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METHODOLOGICAL FRAMEWORK FOR DATA GENERATION IN A GIS ENVIRONMENT DURING AGRICULTURAL LAND AREA MANAGEMENT BASED ON THE LANDSCAPE APPROACH

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This article aims to identify approaches in generating cartographic and attribute information in a GIS environment in order to implement the landscape approach in land management through the example of a land use area formed based on land plots (shares). In so doing, it is important to take into account the topsoil properties and relief features of the area under land management. Research objectives include a wide range of issues: developing methods for organizing agricultural land areas using modern geographic information technology methods; creating a digital cartographic environment for the studied area with separate thematic layers of cartographic information; creating an attribute database featuring a detailed analysis of agroecological soil properties; developing thematic cartographic materials as a basis for agricultural landscape management designs; and drafting land use design plans for the studied area. To accomplish these objectives, soil grouping methods by suitability for agricultural use have been employed. Digitals software functions have been used to bind and convert raster maps into a vector-based format; a professional GIS has been used to create thematic maps and final planning documents, as well as to create an attribute database. The article describes land management methods for agricultural land areas belonging to modern agricultural enterprises in compliance with the requirements of the landscape approach to land use. It outlines the characteristics of the topsoil contouring and structure, in the context of agricultural land with due consideration for its relief. The article presents a detailed analysis of the agroecological state of the topsoil. Soil types are grouped according to their suitability for agricultural use. The article also presents data resulting from the analysis of thematic maps of the area's slopes, topsoil structure and agricultural land structure of the baseline and projected agricultural landscape. Its scientific novelty consists in developing digital data generation methods based on a comprehensive approach to the use of lands used in modern agricultural enterprises. It is proposed that the suggested approach to agricultural land area management should be implemented within land ownership and land use areas in other regions in Ukraine.

Key words: geographic information systems; land management; thematic maps; attribute data; data generation.

Introduction

GIS-aided decision-making in the field of cartography and land management is not limited to mastering the software functions and their application; it is essential to define approaches to establishing a conceptual and theoretical framework for land resource management and consolidating mapping principles, approaches to creating an attribute data system, ways to display information spatially, data sampling, and data range processing methods. In this context, it is important to take into account attribute information quality, as well as the correlation between map attributes and physical data [Brown et al., 2015]. Through the analysis of international literary sources addressing current topical issues pertaining to GIS data generation principles it has been established that the quality of cartographic and attribute data is indicative of the effectiveness of land management planning [Brown et al., 2015; Tayyebi et al, 2014]. Developing geographical maps on a global scale is becoming necessary for successful land resource management [Han et al, 2015]. Scientists emphasize the importance of mapping ecosystem quality indicators for concerted actions across all agencies in the various spheres of the country's economy. Such indicators include vegetative cover, soil fertility, and availability of recreational areas [Brown, 2014; Jacobs, 2015].

When organizing digital data for agricultural land management, it is essential to take into account the natural environment of the agricultural landscape. Maintaining profitable operation through variety, dynamism, and adaptivity to local conditions is an approach put forward by such classical agricultural scientists of the 19th and 20th centuries as O. O. Izmayilskiy, V. V. Dokuchayev, and V. R. Williams. Stable landscapes can be formed based on a thorough study of the natural environment in the area [Kashtanov et al., 1994; Kiryushin, 1996] and due consideration of the agroecological properties of the soils [Kanash, 2002; Tarariko et al., 2003]. Domestic scientists emphasize in their works the necessity to lay down the theoretical foundations of the ecological and economic landscape classification of the arable land capability, as well as the importance of land use typing which involves land resource allocation based on environmental and economic factors [Tretiak et al., 2007]. Of great importance is the idea of introducing basic GIS and applied systems into practical use in every agency associated with land resource use [Balakirskii et al., 2014].

