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SOLVING EXISTING PROBLEMS WITH SOIL MAPS IN UKRAINE

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The current situation with soil cartographic information is considered and it is shown that it is urgently needed to update it in accordance with modern requirements. Analysis of the current situation makes it possible to identify 2 main ways to overcome such a crisis, which together with their advantages and disadvantages. The first way — involves a repeated large-scale soil survey based on innovative scientific and methodological approaches using ground–based surveys, unmanned aerial vehicles and remote sensing of the Earth. However, it has such significant shortcomings as high time and labor costs, the corresponding economic ones, which is relevant for the state budget, and given the lack of sufficient professional staffing, such a path looks not quite realizable in the short term. Based on the analysis of the current political and economic state of Ukraine, it is proposed to use the second possible path, the essence of which is to correct existing soil maps on the basis of archival materials and build on their basis predictive mathematical models of soil cover, including for locations with missing data. Among its positive aspects, we note the use of new low–budget scientific and methodological methods for modeling cartographic soil materials, low time and labor costs, the possibility of using remote sensing data to refine the contours. There are also certain negative aspects that are carefully analyzed and, in particular, concern the access to scanned original archival soil maps and technical reports, as well as the desirability of minimum field expeditions to verify the corrected maps. A step–by–step algorithm for solving such a global problem within Ukraine is proposed. The proposed approach will allow creating a modern soil science GIS with the most adapted set of data, which will be convenient to use, scalable and dynamically supplemented. This will also become a prerequisite for the creation of a national database of soil data and its integration with minimal rearrangements and subsequent development within the future functioning version of the National Geospatial Data Infrastructure. It also adapts it to the maximum extent possible with international similar systems SOTER, SOVEUR and the like. Taking into account the announced start of work in this direction and the detected range of problems, it is necessary to involve the soil science community. Given the scale of such a project and the cost of modern software, special attention should be paid to free free software under the free GNU GPL license: Debian, GRASS GIS, Quantum GIS, SAGA GIS, R-Statistic etc, which allows you to perform the full range of proposed activities in a closed loop.

Key words: soil map, cartogram of agro-industrial groups of soils, training data set, simulation, morphometric parameters, DEM, predicative algorithms.

Introduction. Consideration of the situation regarding the relevance of large-scale soil mapping materials in Ukraine (Polchyna et al., 2004; Achasov et al. 2015; Cherlinka, 2017a) shows that there will be no quick solution to existing problems in the near future. Nearly a quarter of the country's territory (in particular, the mountainous systems of the Carpathians and the Crimea, plain-covered areas of forest vegetation, the prevailing number of settlements, etc.) have never been covered by continuous ground-based surveying. In modern economic conditions, it is not worthwhile to expect to allocate funds for actualization of existing materials and to study white spots. Similar problems exist not only in Ukraine or in a number of other developing countries, but also in countries such as Australia (Bui and Moran, 2003).

Prospects for soil science mapping are the scientific and thorough georectification of existing (created by large-scale mapping) a set of soil maps, their correct digitization and subsequent correction using modern means: DEM analysis, the application of remote sensing data (Achasov and Bydolax, 2008; Achasov, 2009; Achasov and Achasova, 2011; Achasov, 2012; Achasov et al., 2015; Truskaveczkyj, 2006; Truskaveczkyj et al., 2017), modeling of different species (Cherlinka, 2017a, d, Cherlinka, 2017). ; Cherlinka, 2017b; Horácek et al., 2018), creating a three-dimensional map of soil landscapes. Proceeding from the fact that paper maps will have limited use, and work will go to the GIS plane, their scanning, geo-rectification and digitization require high-level performers.

Therefore, due to the current tendency towards changes in the land market, it is expedient to reveal the peculiarities of using previously created cartographic materials in contemporary conditions with the use of geoinformation technologies. This applies in particular to digital terrain models, the location of which in the national structure of geospatial data is currently being announced, and methods for forecasting a soil situation, the use of which should be considered as a transitional stage to the urgently needed of the modern large-scale soil survey.

