reflecting the condition of the main culture during vegetation.

Keywords: geoinformation technology; ontology of lands evaluation; remote sensing of Earth; Terra Modis; agricultural lands; multicriteria evaluation of lands

1. Introduction

The evaluation of the status of lands used for agricultural production is of interdisciplinary nature. It occurs in solving the issues of agro-industrial complex management organization, in crop farming, land management, economics, cadastral registration, etc. Land as the object of evaluation is a complex, hierarchical and multi-factor system.

The analysis of references [1-8] shows high variability of agricultural lands evaluation tasks and methods to solve them. All existing tasks can be divided into two classes: static and dynamic evaluation. In the first case, the goal is to provide an integrated assessment of the current state of the land based on field measurements, knowledge of the history of its use, the state of its infrastructure and other relevant factors. Depending on the peculiarities of the task, the result of solving it may be assessment of the market or cadastral value, assigning quality score, rank in the system of comparative land analysis, etc. In the second case, the goal is to obtain private rapid assessment of the vegetative cover condition or the progress of agro-technical measures. This need arises in the monitoring tasks, the results are used to make management decisions, monitor the effectiveness of measures, budget spending, prediction of crop yields, generation of reports, etc.

2. The Object of the Study

Agricultural lands as the object of the study are characterized as a complex, multi-factor object. Their condition depends on climatic factors, the characteristics of the soil and vegetative cover, infrastructure peculiarities, geospatial characteristics of the analyzed sections of the earth's surface, etc. In the scientific literature there are a lot of overlapping systems of land parameters classification essential for evaluation. Considered, reliable estimates are based on the knowledge of experts in various fields: geobotany, economy, ecology, agriculture, resulting in a complicated and costly process of decision-making support. In order to outline the experts' knowledge and present it in a formalized manner available for use, it is necessary to use the methods and means of getting, presenting, structuring and using the knowledge. The basis for a consistent presentation of information received from different sources is an ontological approach. In this paper, we consider the geoinformation technology of evaluation based on the system of ordering the knowledge of agricultural lands as the object of evaluation in the form of ontology which is invariant to the specific task.

3. Models and Methods

Approaches to the construction of the ontology of evaluation of the land agro-economic potential have been developed in the works [8,11,15]. When building the ontology, the object of evaluation is understood as a spatially localized area of the earth's surface, which is involved in the agricultural production.

The ontology of evaluation is assumed by the four parameters

$$O = < K, T, E, M > \quad (1)$$

where K is the taxonomy of land indicators, T is a set of tasks being solved, E is a set of metrics of indicators' estimation, M is a set of primary metrics that allow to calculate the numerical value of the indicator in physical terms.

The considered ontological model is based on the taxonomy K for evaluation of the agro-economic potential of lands given in Formula 2.

$$K = < N, R > \quad (2)$$

where $N=\{n_i\}$ is a set of taxonomic classes – indicators of the assessed object, $R \subset \{N \times N\}$ is the relation of the N order. The taxonomic tree root vertex corresponds to the desired integral characteristics of the object being assessed. In this version of taxonomy, the classification upper level sets six classes of indicators comprehensively describing the subject area (Fig. 1).

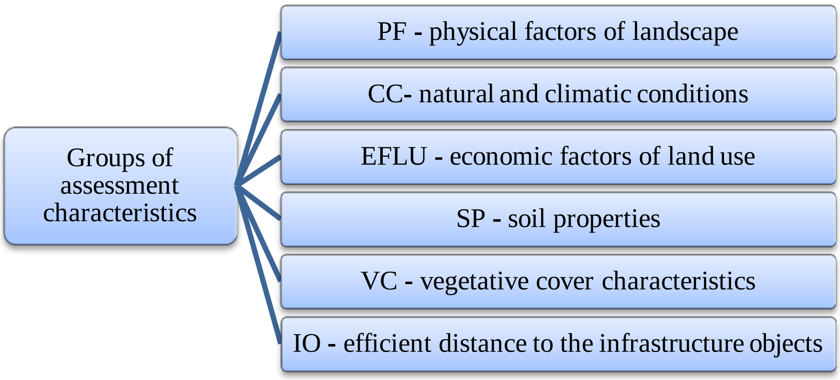

Fig. 1. Structure of the upper level of the taxonomy of the agricultural lands assessment characteristics.

Further, the descending construction of the taxonomy forms subtrees of different depths. Their verteces can be classified as follows: abstract verteces; attributed verteces.

To measure the natural parameters the ontology uses primary metrics given in (1) by the variety M. A specific metric $m_i \in M$ is a functional property put in correspondence to the relative node $n_i \in N$, for which the interval of acceptable values and the measurement unit are determined.