During land management operations on the European continent and in Asian countries, scientists give preference to monitoring the use of lands that are distant from or close to urbanized areas. In this context, particular prominence is accorded to certain issues of economic nature, farmers' refusal to cultivate low-fertility areas, monitoring land use near big cities, land resource management aimed at maintaining environmental safety in view of the increasing urbanization rate, and deforestation [La Rosa et al., 2014; Liu et al., 2015; Petrisor et al., 2014]. Scientists propose using an "integrated environmental importance assessment index for regional space" for geographic information system data generation. Such areas include river basins, wetlands, nature reserves, parks, and scenic sites [Pagella et al., 2014; Xie et al., 2015]. To calculate another index, the "integrated soil quality index", foreign scientists use a general set of GIS data for the following indicators: pH, electrical conductivity, organic matter, cation exchange capacity, equivalent CaCO3 content, heavy metal (Cd, Co, Pb, Cr) content, and soil erodibility factor [Su et al., 2014]. A number of scientists related the problem of agroecological soil deterioration to intensive land use and climate change; they also stress the need to create watershed area models using a GIS [Elhakeem et al., 2018]. International scholars have proposed a methodology for assessing erosion class by using the vegetative cover factor. This factor can be regulated through land management in agricultural areas. The latter is viewed as a tool for developing land use scenarios within the European Union and identifying priority areas for GIS data generation [Panagos et al., 2015].

Aim

The objective of the studies is to identify the areas of and approaches to data generation in a GIS environment during agricultural land management based on the landscape approach.

Methodology

The conducted studies are based on the *analysis* of the current state of agricultural landscapes, and the *adaptation* of land use to agroecological soil groups according to their suitability for use as agricultural lands.

To analyse the current state of the studied area, the following cartographic materials have been generated in the Mapinfo Professional environment: cartograms of parent materials, topsoil structure and agricultural land structure, a slope cartogram with the gradation adopted for contour-ameliorative area arrangement, and a cartogram of soil waterlogging intensity. The cartographic source materials have been obtained by digitizing raster maps and their binding in the *Digitals* application. In particular, the *Topotracer* module was used to digitize contour lines. Attribute information tables have been compiled for all spatial objects.

Land use *adaptation* to soil and environmental conditions has been accomplished by applying geographic overlay methods to cartographic source materials with due consideration for the methods of grouping soils according to their suitability for use.

Results

Since the theoretical framework for sustainable land use is centred around operating agricultural ecosystems based on bioenergetic relationships typical of natural environments, the studies have been based on the landscape approach. Its nature lies in reclaiming land resources by optimizing agricultural land use through reducing their tilling intensity resulting from limited intensive use of environmentally vulnerable lands and conservation of low-yield and heavily waterlogged areas.

The study has been conducted within land use area formed from land plots (shares) located within the jurisdiction of Velyka Khaicha village council in Ovruch District, Zhytomyr Oblast, which lies on the Slovechansk-Ovruch Ridge, where eroded and waterlogged land plots are located side by side.

In order to analyse the natural properties of the studied area, first, a cartogram of the spatial distribution of parent materials was created and an attribute table has been compiled consisting of the following columns: parent material, granulometric composition, chemical composition, groundwater depth. It has thereby been established that parent materials are represented by diluvial and glaciofluvial deposits, as well as ravine diluvium, with groundwater depths between 0.8 and 1.5 m, and, in places, over 4 m. Moraine occasionally underly glaciofluvial deposits. On elevations covering a significant area, parent materials are represented by loess loams, with groundwater depth of over 10 m. Diluvial deposits and ravine diluvium represent the second most frequent type of parent material. A much smaller area is occupied by glaciofluvial deposits. Thus, on the greater part of the agricultural landscape, parent materials are potentially suitable for the formation of relatively fertile soils. They have a low silica content and are enriched with nutrients (calcium, magnesium, potassium) and alkaline-earth elements. They have a light loamy granulometric composition. The downside of such materials is their low erosion resistance and high susceptibility to denudation and water erosion. Parent materials on the remaining area are markedly different from the above. They include ungraded arenaceous, argilloarenaceous, and sandy loam materials. The sandy fraction content varies from 60.8 to 86.8 %. The silty fraction content is insignificant (1.7 %). They are characterized by high water permeability, low water retaining capacity, and low water raising capacity. Because of their high thermal conductivity, they can heat and cool easily. Their chemical composition is dominated by silica (97 %). Their nutrient content is very low (K_2O – 0.33 %, P_2O_5 – 0.008 %). Soils forming on such materials are very low in fertility.