Ukrainian realities, despite the growing role of remote sensing of the Earth and photogrammetric methods for the creation of DEM in the world, do not leave the choice of scientists and practitioners, forcing large-scale topographic maps to be used as the main source for modelling of relief. Long experience points to a number of problematic issues with a topographic basis (Cherlinka and Dmytruk, 2014). As an example, let us point out the problems of constructing a solid, high-density coating of DEM for large areas, in which the cross-linking of fragments of large-scale DEMs used.

In the presence of the adopted Concept of the draft Law of Ukraine "On the National Infrastructure of Geospatial Data" (On approval of the Concept of the Law of Ukraine, 2007), its next approval (KMU, 2018) and the lack of the law itself (About the national infrastructure of geospatial data, 2009) during the years, the functioning of the modern geoinformation environment is constrained. Accordingly, such an important structural element of the basic set of geospatial data as a digital elevation model is not developed at the state level, as is the case in the leading countries of the world. Accordingly, a whole series of modern technological solutions, which are developed in various fields (soil science, cadastre, land management, etc.), is not implemented due to the lack of the basis - large-scale digital models of relief. Announced only pilot projects for the development of geospatial data structures (Derzhgeokadastr Ukrayny. Yaponska agendya mizhnarodnoyi spivprati (JICA), 2015).

The presented final version of the prototype of the National Geospatial Data Infrastructure in Ukraine (Derzhgeokadastr Ukrayny, 2018b) is the only mapping ground on which the basic and profile data groups on coordinates, the boundaries of the administrative-territorial system, hydrographic objects, settlements and road network, industrial, agricultural and socio-cultural objects, highways, railways, land in the specified territory should be consolidated (Derzhgeokadastr Ukrayny, 2018a).

However, a detailed analysis of the presented results shows that there is no detailed information on the soils, that is, the contours of soils are present, but there is no information about them.

Critically important for soil scientists, the digital elevation model in the presented pilot project exists in the form of a cartographic variant (digitized horizontally) and a TIN based on their basis, and none of these options is available for download.

Thus, the state variant of the solution of the problem with geospatial data is hampered by the progressive development of science and practice, and not only the soil science. Therefore, in our opinion, it is worthwhile to involve the public and scientific community in solving these issues. A successful example of the Open Street Maps project (OpenStreetMap contributors, 2018) shows that this approach works globally, with a minimum of financial resources. For example, one of the numerous projects we have undertaken to create a digital model of relief in Chernivtsi (Dmytruk et al., 2013) covering an area of ≈169 km^2 (digitized 26795 vector objects with a total length of 13910 km), and executed for a scientific purpose completely free of charge. However, the use of the potential of scientists and the public to address the problem of saturation of NIGD with geospatial data, even if this practice was adopted, is currently facing a number of obstacles and problems discussed in detail below.

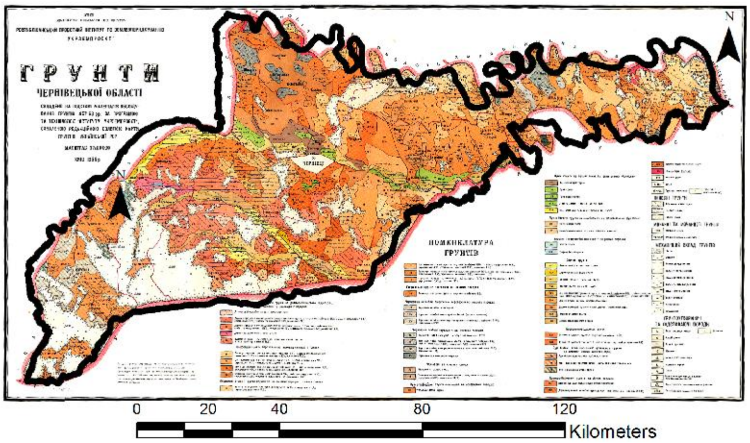
Especially critical situation consists of accessible large-scale and medium-sized soil materials. Note a number of negative points, in particular, medium-sized soil maps that are available for use, contain significant errors due to the peculiarities of their creation during the time of total secrecy in the USSR. An example of a map of the Chernivtsi (Fig. 1a) and Ternopil regions (Fig. 1b), on which the bold black line marks the real contours of the regions: such distortions make it impossible to use such maps in practice.

