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Soil information system of the Ukrainian Carpathians

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Abstract. The theoretical aspects and practical approaches to the creation of a soil information system on the example of the Ukrainian Carpathians, which is based on the use of vectorised large-scale soil mapping materials and GIS tools, are considered. The study is devoted to the development of a soil information system for the Ukrainian Carpathians, which integrates vectorised large-scale soil maps and GIS technologies to ensure efficient collection, storage and monitoring of soil data. The scientific novelty of the work is the creation of a multi-level information platform that combines data of different granularity and allows monitoring of soil transects, profiles, and genetic horizons, as well as determining spatial relationships between point and polygonal objects. Particular attention was paid to collecting cartographic materials reflecting the soil cover of the Ukrainian Carpathians and formalising the data for further integration into the soil information system. The system supports analytical tools that allow calculating various geometric, physical and chemical parameters of soil objects. The use of modern GIS tools enables accurate monitoring and forecasting of changes in soil cover under the influence of natural and anthropogenic factors, making it an important tool for the rational management of soil resources in the Carpathians. The developed system allows storing and updating information, which ensures its adaptability to changes in data analysis and processing methods. This not only increases the efficiency of monitoring, but also ensures the flexibility of the system for the specific needs of users. The practical significance lies in the possibility of using this system for soil protection, sustainable land management, and environmental safety. Expansion of this system to the entire territory of Ukraine will provide additional opportunities for effective monitoring and forecasting of changes in soil cover on a national scale, contributing to sustainable development and environmental protection.
Key words: soil information systems; Ukrainian Carpathians; remote sensing; soil database.

Ґрунтова інформаційна система Українських Карпат

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Анотація. Розглянуто теоретичні аспекти та практичні підходи створення ґрунтової інформаційної системи на прикладі Українських Карпат, яка базується на використанні векторизованих великомасштабних ґрунтово-картографічних матеріалів та ГІС-інструментів. Дослідження присвячене розробці ґрунтової інформаційної системи для Українських Карпат, яка інтегрує векторизовані великомасштабні ґрунтові карти та ГІС-технології для забезпечення ефективного збору, зберігання і моніторингу ґрунтових даних. Наукова новизна роботи полягає у створенні багаторівневої інформаційної

платформи, яка об'єднує дані різної деталізації, та дає змогу контролювати ґрунтові розрізи, профілі й генетичні горизонти, а також визначати просторові зв'язки між точковими та полігональними об'єктами. Особливу увагу приділено збору картографічних матеріалів, що відображають ґрунтовий покрив Українських Карпат, та формалізації даних для подальшої інтеграції у ґрунтову інформаційну систему. Система підтримує аналітичні інструменти, які дають змогу обчислювати різноманітні геометричні та фізико-хімічні показники ґрунтових об'єктів. Використання сучасних ГІС-інструментів сприяє точному моніторингу та прогнозуванню змін ґрунтового покриву під впливом природних і антропогенних факторів, що робить її важливим інструментом для раціонального управління ґрунтовими ресурсами Карпат. Розроблена система дає змогу зберігати й оновлювати інформацію, що забезпечує її адаптивність до змін у методах аналізу та обробки даних. Це не лише підвищує ефективність моніторингу, але й забезпечує гнучкість системи для специфічних потреб користувачів. Практична значущість полягає у можливості використання зазначеної системи для цілей охорони ґрунтів, сталого управління земельними ресурсами та забезпечення екологічної безпеки. Розширення цієї системи на територію всієї України відкриє додаткові можливості для ефективного моніторингу та прогнозування змін ґрунтового покриву в масштабах держави, сприяючи сталому розвитку та екологічному захисту.
Ключові слова: ґрунтові інформаційні системи; Українські Карпати; дистанційне зондування Землі; ґрунтова база даних.

Introduction. The development of soil information systems is becoming increasingly important due to the need for effective land management, especially in environmentally sensitive and strategically important regions such as the Carpathians. The soil cover of the Ukrainian Carpathians is highly diverse, due to the complex topography, climatic conditions and anthropogenic impact. This makes the Carpathians particularly susceptible to degradation processes, including erosion, loss of fertility and pollution. At the same time, the availability of up-to-date and detailed information on soil conditions in this region is critical to ensuring their sustainable use.

The relevance of this work is due to the urgent need to create a systematic soil information system of the Ukrainian Carpathians that would combine geospatial, agrochemical and environmental data for further monitoring and management of land resources. The novelty of the study lies in the integration of multi-level information on soil resources of the Ukrainian Carpathians using modern GIS technologies and the creation of a platform that will be useful for scientists, managers and land users alike.

The purpose of the study is to develop a soil information system for the Ukrainian Carpathians that will allow analysing and monitoring soil dynamics and promote sustainable land management.

The object of the study is the soil cover of the Ukrainian Carpathians, and the subject is information technologies, methods and data used for modelling and monitoring of soil cover in the Carpathian region.