The area's relief has been described on the basis of the digital topographic map, with the elevation of each contour line indicated in the attribute table. A thematic map – a Slope Cartogram – has been created based on the relief map of the studied area.

The area's relief, which is attributable to its location in the northwestern part of the Ukrainian Crystalline Shield, is a lowland with absolute elevations of approximately 200 m. Steep slopes and loess materials, which are susceptible to erosion, result in deep widely branching gullies and ravines. In addition, slopes abound in rills and small active gullies. This situation is typical for the northern and central sections of the studied area (Fig. 1), which has a pronounced mesorelief. Slope sections with varying steepness, length and exposure are located in close proximity to each other. This part of the studied area contains sections with slopes varying from 0^o to 11^o. Ravines are also common features in this area. They are also widely branching and, not infrequently, join together to form isolated water divides. Slope angles decrease and slope lengths increase mainly to the southeast.

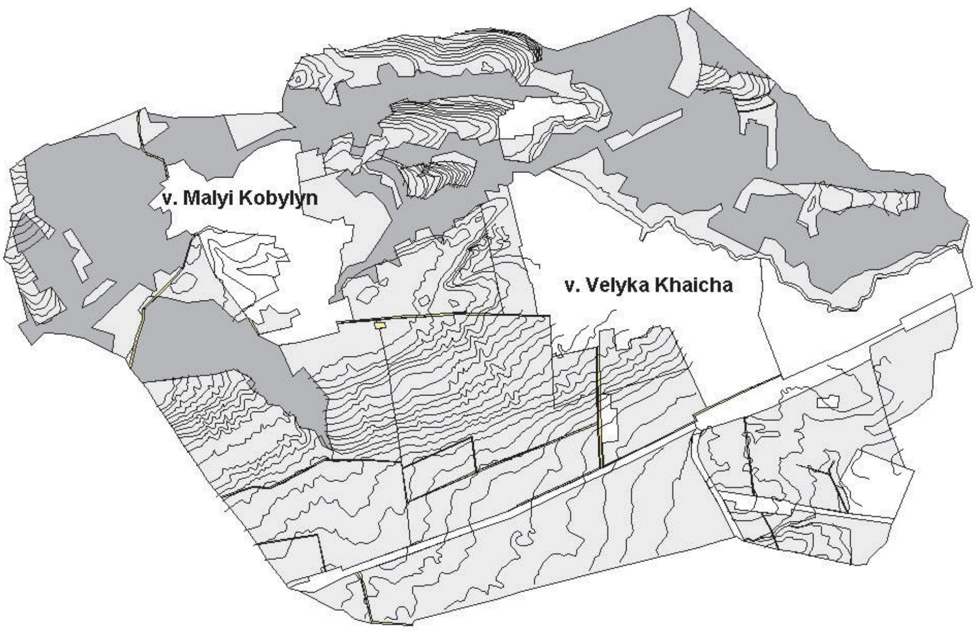

Fig. 1. Schematic map of the area's relief

The southern section of the land use area is an undulating outwash plain characterized by insignificant altitude variations and well-developed microrelief represented by numerous shallow closed depressions, most commonly basins and hollows. They vary in shape and size, and are often waterlogged. The presence of saucerlike depressions on plainland creates the necessary conditions for the formation of small-contour topsoil.

Thus, the relief in the northern and central sections of the studied area is erosion-risky and differs markedly from the southern waterlogged section. The diverse relief and moisture conditions associated therewith, as well as the heterogeneity of the chemical and granulometric composition of the soil materials and a significant variety of plant formations, have contributed to the formation of a varied topsoil. 18 soil varieties located on 169 contours of different size and configuration have been identified within its boundaries. Contours with an area of up to 5 ha predominate (92 contours); almost half of them have an area of less than 1 ha. There are only 5 large soil contours (over 50 ha).