If we consider in greater detail the areas of the surveyed soils in the framework of a large-scale soil survey, then according to our data within the Chernivtsi region, 49,2 % of the territory remain unidentified (Figure 2a), ie 3906 km^2. In Kitsmansky region, for example, 244 km^2 or 40 % of the area remain unexplored (Fig. 2b). As a rule, it is the territory of settlements, forests, some agricultural lands, and so on.

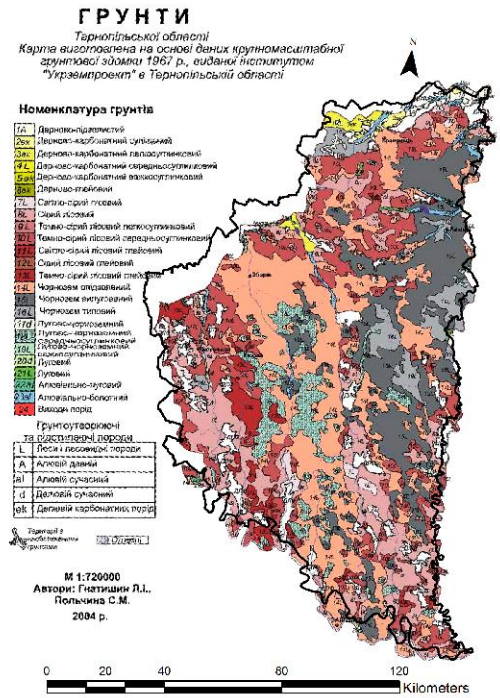
Given this situation, the logical step is to fill the gaps in cartographic information by means predicted data. Indeed, over the past decades, the number of such studies devoted precisely to the simulation of the spatial location of taxonomic soil units has considerably increased (Bui and Moran, 2003; McBratney et al., 2003; Scull et al., 2003; Walter et al., 2006; MacMillan , 2008; Browning and Duniway, 2011; Caten et al., 2013; Brungard et al. 2015; Malone et al., 2016; Heung et al., 2016, 2017). A large range of mathematical methods is used: from multi-factor regression analysis, kriging, neural networks to different types of classification trees (Florinsky, 2016). The general idea underlying the application of such methods is to use the reference points of the landscapes and soil taxa associated with them (Lagacherie et al., 2001). The main source of predictors in this direction of simulation is the digital model of relief (DEM), the analysis of which allows to distinguish a number of geomorphological and related parameters. Since model variables (types of soils) do not refer to the numerical but to the categorical type of data, and the indicators derived from the DEM are usually numeric, then the use of advanced mathematical methods only allows us to establish the non-obvious, at first glance, dependence between all these parameters (Giasson et al. , 2008; Kempen et al., 2009; Debella-Gilo and Etzelmüller, 2009; Hengl, 2009; Cherlinka, 2017; Malone et al., 2016).

Our research on the basis of domestic soil materials showed that the morphometric indices of the relief are a reliable basis for the predictive modeling of the soil cover (Cherlinka, 2017b), the effect of the resolution of the DEM on the quality indicators of predictive maps (Cherlinka, 2017) is considered, the optimal methods of constructing the training samples (Cherlinka, 2017d) and a comparative estimation of the quality of simulation of soil maps and cartograms of agro-industrial groups of soils (Cherlinka et al., 2017).

Accordingly, the purpose of our work was (in addition to analyzing the critical situation with soil materials) is showing the possibilities of the developed methodology for analyzing not only local areas at the level of individual village councils, but also scaling to the level of administrative districts.

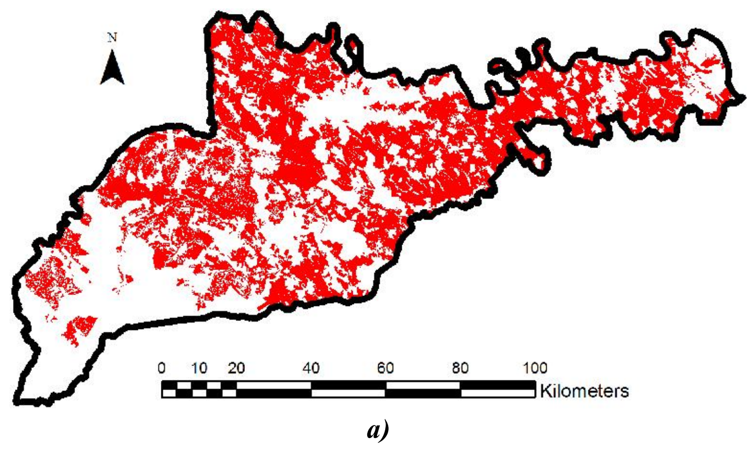


a)