For the attribution based on measurements the ontology has a lot of metrics of evaluation $E_m \subset E$, also set in the form of functional properties $e_j \in E_m$ compared to the node n_j. For e_j a functional relationship is determined which allows to calculate a numerical estimate of the property n_i based on the value of the primary metric m_j. The resulting combination $<n_i, m_j, e_j> \in N \times M \times E_m$ sets the instance of the corresponding ternary relation that uniquely identifies the attribution rules on the basis of the measurement.

For attribution on the basis of aggregation the ontology has a lot of evaluation metrics $E_a \subset E$; $E = E_m \cup E_a$.; $E_m \cap E_a = \emptyset$. The specific metric ei is described by:

1) functional property relating e_i to the evaluated property n_j;

2) weighted tree of aggregation with depth 1 with the root vertex e_i and a set of vertices - evaluation metrics that are incident to the elements of the subset X of the set of attributed verteces Y of the top n_j in the taxonomy of evaluation. The weights of the tree arc characterize the degree of influence of assessment of the relevant subsidiary top on the evaluation of the root vertex;

3) calculation procedure that allows to calculate the evaluation e_i for the property n_j on the basis of aggregation of evaluation values for the nodes $x_l \in X$ and weights of the aggregation tree arcs.

The ontology components considered above give basis for constructing the evaluation tasks solution system. The tasks being solved t_j determine the set T of the tasks given in the taxonomy. The structure of describing a certain task t_i is determined as follows (Formula 3):

$$t_i = < K_i, E_i, M_i > \tag{3}$$

where $K_i \subset K$ is a subgraph of the taxonomy corresponding to the task being solved, $M_i \subset M$ is a set of primary metrics relevant to the task of evaluation, E_i is a set of evaluation metrics.

Input geospatial data

Factographic information required for calculation of E_i values includes vector and raster layers in shape format and geo-tiff. The main layer necessary for setting the task is the vector layer that contains polygons of agricultural lands to be evaluated. Geometric attributes of the layer include area, perimeter, as well as derivative properties of shape, such as the relation of area to the area of convex shell, elevation pattern etc. Other layers are selected based on the requirements defined by the task being solved and the possibility to obtain the relevant data for the territory being analyzed. Thus, the results of research of agrochemical centers are used to generate 5 layers that describe the chemical composition of soil: concentration of N, P, K, soil humus content and acidity. The practice of obtaining such data in the Russian Federation proves that the contours of land used by agrochemical centers and contours of actual agricultural lands greatly differ. Consequently, the processing of imported data includes overlay analysis and the values of field attributes are recalculated correspondingly. The attributes related to the distance from infrastructure facilities are defined using the models developed in [14]. Other metrics are used (beside Euclidean distance) that define the efficient distance based on the terrain features, road network and other factors. The terrain also has got its own significant attributes, such as altitude above the sea level, slope aspect and angle, integral estimate of elevation difference and other attributes comparable to each contour based on SRTM model analysis. The following groups of attributes are generated by operator input (for instance, in case of field measurements), analysis of meteorological information and processing of aerospace images. The latter are used as baseplates for data visualization and are utilized for calculation of index properties, such as NDVI, SAVI, PVI etc. The sources of data include open USGS archives, data of the Russian Federal Space Agency, as well as high-definition images purchased for the territory being analyzed.

Description of the Technology

The ontology discussed above acts as reference data required to solve the task. Forming and maintaining the ontology in a consistent state can be regarded as a preliminary stage providing operation of the technology. The goal of evaluation is formed in the dialogue with the end user.

1. The technology develops the assessment task. The task is developed in the dialogue with the end user. As an example, you can specify the task as "To assess the potential effectiveness of the land use for the production of grain crops"; "To carry out the ranking of fallow lands from the standpoint of expediency of their remediation". The purpose is expanded by the indication of geographical co-ordinates of the research object, the layer of agricultural lands to be assessed and additional attribute information is loaded.

2. The calculating procedure of the assessment is developed. In accordance with the basic procedure, assessment of agricultural lands equals the linear combination of the values of indicators being evaluated in accordance with Formula.

$$O(agricultural\_lands) = \sum_{i=1}^{n} l_i * f_i(agricultural\_lands) \quad (4)$$

where f_i is the value of the i-th indicator, l_i is the value of weight coefficient of this indicator, n is the amount of indicators used in the assessment.