The theoretical basis of the research is the work of domestic and foreign soil scientists in the field of accumulation and formalisation of regional soil data: V. G. Gaskevych, I. M. Gogolev, G. V. Dobrovolsky, G. S. Ivaniuk, O. P. Kanash, M. G. Keith, A. A. Kirilchuk, I. A. Krupenikov, V. V. Medvedev, Z. P. Pankiv, I. Y. Papish, S. P. Pozniak, O. G. Telehuz and others, as well as in the development and functioning of information systems, including soil systems: K. D. Glinka, R. Dudal, V. A. Kovda, K. Omuto, D. Papadakis, I. V. Plisko, T. N. Laktionova, S. A. Balyuk, M. M. Miroshnychenko, P. Sanchez, V. F. Sytnyk, P. Tempel and others.

Research methodology. The study used comprehensive methods of collecting, processing and analysing soil data from the Ukrainian Carpathians. The basis for the creation of the soil information system was the integration of field research data, geoinformation technologies and modern mapping methods.

The first stage of the study was the collection and systematisation of primary data, which included information on soil cover, agrochemical characteristics, geological features and the ecological state of the territory. At the next stage, GIS technologies (ArcGIS, QGIS) were used to create digital mapping models for individual research areas, which allowed us to visualise and spatially analyse the collected data within certain key areas. To analyse the dynamics of land cover changes, remote sensing methods were used, including satellite imagery and aerial photography (Batjes, et al., 2007). This made it possible to identify and map degradation processes such as erosion, podzolisation and soil pollution.

The results were integrated into a soil information system that will allow for spatial analysis and monitoring of soil conditions (Hrytsunov, 2010). This approach provides a multi-level analysis of the state of soil resources, which is the basis for making effective decisions on the sustainable use of land in the Carpathian region.

Results. The empirical basis of the study is based on the results obtained over the past 20 years at the Department of Soil Science and Soil Geography of the Ivan Franko National University of Lviv, as well as experimental data collected as part of research projects implemented in the region. Particular attention was paid to the collection of cartographic materials reflecting the soil resources of the Ukrainian Carpathians, as well as the integration of data from the State Land Cadastre of Ukraine.

The creation of a soil information system for the Ukrainian Carpathians involves the use of modern information technologies to organise and analyse data on soils and land cover. The main stages of the work included formalisation of data, which enables them to be processed using geographic information systems (GIS). The process of formalisation involves the transformation of metric and substantive properties of soil objects into a digital form that allows data to be stored and analysed interactively (Jones, 2014).

An analysis of modern soil information systems such as SOTER and CanSIS allowed to identify best practices for the development of a soil information system for the Carpathian region (Tempel, 2002). The use of technologies that integrate spatial and attribute data has created a platform for predicting land cover changes, monitoring degradation processes and assessing the region's resources (Sytnyk, et al., 2001). The results demonstrate the system's potential to support sustainable land development and rational land use.

The methodology for creating a soil information system for the Ukrainian Carpathians is based on the leading approaches of modern reference soil systems. The first stage includes information and cartographic processing of spatial data using GIS methods, which allows formalising the data obtained for further analysis and storage.

At the initial stage, spatial and substantive geodata are used to localise objects, determine their geographical coordinates and convert them into digital form. This process includes data vectorisation and creation of topological models of spatial objects. In the field, data collection is supported by GPS technologies, laser scanning and aerial photography using drones (Zhu, et al., 2001).

The second stage focuses on cartographic coding, a process that reflects the geographical characteristics of objects through a system of symbols. The final stage involves analytical manipulation of GIS layers to obtain new spatial and temporal information, which allows to preserve data integrity when creating derived map layers with different spatial criteria (Omuto, et al., 2013).

Within this system, soil and other thematic data are organised into a database based on a DBMS, which ensures their creation, maintenance and modification to solve a range of soil science tasks (Fig. 1).

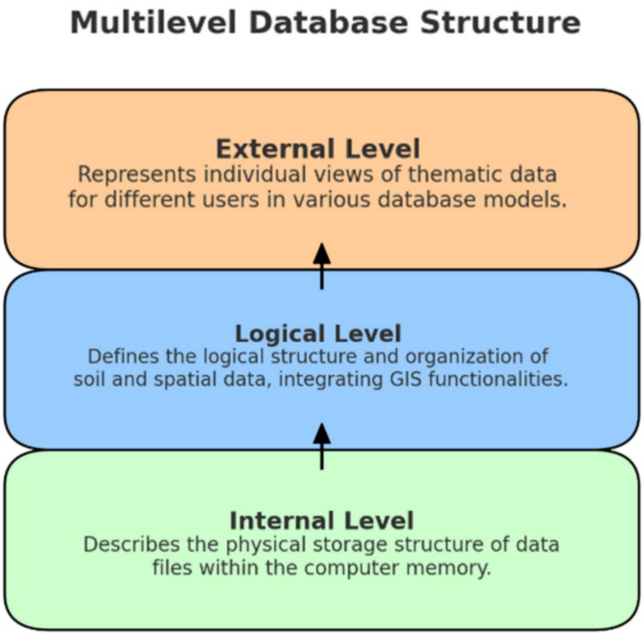


Fig. 1. Multi-level structure of the database (Omuto, 2013)

The internal level of a soil database is closely related to the physical representation of data in computer memory and determines the structure of files in which data is stored. The need to display the spatial properties of soil objects represented graphically in the GIS environment, as well as the use of soil mapping and other thematic materials as primary sources of information, determine the choice of the vector model of data representation as the main one for the development of soil databases in GIS (Arctur, et al., 2004; Frank, 1988).