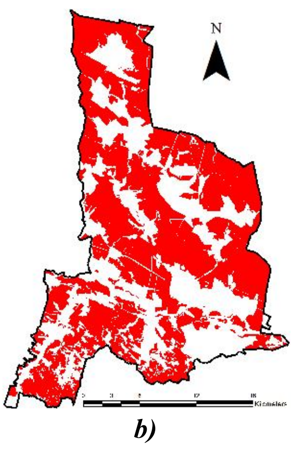


b)

Fig. 1. Distortion of contours of administrative regions on existing medium-scale soil maps
a) soil map of Chernivtsi region; b) soil map of Ternopil region (http://ibhb.chnu.edu.ua/uploads/images/soilscience/maps/ternop.jpg)



a)



b)

Fig. 2. Available results of large-scale soil surveys of Chernivtsi region (a) and Kitsman district (b). White is an unconscious habitat

Materials and methods. In accordance with the stated goal, we identified the following tasks: a) digitization and attribution of cartographic materials; b) construction of DEM with a resolution equal to 25 m; c) analysis of digital elevation models and the selection in the GIS GASS set of maps of morphometric and other derivative characteristics; d) generation of training samples; e) creation of R-statistic simulation models using predictive algorithms KNN (Liu, 2011) and BGT (Hastie et al., 2009; Kuhn and Johnson, 2013) as for areas with available soil information, and for those where it is not presented.

The Kitsman district of the Chernivtsi region was selected as an object (Fig. 2b). This area with a total area of ≈ 610 square km. It has a different administrative subordination and economic use, and when selected, the typical problems often encountered in works of this nature were solved (Cherlinka and Dmytruk, 2014; Cherlinka, 2015, 2017a). Currently covered by large-scale soil surveys is only 366 km^2, or 60 %.

To process the data, the tools of the free software were used: georectification of the cartographic material - GIS Quantum (QGIS Development Team, 2015), digitization - Easy Trace (EasyTrace group, 2015), preparation of morphometric parameters and generation of DEM – GIS GRASS (GRASS Development Team, 2017) and simulation of soil maps – the language of statistical calculations R-statistic (R Core Team, 2018). Based on the digital elevation model, a number of morphometric characteristics of the relief were provided by predictors: steepness and exposure of slopes, curvature of the surface (longitudinal and maximum), solar radiation, and relief forms. Additional maps of hydrological indicators were also generated: the topographic wetness index, accumulation, direction and length of water streams and the distance to them.

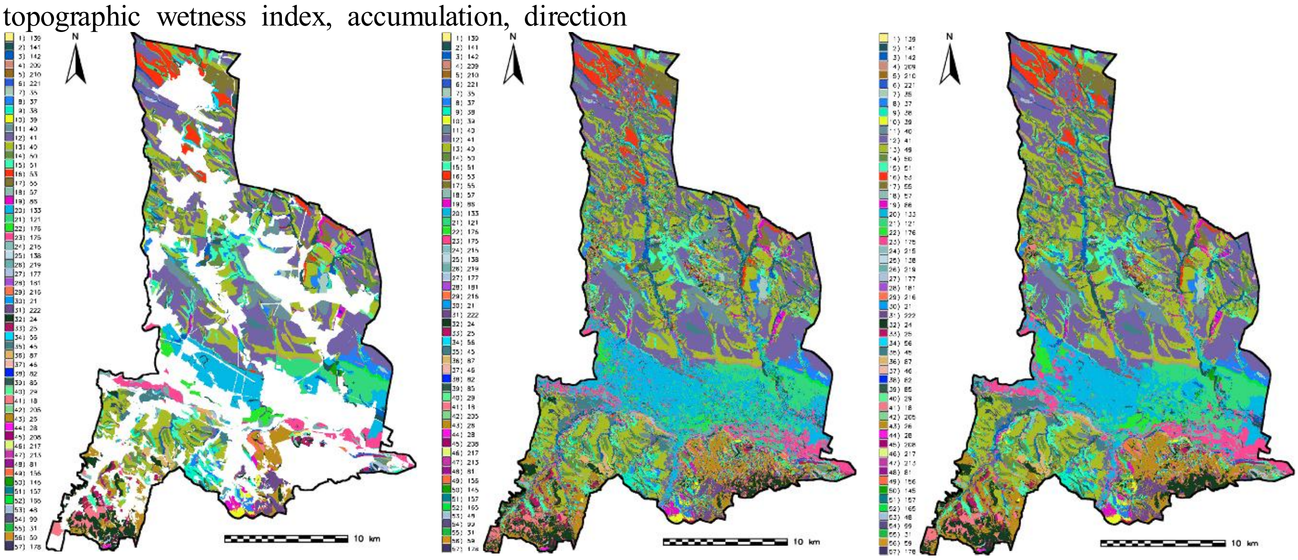
The R-statistic script (R Core Team, 2018), which includes a number of adaptations for solving set tasks and implements 14 basic types of predicative algorithms, of which 2 were used in this study, was used to create simulation models of soil cover.