The purpose of this stage is to develop the sequence of indicators $F=\{f_i\}$, relevant to the goal of evaluation, as well as to determine the calculation method for each $f_i \in F$. The stage is carried out in the dialogue between the user-expert and the system. Then, the indicators measurement scales (primary metrics) are determined, the metrics of the measurement result assessment is set and the calculating procedure for the conversion of the primary metrics to the metrics of evaluation is determined. The scale of measurement of the primary metrics is determined by the physical parameters of the measured value. For the metrics of evaluation scale intervals are used.

3. The expert committee is formed. The committee members are selected out of the most authoritative experts in the subject area. The elements of the "snowball" method were used to create the expert committee for the development of scoring. The coefficient of concordance was used to measure the closeness of the connection between groups of factors being ranked.

4. The system of indicators formed earlier was ranked using the methods of expert estimates. In order to collect the opinions of experts the author's questionnaire was developed. The expert survey is carried out in one round by a one-time filling out of the questionnaire. Experts are invited to determine the importance of specific factors. The experts assess the significance of versions using a ranking procedure.

5. At the fifth stage of the method, the consistency of experts' opinions is assessed in accordance with Formula 5.

$$W = \frac{s}{\frac{1}{12} m^2 (n^3 - n)} \quad (5)$$

The importance of the concordance coefficient is assessed by Pearson criterion according to Formula 6.

$$X^2 = \frac{s}{\frac{1}{12} mn(n+1)} \quad (6)$$

where n – the number of experts, m – the number of factors, S – the sum of squared sums of factor deviations. In case the relevance or significance of concordance coefficient is less than the preset threshold values, expert estimate shall be repeated by an expert committee with different members (see cl.3) or the sequence of parameters shall be adjusted (see cl.1).

6. The primary metrics and metrics of evaluation are calculated and the results of calculation of the primary metrics' fields are collected. These results are presented to the experts for evaluation according to the binary scale "Acceptable\Unacceptable". If the percentage of negative evaluations is more than 10%, then the return to the 4^{th} stage is done for re-adjustment of the weight coefficients.

7. The scheme for solving the task is generated and saved to form the version of the knowledge base.

8. The necessary calculations; the solution of the task is generated in the form of an atlas of agricultural lands, as well as in the form of tables and diagrams.

4. Results and Discussion

At the present moment a working prototype of the system has been developed using the technology considered above. The software tool for the system is free software Protégé 3.5, Quantum GIS 1.8, as well as author's software written in language C# implemented on the basis of the programming package Microsoft Visual Studio 2013.

The ontology is built on the basis of the conceptual model considered in [8]. The upper level of the taxonomy of evaluation K is set by the following classes:

- Physical factors of landscape (PF). This group consists of factors that characterize agricultural lands as a three-dimensional surface in the world coordinate system, including contours, shape factors, the height above sea level, the normalized exposure, angle of elevation, area.
- Natural and climatic conditions (CC) determine the type and the main directions of agricultural production, the choice of the best or most profitable crops for a particular area.

- Economic factors of land use (EFLU) are determined by the income received from this area, investments in the territory.
- Soil Properties (SP) influence crop yields and productivity of land plots.
- The vegetative cover (VC) - for the lands in agricultural turnover, this factor corresponds to the current crop, and is also determined by the characteristics of contamination.
- The efficient distance to infrastructure objects (IO): settlements, roads, electric power lines and other facilities that are essential for agricultural production.

To demonstrate the functioning of the system, we considered the schemes obtained in the course of solving the following tasks: 1) assessment of the potential effectiveness of the land use for the production of spring wheat (t_1), 2) determining the degree of contamination of fallow fields (t_2).

For generation of the task solution scheme t_1=<K_1,E_1,M_1>, the classification tree of evaluation features K_1 is built shown in position 1 at Fig. 2 (in blue colour). Each of the leaves of the tree is set in correspondence with the functional property $m_i \in M_1$ characterizing the numerical value, unit of measurement and acceptable range of values of the corresponding primary metrics and the functional property $e_{jm} \in E_{1m}$ determining the method for calculation of the assessment. For easy operation all functional relationships ejm show the measurable interval of the primary metrics in the range [0..1]. Analytically or table-set conversion functions are used. The figure shows schematically the corresponding slots of describing the data of the properties (in red colour). Thus, the value of the field contour and the distance to the recycling centre is inversely proportional to the value of the assessment; functions to evaluate the effect of humus content, soil acidity and field areas are given in a table. The set $E_{1a}=\{e_{1a}\}$ in the description of the task t_1 contains the only vertex that is incident to the root node of the tree K_1. The metrics is in correspondence with the weighted tree, which is shown in green colour on the Figure. Computational relation for this metrics is determined as:

$$O(e_{1a}) = \sum_{i=1}^{5} l_i \times e_{im} \qquad (7)$$

where l_i is the weight of the corresponding arc.