The vector model proves to be effective both at the stages of data collection and storage, and in performing various spatial analytical tasks in GIS. In addition, the use of remote sensing data often requires the use of raster models, which, when combined with vector data, form a vector-raster representation (Boone, et al., 2008). This allows for the joint use of vector layers and raster data, which is particularly useful for automated creation and updating of soil maps and the creation of derived thematic maps, such as erosion maps (Kurilov, et al., 2014).

Practice shows that in soil information systems, the most commonly used approaches to organising geospatial data are layer-based and object-mapping. The layer-based principle allows to efficiently operate with groups of objects grouped in one layer by common features (object semantics, attributes, quantitative and qualitative characteristics) (McBratney, et al., 2003). This approach combines semantically heterogeneous data available in thematic mapping sources into a single GIS model.

The object-mapping approach ensures the organisation of positional data by grouping them in different thematic layers, while the semantic and attribute characteristics of objects are stored separately in the attribute database, which serves as the attribute component of the system. The unification of conceptual representations of semantically heterogeneous data in the database structure is based on the content of maps and their legends, which provides a comprehensive display of the hierarchy and diversity of objects (Sester, et al., 2003).

The layered nature of the object-mapping model gives the database structure flexibility, allowing you to add new map layers and establish relationships between objects in attribute tables. It also allows you to change the classification of objects by making adjustments only to the relationships in the attribute tables, without changing the basic structure of the classifier.

To ensure efficient storage and processing of information, soil data in the information system is organised according to the hierarchy principle, where each level of the model performs a specific function in reflecting real geographical and soil processes. In particular, the data structure provides for the possibility of integrating different types of information: spatial, attribute, semantic, which together allows for more accurate forecasts and analyses.

In addition, at each level of the model, an important aspect is the ability to interact with other information systems or agronomic or environmental databases, which allows for the combination of different data sources for a comprehensive analysis of the state of the soil cover. For example, analysing changes in soil properties over time can be important for determining the effectiveness of agricultural practices or for monitoring environmental changes.

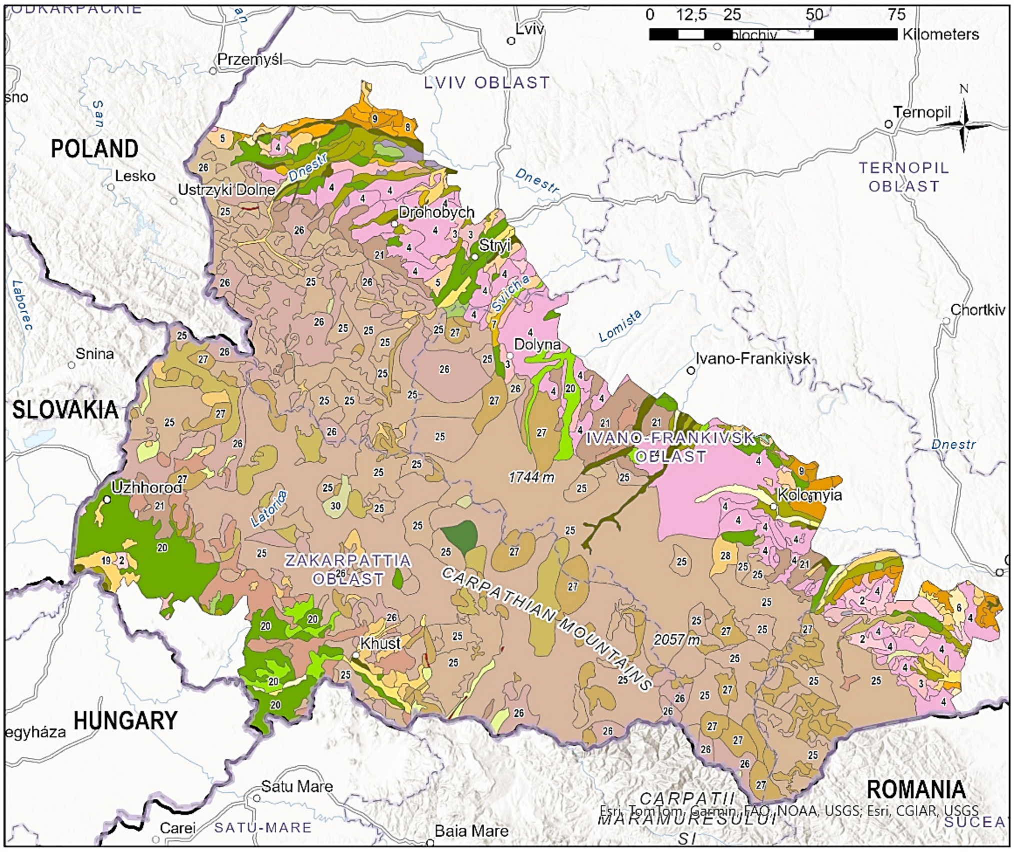
In addition, the logical model of the soil information system allows for easy integration with other types of spatial data, such as climate data, which can be useful for studying the impact of climate change on soil characteristics. With the help of such integration approaches, it is possible to predict changes in soil structure, identify risks of erosion or pollution, and take the necessary measures in a timely manner.