To evaluate the quality of the obtained models, the Cohen's Kappa index was used (Kuhn, 2008; Li and Zhang, 2007; Grinand et al., 2008; Malone et al., 2016; Landis and Koch, 1977), which shows the degree of correspondence between the original and the simulative data.

In the mathematical experiment, the cartography of agro-industrial groups of soils, without definitions of granulometric composition, was analyzed, that is, the alphanumeric indices in the codes of numbers of agro-industrial groups were not used.

Results and discussion. In this experiment, we did not use the methodology for creating a training sample (Dobos and Hengl, 2009; Hengl, 2009), but a randomized-weighted one, which shows much better results in our studies.

Two simulations of the territory covered by agro-industrial groups of soils were obtained, analysis of which revealed quite interesting patterns. Unlike the original cartograms of the agrogroups (Fig. 3a), both KNNs (Fig. 3b) and BGT (Figure 3c) created a solid coating that filled in the gaps in the existing map, with a precision of 78.08 % and 86.95 % respectively. Given the diversity of agro-industrial groups (57) and the complexity of the area in a geomorphological sense, this is a very high indicator, which allows you to use these maps for practical purposes. Taking into account that with the decrease of the DEM step the quality of the prediction increases, for local areas, if necessary, it is possible to re-engineer the model with higher accuracy.



a) *b)* *c)*

Fig. 3. Results of simulation of the reduced agro-industrial groups of Kitsmansky district of Chernivtsi region (without taking into account the granulometric composition):
a) initial cartogram; b) Model K-Nearest Neighbors, k = 78.08 %; c) Model Bagged Trees, k = 86.95 %

The absence of the National Geospatial Data Infrastructure (NIGD) limits innovative management solutions. Let's also highlight the relevant basic problems (Cherlinka (2015, 2017c), discussed in more detail Cherlinka (2015, 2017c), which at the moment concern almost all areas of activity when working with both topographical and ground maps (cartograms of agro-groups) of a large scale, and the solution of which is urgently needed:

1) the choice of coordinate system for use as a common denominator. The current state-of-the-art geodetic coordinate system USK-2000 meets all modern requirements for accuracy, so it is advisable to do all the work on the creation of DEM in it. To do this, we must make well-known data on the parameters of the transition to the national SC for accurately linking the topographic basis with SK-42, SK-63 and local coordinate systems (MSCs), and to remove the secrecy stamps.

2) the creation of a national DEM in USK-2000. Potentially, this minimizes the errors and errors associated with changing the shape of the cells to the DEM in process perturbation with projections;

3) limited access to topographic and soil data (secret / DSC) and their obsolete nature. At the moment it is difficult for scientists to obtain large-scale maps for scientific purposes, especially with the growth of total "commercialization" of relations;

4) correct georectification of topographic and soil maps;

5) qualitative digitization and attribution of topographic maps and soil materials.