Basing on the generated scheme of the task t_1 description, the outlined set of land plots is ranked in accordance with the degree of applicability for spring wheat farming. The resulting information is prepared in the form of atlases of lands from the perspective of farms, as well as in the form of column charts demonstrating the rank of a specific field.

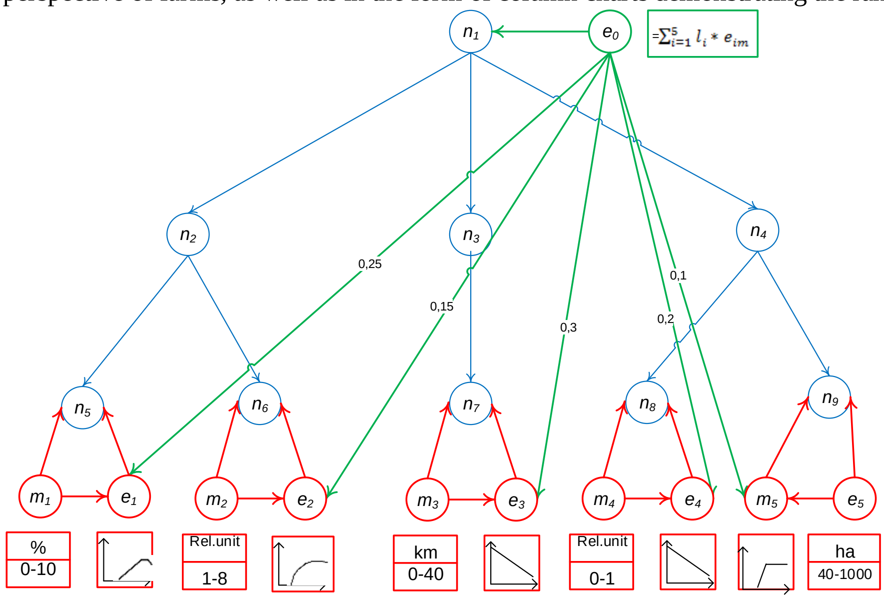

Fig. 2 Task t1. Designation: n2 - SP; n3- IO; n4 – PF; n5 – humus content; n6 – acidity; n7 – distance to the processing centre; n8– contours; n9 – area.

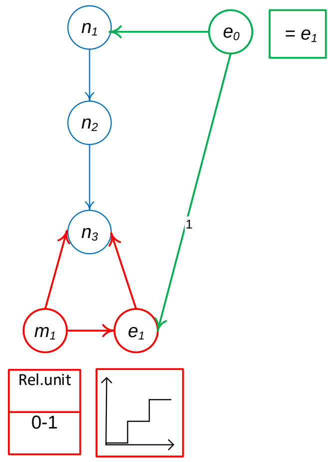

Fig. 3. Task t2. Designation: n2 - VC; n3- NDVI value.

Task-solving graph t_2 is shown in position 2 at Figure 2. 2. The scheme is based on the use of a single parameter - the NDVI index calculated by Terra Modis data. Direct application of the scheme allows to perform the integrated assessment of contamination of the fallow field by referring to one of the predefined classes: “open soil”, “field that requires treatment”, “field with a high degree of contamination”. The resulting information is prepared in the form of atlases of fallow lands from the perspective of farms, as well as, in the case of calculations for the field season - in the form of graphs of the change of the fields contamination degree in time.

5. Conclusion

The intellectual technology of agricultural lands evaluation has been developed. The technology is based on a constantly updated and adjustable system of knowledge about agricultural lands as complex, multi-factor objects. The mechanism to specify and expand the knowledge base is provided through the version control system. The developed system complements the agricultural monitoring automated system previously developed by the team, allowing to generate and store a library of schemes for solving agricultural lands evaluation tasks, including the ability of dynamical monitoring of their change during the vegetation season and support of management decision-making. The schemes for solving the tasks are generated on the basis of expert assessments and, after check-out on the significant amount of experimental data; they can be used as an objective tool by scaling to other areas that have a similar set of climatic conditions. Thus, the four-level view of information is supported: 1) the system of knowledge describing the subject area of agricultural lands assessment; 2) the scheme of the task describing the specific formulation of the task and containing declarative and procedural means to solve it; 3) the copy of the task to be solved, which is localized in the field; 4) the solution of the task localized in time.

The technology presented in the work is currently being pilot tested on solving the tasks of agricultural lands evaluation in the Sukhobuzimsky District of the Krasnoyarsk Territory on behalf of the district administration and economic entities.

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