The layers on which the system is built also allow for effective data management at various stages of its use - from collection and analysis to storage and archiving. The database interface supports the necessary functions for displaying various options and scenarios, which allows working with large amounts of data while maintaining ease of access and processing (Van Engelen, et al., 2005).

In general, the principles of soil information systems facilitate the creation of high-precision models for research and monitoring of the soil cover, as well as the efficient use of data in agronomy, ecology, agriculture and other industries that depend on the condition of soils and soil cover.

According to this conceptual scheme, the highest hierarchical level of the soil information system is a separate soil unit, the definition of which depends on the scale of the survey and the detail of soil research. This can be an elementary soil area, but there can also be separate taxonomic units of a higher rank, which depends on the scale of soil mapping. In our case, as the base layer of the soil information system, we used a

1:200,000-scale vector soil map digitised from large-scale soil surveys conducted by the Ukrzemproekt Institute in 1966-1967 (Fig. 2).



Soil Legend (WRB)

1	Albic Arenosols (Ochric)	11	Gleyic Chernozems (Pachic)	20	Fluvic Gleyic Phaeozems Albic
2	Albic Retisols (Arenic)	12	Gleyic Chernic Phaeozems (Pachic), Gleyic Fluvisols (Humic)	30	Dystric Gleyic Fluvisols
3	Albic Gleyic Retisols (Arenic)	13	Mollic Gleysols (Humic), Gleyic Fluvisols (Humic)	21	Neocambic Gleyic Retisols
4	Stagnic Retisols	14	Histic Gleysols, Gleyic Histic Fluvisols	25	Dystric Cambisols
5	Plaggic Retisols (Arenic)	15	Gleysols	26	Dystric Cambisols
7	Haplic Luvisols	16	Histic Gleysols	27	Cambic Umbrisols
8	Luvic Greyzemic Phaeozems	17	Histosols	28	Cambic Umbrisols Albic
9	Greyzemic Phaeozems	18	Arenosols (Ochric)	29	Cambic Gleyic Umbrisols
10	Haplic Chernozems	19	Fluvisols	30	Dystric Gleyic Fluvisols

Fig. 2. Soil map of the Ukrainian Carpathians at a scale of 1:200,000 (based on large-scale soil surveys conducted by the Ukrzemproekt Institute in 1966-1967)

The number of vectorised soil contours is 776, and according to the map legend, 37 soil classification units are distinguished. In addition, an attribute database was created that contains the name of the soil according to the Ukrainian classification, the name of the soil according to the WRB 2014 classification (WRB, 2014), the area of the soil contour (in hectares), selected soil characteristics of the upper soil horizon, in particular: the upper horizon index, two indicators of physical and chemical properties (Fig. 3).