From the point of view of the actual tasks of soil science, we propose such an algorithm of works:

1. Removal of secrecy stamps and DSC from soil and topographic materials of arbitrary scale.
2. Opening of access to archival materials of large-scale soil surveys and their corrections.
3. Scanning maps and cartograms with a resolution of 600 dpi in 24-bit color and TIFF compression with LWZ compression.
4. Creation of a database by soil profiles, fixed in the technical reports on large-scale soil surveys and their corrections.
5. Construction of the mathematical basis of topomaps in their corresponding coordinate systems, their correct georectification.
6. Pruning of soil maps on the lines of former collective farms and state farms; their georectification for the maximum number of characteristic points of the terrain according to the data of the topographic map and orthophotographs using transformation algorithms according to the type of "rubber sheet".
7. Digitization of contours from topomaps and soil contours in Easy Trace (EasyTrace group, 2015), GIS GRASS GRASS Development Team (2017) or Quantum GIS QGIS Development Team (2015).
8. The construction of DEM by the method of Regularized Spline with Tension (RST) (Mitásová and, 1993; Hofierka et al., 2002; Mitášová and Hofierka, 1993; Hofierka, 2005; Dmytruk et al., 2013; Cherlinka, 2014).
9. Generation of additional map set using DEM in GIS GRASS (GRASS Development Team, 2017; Cherlinka, 2017a, d; Cherlinka, 2017; Cherlinka, 2017b).
10. Creation of predictive versions of soil maps or cartograms of agro-industrial groups of soils using a set of predictive algorithms (R Core Team, 2018; Hengl, 2009; Venables and Ripley, 2002; Cherlinka, 2017a; d; Cherlinka, 2017; Cherlinka, 2017b) for those areas, where she is not represented.
11. Clarification of the actual boundaries between soil polygons during field surveys and remote sensing data (Achasov, 2012; Truskavecz'ky'j, 2006; Shatokhrn and Achasov, 2005).
12. Creation of a final variant of a mapping model of soils.

The offered approach will allow to create a modern soil science GIS with the most adapted data set that will be easy to use, scalable and dynamically supplemented. It will also become a prerequisite for the establishment of a National Base Soil data and its integration with minimal redevelopment and further development within the framework of the future functioning version of the National Geospatial Data Infrastructure. It also adapts it to the international analogical systems SOTER, SOVEUR, etc., as much as possible.

Considering the announced start of work in this direction and the range of problems revealed, it is absolutely necessary to involve the soil science community.

Given the magnitude of such a project and the cost of modern software, special attention should be paid to free software under the GNU GPL (GNU GPL, 2016), Debian (Debian, 2018), GRASS Development Team (2017), Quantum GIS (QGIS Development Team, 2015), SAGA GIS (Conrad et al., 2015) etc., which allows you to complete a whole range activities in closed-loop.

Concerning the lower quality of the prediction of soils in comparison with agrogroups of soils, it can be assumed that the used set of predictors of the model does not fully describe the definitions of the distribution of soils on the elements of the relief. Therefore, the study of this issue will be the subject of our next research.

An analysis of the level of comparability of our results on the quality of simulation with similar studies shows that the kappa of our models exceeds the averaged values from literary sources. So, in the work (Hengl, 2009) 51-67 % is considered a good indicator. In work Grinand et al. (2008) κ=67-87 % for the study sample and is about 30 % for the main data set. For small-scale soil maps Giason et al. (2008) obtained κ 37-54 %, and Malone et al. (2016) its value ranges from 35-40 %. According to the ranges given by Landis and Koch (1977), the results we have obtained and the results described above have, in the worst cases, a significant convergence (κ=0.61-0.80), and in the best cases, almost complete convergence (κ=0,81-0,99). Accordingly, this allows us to assess the quality of simulation card versions as good and not below the level of similar literary data. In addition, we believe that there is still some potential for increasing the overall κ, in particular by more accurately selecting the model's predictors and extending their number by incorporating Earth remote sensing data, anthropogenic deposits maps, and more. A significant beneficial effect of this kind of modeling is the ability to fill gaps on existing cartographic materials with data from predicative map-versions and, thus, obtaining composite soil maps. This certainly does not exclude the need for a large-scale soil survey of such areas, but in the absence of the possibility of its carrying out, it allows to obtain at least some scientific data with a certain level of statistical reliability.

It also allows it to be used in applied problems of soil science, agronomy, land management and land management, that is, areas where the need for such data is most acute.