On the whole, topsoil structure is extremely varied, with complex boundaries and soil contour configurations (Fig. 2). Geographic information system tools make decision-making about using each soil contour and designing agricultural land boundaries significantly easier.

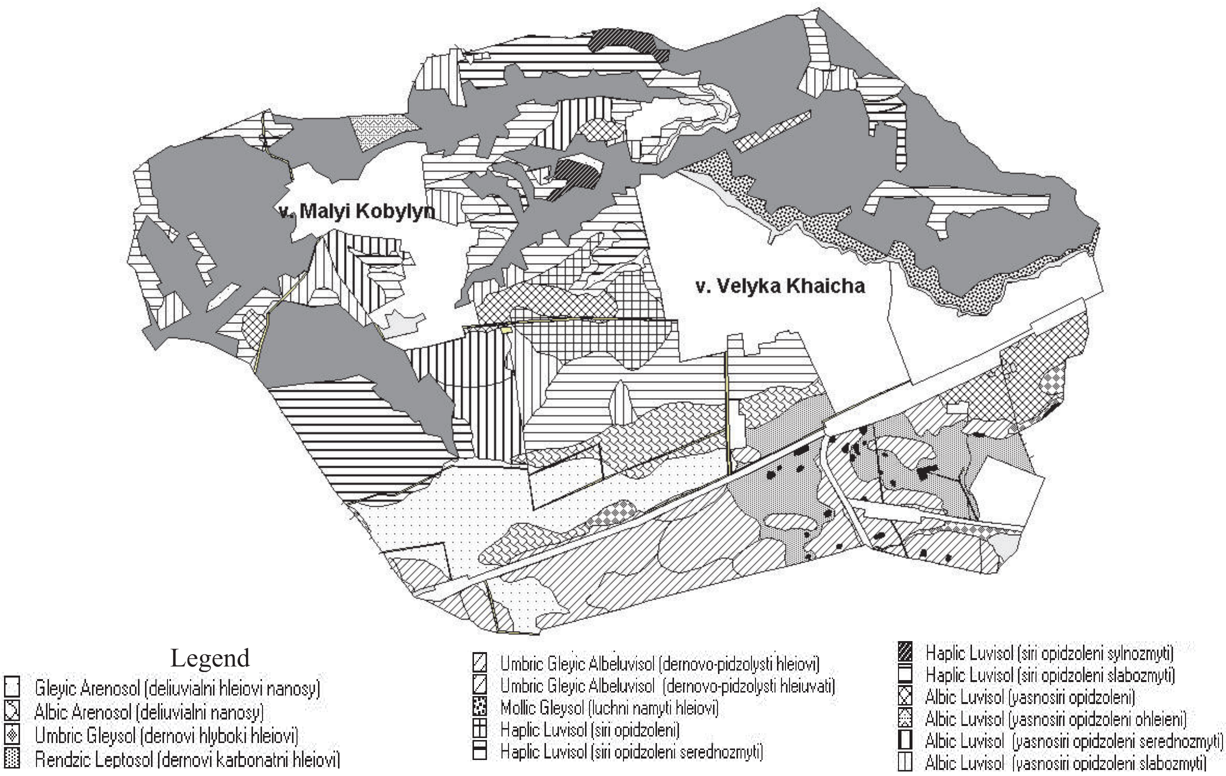

Fig. 2. Topsoil structure

The most common soil types are classified as grey podzolised soils. Their total area is 948.9 ha (54 %), of which grey podzolised coarse-silt light-loamy soils make up 65 %, whereas light-grey podzolised coarse-silt light-loamy soils make up 35 %. They have formed on loess loams. The total area of diluvial sediments is 298.0 ha (17 %). They include sandy light-loamy diluvial sediments (30 %) and diluvial calcareous gley coarse-silt light-loamy deposits (70 %). Diluvial sediments with a sandy light-loamy granulometric composition have formed between water-dividing depressions on slope aprons. Diluvial calcareous gley sediments have formed on diluvial deposits and ravine diluvium on sections with groundwater depths between 0.8 and 1.2 m. Soils formed on diluvial deposits also include soddy calcareous gley, and meadow cumulic calcareous gley soils. They are found on shallow wide depressions, in the river valley and on the bottoms of gully-like formations with groundwater depths between 1.0 and 1.5 m. They account for 12 % of the total agricultural land. Soddy-podzolic sandy loam soils are located in the southern section of the land use area on depressions. They have formed on glaciofluvial deposits underlain with moraine at depths of 1.0 to 2.0 m and account for 16 % of the total area of agricultural land. The shallow location of moraine, which is poorly permeable and viscous when wet, creates favourable conditions for the gley process of humification. Therefore, gley types of soddy-podzolic soils are prevalent in this section of the area.