FID	Shape *	OBJECTID	Merge	name	name_wbr	index	pHkcl	humus
0	Polygon	1	1	Дерново-прихованопідзолисті	Albic Arenosols (Ochric)	HE	3,9	1,2
1	Polygon	2	2	Дерново-слабо- та середньо-підзолис	Albic Retisols (Arenic)	HE	3,9	1,4
2	Polygon	3	3	Дерново-підзолисті глейові	Albic Gleyic Retisols (Arenic)	HEgl	4,1	0,9
3	Polygon	4	4	Дерново-підзолисті поверхнево-оглеє	Stagnic Retisols	HEgl	4,5	1,2
4	Polygon	5	5	Підзолисто-дернові	Plaggic Retisols (Arenic)	HE	6,5	1,9
5	Polygon	6	6	Ясно-сірі лісові, в т.ч. оглеєні	Albic Luvisols, Albic Gleyic Lu	HE	3,9	1,9
6	Polygon	7	7	Сірі лісові, в т.ч. оглеєні	Haplic Luvisols, Gleyic Luvisol	He	3,9	2,8
7	Polygon	8	8	Темно-сірі опідзолені, в т.ч. оглеєні	Luvic Greyzemic Phaeozems,	He	6,5	2,8
8	Polygon	9	9	Чорноземи опідзолені, в т.ч. оглеєні	Greyzemic Phaeozems, Greyz	He	6,7	3,1
9	Polygon	10	10	Чорноземи типові малогумусні	Haplic Chernozems	H	6,4	3,2
10	Polygon	11	11	Лучно-чорноземні	Gleyic Chernozems (Pachic)	H	6,3	5,6
11	Polygon	12	12	Лучні та алювіальні лучні	Gleyic Chernic Phaeozems (P	H	6,1	4,1
12	Polygon	13	13	Лучні глейові	Mollic Gleysols (Humic)	Hgl	7,3	3,4
13	Polygon	14	14	Лучно-болотні	Histic Gleysols	Hgl	6,2	4,3
14	Polygon	15	15	Болотні та алювіальні болотні	Gleysols, Gleyic Histic Fluvisol	Hgl	6,2	7,3
15	Polygon	16	16	Торфувато- та торфово-болотні	Histic Gleysols	THk	7,5	0
16	Polygon	17	17	Торфовища низинні	Histosols	Th	7,4	0
17	Polygon	18	18	Дернові піщані та зв'язно-піщані, в т.ч.	Arenosols (Ochric), Gleyic Are	H	6,1	1,3
18	Polygon	19	19	Дернові та алювіальні дернові супіща	Fluvic Arenosols (Ochric); Flu	H	6,1	1,4
19	Polygon	20	20	Дернові опідзолені оглеєні	Fluvic Gleyic Phaeozems (Albi	He	5,4	4,8
20	Polygon	21	21	Буроземно-підзолисті оглеєні	Neocambic Gleyic Retisols	HEgl	2,7	3,6
21	Polygon	22	22	Чорноземи карбонатні	Skeletic Calcic Chernozems	Hk	0	5,7
22	Polygon	23	23	Лучні карбонатні	Gleyic Rendzic Phaeozems	Hk	0	5,8
23	Polygon	24	24	Рендзини	Rendzic Leptosols	Hk	7,5	4,6
24	Polygon	25	25	Буроземи гірсько-лісові, в т. ч. оглеєні	Dystric Cambisols, Dystric Gle	H	3,3	2,1
25	Polygon	26	26	Буроземи гірсько-лісові опідзолені, в т	Dystric Cambisols, Dystric Gle	H	3,3	2,1
26	Polygon	27	27	Дерново-буроземні, в т.ч. оглеєні	Cambic Umbrisols, Cambic Gl	H	5,3	4,3
27	Polygon	28	28	Дерново-буроземні опідзолені	Cambic Umbrisols (Albic)	He	5,1	3,3
28	Polygon	29	29	Дерново-буроземні опідзолені глейові	Cambic Gleyic Umbrisols	He	5	3

Fig. 3. Fragment of attribute data of soil contours of the map with a scale accuracy of 1:200,000

The limited number of specified soil properties for soil contours vectorised at a scale accuracy of 1:200,000 is due to the fact that the developed information system provides a detailed description of all soil properties at lower hierarchical levels, and therefore it is possible to extrapolate additional data to a higher hierarchical level.

At the highest level of the developed regional information system, a set of thematic vector and raster data has also been created, which is used for various applied tasks, namely: vector layers of natural and agricultural zoning, soil and geographical zoning, hydrological and transport network, and a raster layer of land cover. These thematic layers are necessary for preliminary determination of the location of soil objects in the geographical and thematic space.

The next level involves the use of large-scale soil mapping materials, which are mostly stored on paper and require vectorisation with subsequent entry into the soil information system.

The advantages of using vector soil mapping materials with a scale accuracy of 1:10,000 are as follows:

- the possibility of updating soil mapping materials, primarily by supplementing them with new information (e.g., clarifying existing soil boundaries, soil composition, etc.);
- the possibility of systematising information in the created soil information system, namely, effective ordering and editing of quantitative and qualitative information;

- performing spatial data analysis using GIS tools, modelling, including the creation of three-dimensional soil map models for a more visual perception of information;
- the need to use existing soil maps to produce map versions of the soil cover as a basic component for repeated soil mapping surveys;
- the ability to quickly display tabular information in graphical form (creation of various thematic soil maps, graphs, etc.);
- the possibility of a fairly simple process of transitioning the scaling of electronic maps, which was a complex process with paper samples;
- the ability to change the mapping projections of the surface display depending on the needs (for example, to create soil maps of different territories, countries, etc.);
- wide access of users to the necessary information through computer network sources.