Conclusions. The current situation with soil maps information is considered and it is shown that its updating is urgently needed in accordance with modern requirements. Analysis of the current situation allows us to identify 2 main ways to overcome such a crisis, which we will present together with their advantages and disadvantages. The first way - implies the modern large-scale survey of soils based on innovative scientific and methodological approaches using soil surveys and remote sensing. However, he has such significant disadvantages as high time and labor costs, relevant economic ones that are not time-consuming for the state budget, and given the lack of sufficient professional staffing, such a path seems not entirely realized in the short term.

On the basis of the analysis of the current political and economic state of Ukraine, it is proposed to use the second possible path, the essence of which is to correct existing soil maps based on archival materials and build on them predictive mathematical models of soil cover, including for locations with missing data. From its positive moments, note the use of new low-budget scientific methodological methods for modeling of cartographic soil materials, low time and labor costs, the possibility of using remote sensing to clarify the boundaries of soils. There are certain negatives that are carefully analyzed and related, in particular, to problems with access to scanned originals of archival soil maps and technical reports, as well as the desirability of a minimum field expedition for verification of corrected maps. A step-by-step algorithm for solving such a global problem within the boundaries of Ukraine is proposed.

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ВИРІШЕННЯ ІСНУЮЧИХ ПРОБЛЕМ ІЗ КАРТАМИ ҐРУНТІВ В УКРАЇНІ

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Розглянуто поточну ситуацію з ґрунтовою картографічною інформацією та показано, що нагально необхідне її оновлення відповідно до сучасних вимог. Аналіз ситуації, яка склалася, дозволяє виділити 2 основних *шляхи подолання такої кризи, які наведемо разом з їх перевагами та недоліками. Перший шлях — передбачає новітнє великомасштабне обстеження ґрунтів на основі інноваційних науково–методичних підходів з використанням наземних обстежень, безпілотних літальних апаратів та дистанційного зондування землі. Проте він має такі суттєві недоліки, як високі часові та трудові витрати, відповідні економічні, які не на часі для бюджету держави, а враховуючи відсутність в достатній кількості фахового кадрового забезпечення, такий шлях виглядає не зовсім реалізовуваним в найближчій часові перспективі. На основі аналізу сучасного політико–економічного стану України, запропоновано використовувати другий можливий шлях, суть якого полягає в корекції існуючих ґрунтових карт на основі архівних матеріалів та побудові на їх базі прогнозних математичних моделей ґрунтового покриву, в тому числі й для локацій з відсутніми даними. З позитивних його моментів відмітимо використання нових низькобюджетних науково–методичних методів моделювання картографічних ґрунтових матеріалів, низькі часові та трудові витрати, можливість використовувати дані дистанційного зондування для уточнення контурів. Існують і певні негативи, які ретельно проаналізовані і стосуються, зокрема, проблем доступу до сканованих оригіналів архівних ґрунтових карт та нарисів/технічних звітів, а також бажаності мінімальних польових експедиція для верифікації корегованих карт. Запропоновано покроковий алгоритм вирішення такої глобальної задачі в межах України. Пропонований підхід дозволить створити сучасну ґрунтознавчу ГІС з максимально адаптованим набором даних, який буде зручним у використанні, масштабованим та динамічно доповнюваним. Це також стане передумовою створення Національної бази ґрунтових даних та її інтеграції з мінімальними перебудовами і подальшим розвитком в межах майбутнього функціонуючого варіанту Національної інфраструктури геопросторових даних. Водночас відбуватиметься адаптація до міжнародних аналогічних систем SOTER, SOVEUR тощо. Враховуючи анонсований початок роботи в цьому напрямку та виявлений спектр проблем, обов'язково необхідним є залучення ґрунтознавчої спільноти. Зважаючи на масштабність такого проекту та вартість сучасного програмного забезпечення слід звернути особливу увагу на безкоштовне вільне програмне забезпечення під Вільною громадською ліцензією GNU GPL: Debian, GRASS GIS, Quantum GIS, SAGA GIS, R–Statistic тощо, яке дозволяє виконати весь комплекс пропонованих заходів у замкнутому циклі.*

Ключові слова: ґрунтова карта, картограма агровиробничих груп ґрунтів, навчальна вибірка, симуляція, морфометричні параметри, ЦМР, предикативні алгоритми.

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