Table 1

Soil Type by Slope Steepness on Arable Land

Slope	Soil	Area (ha)
1–3°	Light-grey podzolised mildly truncated and untruncated	243.0
	Grey podzolised mildly truncated and untruncated	484.0
	Light-grey podzolised pseudogleyed	11.5
Total		738.5
3–5°	Light-grey podzolised moderately truncated	47.6
	Grey podzolised moderately truncated	42.2
Total		89.8
5–7°	Light-grey podzolised moderately truncated compounded highly truncated	31.8
	Grey podzolised moderately truncated compounded highly truncated	71.1
Total		102.9
>7°	Grey podzolised highly truncated	17.7
Total		948.9

Table 2

Land Suitability for Use

The Suitability Soil Groups	Area (ha)
for all crops	261.4
for all crops conditional on cross-slope cultivation	555.3
for close-growing crops	89.8
lands on slopes requiring grassland restoration	102.9
forestry purposes	17.7
haymaking purposes	412.7
pasture purposes	298.0
Total	1737.8

Bog and peat-bog soils are found in small patches (from 0.1 to 1.1 ha) in saucerlike depressions in water divides and on near-terrace sections of floodplains with groundwater depths between 0.3 and 1.0 m; they form complexes with soddy and soddy-podzolic gley soils.

The database of attribute information pertaining to the soil cartogram contains the following data for each soil contour: contour number, soil type, its granulometric composition, parent material, groundwater level, humus content, nutrient content, acidity, agricultural use.

Thus, analysis of the cartographic source information results in a parent material cartogram, a soil cartogram, a topographic map, and thematic slope and waterlogging intensity maps.

Based on the findings of spatial and attribute data comparison, a land use design plan, which takes into account the suitability of each soil contour for agricultural use and its soil erosion class or waterlogging intensity, has been drafted. In addition, summary tables have been compiled to describe the current land use (Table 1) and the projected state of the area (Tables 2 and 3).

Table 3

Agricultural Land Structure

Agricultural Land	Baseline		Projected	
	ha	%	ha	%
Arable land	1430.4	82	906.5	52
Hayfields	69.3	4	412.7	24
Pastures	238.1	14	298.0	17
Grassland restoration on slopes	–	–	102.9	6
Reforestation	–	–	17.7	1

The process of digital data generation in a GIS environment applied to agricultural land management in the studied area included the following steps:

1. Review and detailed analysis of the physical features of the agricultural landscape area.
2. Mapping the spatial distribution of parent materials, vegetative cover, relief, soils, and agricultural land.
3. Generating attribute data: granulometric composition, gleization extent, erosion class, soil acidity, groundwater level.
4. Creating thematic maps (cartograms) representing slopes and waterlogging intensity.
5. Comparing the resulting spatial and attribute data, applying cartographic overlay methods. Mapping a cartogram of land suitability for agricultural use and a land area arrangement plan based thereon.

Scientific novelty

This study is the first to base GIS data generation on the correspondence of the spatial location of soil types, with due consideration for their natural properties and erosion class, to the structural elements of the agricultural landscape.

The study presents the rationale for the spatial allocation of agricultural lands within appropriate agroecological soil groups.

Practical significance

Practical significance lies in the applicability of the methodological approaches outlined in the article to the following:

− creating environmentally stable agricultural landscapes in any region within Ukraine, or elsewhere, which significantly slows soil degradation and increases soil fertility;

− developing land consolidation projects, which take into account land mass integrity in order to maintain agricultural landscapes in satisfactory ecological condition and increase agricultural productivity;

− developing regional land use and conservation programmes, land management projects for agricultural enterprises, as well as feasibility studies pertaining to the use of lands belonging to administrative divisions.