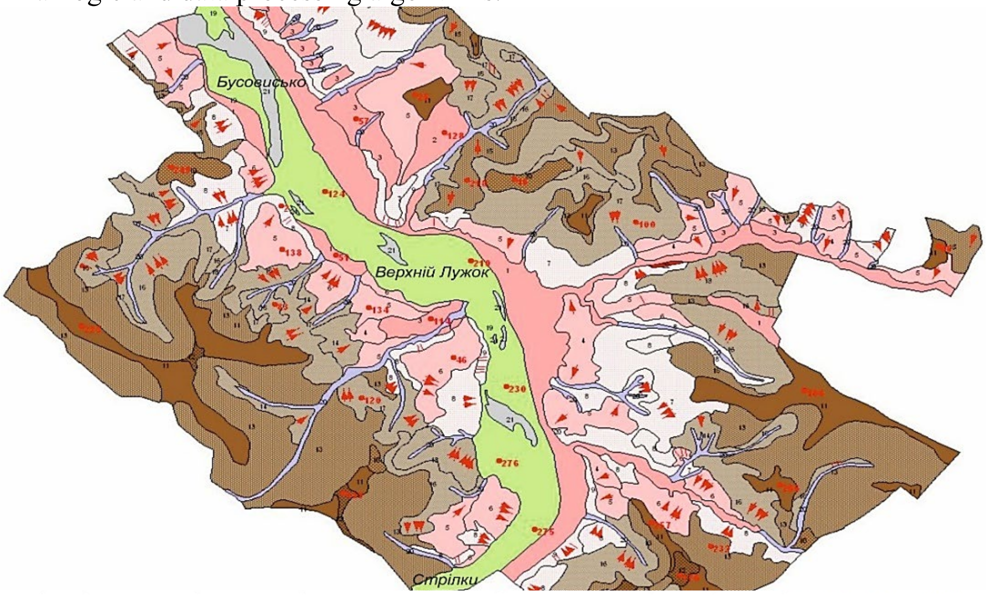
A set of soil maps at a scale of 1:10,000 within the Ukrainian Carpathians, which are available in the database of the information system, was vectorised. As input data, we used cartographic materials from large-scale soil surveys conducted by the Ukrzemproekt Institute, regional branches of the Land Management Institute, and Research Laboratory No. 50 of the Ivan Franko National University of Lviv (Fig. 4).

In total, more than 11,000 soil contours were vectorised, covering all background soils in the region, with a total area of vectorised soil data of almost 44,000 hectares. In addition, an attribute database was created that contains the name of the soil according to the Ukrainian classification, the name of the soil according to the WRB classification (WRB, 2014), the area of the soil contour (in hectares), particle size distribution, soil-forming and underlying rocks, the number of the agro group and the bonus score.

The limited number of soil indicators for soil contours vectorised at a scale accuracy of 1:10,000 is due to the fact that the developed information system provides a detailed description of all soil properties at the profile level, and therefore it is possible to extrapolate additional data to higher hierarchical levels (Pankiv, et al., 2020).

The use of vectorised large-scale soil mapping materials is important for ensuring control over the data entered at the next hierarchical level, in particular for describing soil transects, soil profiles and soil genetic horizons. Thanks to the use of modern GIS tools, it is possible not only to automate the extraction of semantic information from available polygonal data, but also to calculate the relative spatial location of point (e.g., profiles) and polygonal objects (soil contours, natural zones, etc.), which allows, for example, to perform parameter averaging within a geometric polygon (Schelling, 1975). This greatly improves the efficiency of soil characteristics analysis and allows for more accurate forecasts.

At the next level of the developed information system – the level of soil transects – a unified database of soil resources in the region is formed through the inventory and formalisation of soil information with the selection of representative transects and consideration of factors of soil cover differentiation. This stage is still under development and requires further testing and filling with data to cover the entire region. The developed system allows storing and processing a large amount of soil data, creating links between soil indicators and objects that form the soil body using formal logic and data processing algorithms.



Soil ID	Area	The name of soil	Granulometric composotion	The degree of erosion	Soil creative rocks	№ of agro-group	The score point of bonity	Correction of the classification of soils of Ukraine	
								WRB	FAO
1	167.87	Sod-brownzems	slightly clayey	---------------------------	modern alluvium	185г	20	Umbrisols Haplic	Combisols Dystric
2	15.36	Sod-brownzems terraced	slightly clayey	---------------------------	elluvium-delluvium of the Carpathian Fleesh	192г	16	Umbrisols Haplic	Combisols Dystric
3	49.88	Sod-brownzems	slightly clayey	with spots of weakly washed (10-30%)	elluvium-delluvium of the Carpathian Fleesh	192г	16	Umbrisols Haplic	Combisols Dystric
4	37.00	Sod-brownzems	slightly clayey	with spots of weakly washed (30-50%)	elluvium-delluvium of the Carpathian Fleesh	194г	13	Umbrisols Haplic	Combisols Dystric
5	177.26	Sod-brownzems	slightly clayey	weakly washed	elluvium-delluvium of the Carpathian Fleesh	194г	13	Umbrisols Haplic	Combisols Dystric
6	94.74	Sod-brownzems	slightly clayey	weakly washed with spots of mean washed (10-30%)	elluvium-delluvium of the Carpathian Fleesh	194г	13	Umbrisols Haplic	Combisols Dystric
7	87.58	Sod-brownzems	slightly clayey	weakly washed with spots of mean washed (30-50%)	elluvium-delluvium of the Carpathian Fleesh	199г	3	Umbrisols Haplic	Combisols Dystric
8	175.75	Sod-brownzems	slightly clayey	mean washed	elluvium-delluvium of the Carpathian Fleesh	199г	3	Umbrisols Haplic	Combisols Dystric
9	62.51	Sod-brownzems	slightly clayey	weakly washed with spots of heavily washed (10-30%)	elluvium-delluvium of the Carpathian Fleesh	199г	3	Umbrisols Haplic	Combisols Dystric
10	22.93	Brownzems shallon	slightly clayey	---------------------------	elluvium-delluvium of the Carpathian Fleesh	198г	11	Combisols Dystric	Combisols Dystric
11	133.70	Brownzems mean deep	slightly clayey	---------------------------	elluvium-delluvium of the Carpathian Fleesh	190г	13	Combisols Dystric	Combisols Dystric
12	9.90	Brownzems deep	slightly clayey	---------------------------	elluvium-delluvium of the Carpathian Fleesh	190г	13	Combisols Dystric	Combisols Dystric
13	417.34	Sod-brownzems	slightly clayey	with spots of weakly washed (10-30%)	elluvium-delluvium of the Carpathian Fleesh	190г	13	Combisols Dystric	Combisols Dystric
14	45.86	Sod-brownzems	slightly clayey	with spots of weakly washed (30-50%)	elluvium-delluvium of the Carpathian Fleesh	194г	13	Combisols Dystric	Combisols Dystric
15	92.32	Sod-brownzems	slightly clayey	weakly washed	elluvium-delluvium of the Carpathian Fleesh	194г	13	Combisols Dystric	Combisols Dystric
16	196.54	Sod-brownzems	slightly clayey	weakly washed with spots of mean washed (10-30%)	elluvium-delluvium of the Carpathian Fleesh	194г	13	Combisols Dystric	Combisols Dystric
17	126.82	Sod-brownzems	slightly clayey	mean washed	elluvium-delluvium of the Carpathian Fleesh	199г	3	Combisols Dystric	Combisols Dystric
18	80.82	Sod-brownzems	slightly clayey	weakly washed with spots of heavily washed (10-30%)	elluvium-delluvium of the Carpathian Fleesh	189г	3	Combisols Dystric	Combisols Dystric
19	211.76	Meadow-brownzems	slightly clayey	---------------------------	modern alluvium	186г	7	------------------	------------------
20	75.27	Washed and washed off soils	-------------------	---------------------------	elluvium-delluvium of the Carpathian Fleesh	218	2	------------------	------------------
21	31.02	Boulders	-------------------	---------------------------	---------------------------	219	2	------------------	------------------
22	0.66	Root rocks outcrops	-------------------	---------------------------	elluvium-delluvium of the Carpathian Fleesh	218	2	------------------	------------------

Figure 4. A fragment of a vectorised soil map with legend in scale accuracy of 1:10,000 within the Strilky territorial community (territory of Busovsko-Verkhniy Luzhok-Strilky villages) in Lviv Oblast

The flexibility and openness of the developed soil information system of the Ukrainian Carpathians allow for a full description of soil transects as they existed on paper, while maintaining logical connections between soil indicators and objects. An important advantage is the openness of the software, the ability to personalise the interface, save data processing algorithms and obtain new information in case of changes in the set of indexed indicators. This makes it possible to solve the important task of accounting for soil information and combining data on various topics, using digital soil maps and materials from large-scale soil surveys of the region as a basis, which significantly improves the quality of monitoring and management of soil resources.

Conclusions. The development and implementation of a soil information system for the Ukrainian Carpathians will allow for effective monitoring of soil conditions, collection and processing of large volumes of soil data, integrating various types of information – from cartographic materials to characteristics of soil profiles and horizons. The use of vectorised large-scale soil mapping materials and GIS tools to analyse spatial relationships between point and polygonal objects significantly improves the accuracy and efficiency of soil cover monitoring. The system allows you to store all semantic and logical relationships between soil indicators and objects in a digital format, which guarantees the integrity and reliability of the data and provides flexibility in adapting to changes. It is open and personalised, which allows it to be adapted to the specific needs of users and ensures that information is constantly updated and supplemented.

The scientific and practical significance of research in the field of soil information systems lies in the creation of integrated models that allow storing, processing and analysing various geospatial data related to soil properties, their changes and interaction with other natural processes. These systems allow for the integration of various types of data, including geometric, topological, semantic and attribute characteristics of soil objects, which ensures accurate and efficient forecasting of changes in the soil cover under the influence of both anthropogenic and natural factors. From a practical point of view, such research is of great importance for optimising agricultural technologies, managing land resources, monitoring soil conditions and combating soil erosion, degradation and pollution, as well as developing effective strategies for environmental protection and sustainable development. In addition, the integration of soil data with other information systems, such as climate and environmental databases, allows for a more detailed and scientifically based approach to planning and monitoring changes in natural ecosystems, which is an important tool for decision-making in the field of natural resources and environmental protection.

Prospects for further research include filling the database of the soil information system with thematic multi-level and multi-scale data, in particular for the Ukrainian Carpathians, as well as expanding this database to cover the entire territory of Ukraine. This will allow for a more detailed and accurate analysis of soil resources at the national level, taking into account regional peculiarities, and will help improve land management, forecast changes in soil cover, and develop effective environmental protection strategies throughout the country.

REFERENCES

Architecture of modern GIS based on geospatial data bases. *Bulletin of Geodesy and Cartography*. 2011. № 5. Pp. 45–50 (in Ukrainian).