Conclusions

While generating digital cartographic and attribute data pertaining to agricultural land management within the jurisdiction of Velyka Khaicha village council, an algorithm has been followed which involved using lands in accordance with their agroecological state. In particular, soil degradation degree and waterlogging intensity have been taken into account. It is proposed to use mildly truncated and untruncated soil types located on slopes discriminately in accordance with the contour-ameliorative area arrangement methods. Waterlogged and boggy sections are allocated for fodder-producing lands with due consideration for the extent of soil gleization and their granulometric composition. Hayfields are arranged on diluvial sediments, calcareous gley light-loamy, soddy deep calcareous gley light-loamy, and meadow cumulic calcareous gley light-loamy soils. Soils with a lighter granulometric composition (soddy-podzolic gley sandy loam soils, soddy deep calcareous gley sandy light-loamy soils) are used as pastures. Before generating projected boundaries between agricultural lands, a cartographic framework has been created, and attribute tables, based on a thorough study of the natural environment in the land use area, have been compiled. Thus, when developing approaches to creating a database of attribute and spatial data, due consideration has been given to the requirements of compliance with the principles of environmental protection, sustainable development, and efficient land resource management in agricultural landscape area management.

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МЕТОДОЛОГІЧНІ ОСНОВИ ФОРМУВАННЯ ДАНИХ У СЕРЕДОВИЩІ ГІС ДЛЯ ВПОРЯДКУВАННЯ ТЕРИТОРІЇ СІЛЬСЬКОГОСПОДАРСЬКИХ УГІДЬ НА ОСНОВІ ЛАНДШАФТНОГО ПІДХОДУ

Метою статті є виявлення підходів до формування картографічної та атрибутивної інформації в програмному середовищі ГІС з ціллю впровадження ландшафтного методу для землеустрою на прикладі землекористування, сформованого на основі земельних часток (паїв). Важливим при цьому є врахування особливостей ґрунтового покриву та рельєфу території, що впорядковується. Завдання досліджень містить широке коло питань: розроблення методології організації території сільськогосподарських угідь з використанням сучасних методів геоінформаційних технологій; створення цифрового картографічного середовища на досліджувану територію з виділенням тематичних шарів картографічної інформації; формування бази атрибутивних даних, що відображає детальний аналіз агроекологічних властивостей ґрунтів; розроблення тематичних картографічних матеріалів, які є основою для проектних рішень щодо землеустрою агроландшафту; креслення проектних планів використання земель досліджуваної території. Для виконання завдань використано методику групування ґрунтів за придатністю під сільськогосподарські угіддя. Прив’язку та переведення растрових планів у векторний формат здійснено за допомогою функцій програми Digitals, створення тематичних карт та остаточних планових матеріалів, а також, формування бази атрибутивних даних виконано за допомогою професійної ГІС. Подано основи методології землевпорядкування території сільськогосподарських угідь сучасних агроформувань, які враховують вимоги ландшафтного підходу до використання земель. Наведено характеристику контурності та структури ґрунтового покриву в розрізі сільськогосподарських угідь з урахуванням рельєфу. Виконано детальний аналіз агроекологічного стану ґрунтового покриву. Ґрунтові відміни згруповано відповідно до придатності для використання під сільськогосподарські угіддя. Також подано дані, отримані на основі аналізу тематичних карт ухилів території, структури ґрунтового покриву та структури угідь вихідного та проектного стану агроландшафту. **Наукова новизна** полягає у розробленні методів формування цифрових даних на основі комплексного підходу до використання земель, які є у користуванні сучасних агроформувань. Запропонований підхід до землеустрою території сільськогосподарських угідь можна упроваджувати в межах землеволодінь та землекористувань інших регіонів України.

Ключові слова: геоінформаційні системи; землеустрій; тематичні карти; атрибутивні дані; формування даних.

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