Arctur, D., Zeiler, M., 2004. Designing Geodatabases: case studies in GIS data modelling. ESRI, Inc.

Batjes, N. H., 2008. Mapping soil carbon stocks of Central Africa using SOTER. *Geoderma* 146. Pp. 58–65.

Batjes, N. H., Al-Adamat, R., Bhattacharyya, T., Bernoux, M., 2007. Preparation of consistent soil datasets for SOC modelling purposes: secondary SOTER datasets for four case study areas. *Agriculture, Ecosystems and Environment.* 122. Pp. 26–34.

Batjes, N. H., 1996. A qualitative assessment of water erosion risk using the 1:5 M SOTER database for Northern Argentina, Southeastern Brazil and Uruguay. Working Paper and Preprint 96/0. Wageningen: ISRIC. 18 p.

Boone, J. E., Gordon-Larsen, P., Stewart, J. D., Popkin, B. M., 2008. Validation of a GIS facilities database: quantification and implications of error. *Annals of epidemiology*, 18(5). Pp. 371–377.

Frank, A. U., 1988. Requirements for a database management system for a GIS. *Photogramm. Eng. Remote Sens.* 54(11), Pp. 1557–1564.

Hrytsunov, O. V., 2010. Information systems and technologies: a textbook. Kharkiv National Academy of Municipal Economy. Kharkiv. 222 p. (In Ukrainian).

Jones, C. B., 2014. Geographical in formation systems and computer cartography. Routledge.

Karpenko, S. G., Popov, V. V., Tarnavsky, Y. A., Shportiuk, G. A., 2004. Information systems and technologies: a textbook for students of higher educational institutions. Kyiv: IAPM, 192 p. (In Ukrainian).

Kurilov, V. I., 2014. GIS and spatial databases in soil mapping. Man and the environment. *Problems of neoecology.* № 3-4. P. 63–67. (In Ukrainian).

McBratney, A. B., Mendonça Santos, M. L., Minasny, B., 2003. On digital soil mapping. *Geoderma* 117, 3–52.

Omuto, C., Nachtergaele, F., Rojas, R.V., 2013. State of the art report on global and regional soil information: Where are we? Where to go? *Global Soil Partnership Technical Report*. FAO, Rome. 70 p.

Pankiv, Z., Malyk, S., Yamelynets, T., 2019. Diagnostic criteria for lessivage of profile-differentiated soils of the Precarpathian region (Ukraine). *Die Bodenkultur: Journal of Land Management, Food and Environment.* Volume 70, Issue 4. P. 189–207 https://doi.org/10.2478/boku-2019-0018.

Pankiv, Z., Yamelynets, T., 2020. Ferrum concretions forms in the mollic gley soils of Low (Male) Polissya. *Polish Journal of Soil Science.* 53(1). P. 137–149. doi:http://dx.doi.org/10.17951/pjss.2020.53.1.137

Pankiv, Z., Malyk, S. and Yamelynets, T., 2020. Soil-forming processes in profile textural-differentiated forest soils of the Cis-Carpathian region, Ukraine. *Baltic Forestry* 26(2): article id 472. https://doi.org/10.46490/BF472

Pankiv, Z., Kalynych, O., Yamelynets, T., 2020. Concretionary pedofeatures of profile-differentiated soils of the Beskydy Pre-Carpathian region (Ukraine). *AgroLife Sci. J.* Vol. 9, No. 2, 206–211.

Schelling, J., 1975. The role of soil information systems. In Soil Information systems. Wageningen: Pudoc. P. 13–16.

Sester, M., Butenuth, M., Gösseln, G. V., Heipke, C., Klopp, S., Lipeck, U., Mantel, D., 2003. New methods for semantic and geometric integration of geoscientific data sets with ATKIS-applied to geo-objects from geology and soil science. *Geotechnologien Science Report.* Part 2. P. 51–62.

Sytnyk, V. F, Pysarevska, T. A, Yeremina, N. V, Kraeva, O. S., 2001. Fundamentals of information systems: a textbook / edited by VF Sytnyk. 2nd edition, revised and supplemented. Kyiv: KNEU, 420 p. (In Ukrainian).

SOTER [Electronic resource]. URL: https://esdac.jrc.ec.europa.eu (03.02.2024).

Tempel, P., 2002. SOTER – Global and National Soils and Terra in Digital Databases. Database Structure v3. *Working paper N.* 02/01. 93 p.

Van Engelen, V. W. P., Batjes, N. H., Dijkshoorn, K., Huting, J., 2005. Harmonised Global Soil Resources Database (Final Report). Report 2005/06. Wageningen: FAO and ISRIC–World Soil Information. 53 p.

World reference base for soil resources. Rome: IUSS, ISRIC, FAO. 2014. 133 p.

Zhu, A. X., Hudson, B., Burt, J., Lubich, K., Simonson, D., 2001. Soil mapping using GIS, expert knowledge, and fuzzy logic. *Soil Science Society of America Journal,* 65(5), 1463–1472.

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