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ORIGINAL ARTICLE

Possibilities of geoinformational analysis for assessment of the state and directions of development of geodetic support of the territory of Ukraine

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Abstract

Topographic, geodetic and cartographic activities are one of the main activities for the effective development of the economy, science of strengthening national security and defense. It is a set of management, production, scientific and educational activities for the storage and communication to users of geodetic and cartographic information and data. The article considers one of the segments of this activity – the state of geodetic support of the territory of Ukraine and its assessment according to official data on the possibility of creating topographic maps and plans of scale 1:25 000 – 1:2000 in compliance with applicable regulations. To carry out the assessment, around the points of the State Geodetic Network of Ukraine (DGM) buffer zones of radii of circles of standard sizes were constructed, zoning of the territory with Thissen-Voronoi polygons and covering of the territory in the form of a hexagonal grid were done by means of ArcGIS. The results of the current assessment as of 2022 conducted by three methods are summarized in the table in terms of oblasts of Ukraine. The data obtained are compared to the previous assessment conducted five years ago. Changes in the state of geodetic support have been identified and their objective reasons explained. The advantages and disadvantages of each of the proposed methods of geoinformation analysis of the assessment of the state of geodetic support of the territories are given. It is established that the combination of different methods will allow to use the existing points of DGM with greater efficiency and to substantiate the priority places for further development of the network. The complex of scientific and applied works related to the modernization of the state geodetic network will allow to quickly and locally develop a network based on satellite and computer technologies and create and present digital cartographic information at the modern scientific and technical level in accordance with current needs.

Key words: buffer zones, geodetic support, hexagons, GIS, State Geodetic Network of Ukraine, Thissen-Voronoi polygons.

1 Introduction

Today geodetic support and cartographic production of developed countries is one of the priorities in creating national geographic information resources, which are collected, stored, updated and provided for multisectoral use in the country to numerous users under the direct supervision of a special authorized central executive body (State Service of Ukraine for Geodesy, cartography and cadastre).

A review of recent publications convincingly shows that the existing number of points of the State Geodetic Network (DGM) in Ukraine does not always provide the opportunity to use them to monitor and assess the accuracy of measurements when creating survey bases for large-scale surveys (Burak, 2015).

Low density and lack of accuracy of geodetic network points lead to inconsistency of the current state of the gravimetric network with world and European requirements, delay its integration into the global gravimetric network, hinder the development of the main altitude base of the country and coordination of the state leveling network , as well as slow down the construction of a quasi-geoid model for the territory of Ukraine in the centimetre range of accuracy (Korol and Manko, 2016).

One of the strategic sources of state information on the state of natural resources, environmental monitoring of the Earth's surface, identification of natural and anthropogenic formations, etc. – is the use of information systems with modern technologies based on space remote sensing systems (Lunova and Buglak, 2019). The process of orthotransformation, as well as further assessment of its accuracy will be more optimal with the use of more points of the State Geodetic Network of higher classes.

In addition, the provision of topographic products, which directly depends on the component of the geodetic basis is in poor condition. Non-compliance with the deadlines set by the "Basic provisions for the creation and updating of topographic maps on the territory of Ukraine" has led to aging and inconsistency with the current state of the region almost 70% of topographic maps of all sizes for more than 15 years (Antoniuk et al., 2011). In Karpinskyi and Liaschenko (2001) it is noted that the original cartographic materials with a base scale of 1:10 000 are heterogeneous in age not only in individual regions, but even in one district, which in turn inhibits the development of geographic information projects. Experience with the latter shows that the main costs are related to the collection of reliable data and keeping them up to date.

According to the State Service of Ukraine for Geodesy, Cartography and Cadastre, as of January 1, 2020, there are 28,299 settlements in Ukraine (excluding the Autonomous Republic of Crimea and the temporarily occupied territories of Donetsk and Luhansk oblasts), of which boundaries have been established in 21,702 settlements, which is 76.7% of their total. Insufficient information and cartographic support in recent years has been identified as one of the problems in the development of projects to establish the boundaries of settlements (Drebot et al., 2020).

In the period from 2015 to 2021, as a result of the decentralization reform, changes in the administrative-territorial structure of Ukraine took place, which in particular led to the creation of 1469 territorial communities. One of the five criteria for capacity is community size. Area as a physical quantity that determines the size of the surface can not be formed without clearly defined boundaries. Thus, newly created entities cannot function properly because they do not have authority over lands within their territories located outside settlements. On July 28, 2021, the State Service for Geodesy, Cartography and Cadastre added a new layer of territorial data communities to the Public Cadastral Map, but it is informative and does not have the status of official information of the State Land Cadastre.

Planning and development of territories in cities is considered developed and is carried out on the basis of approved urban planning documentation (master plans), the territory of land tenure and land use outside settlements is not fully covered by the development of land management documentation. This leads to irrational planning of rural development, violations of the legal regime, land use conditions, inefficient use of economic mechanisms for regulating land relations, which complicates land management. In recent years, there have been virtually no land management works to organize the territory of existing and newly created agricultural formations, and no land management plans have been drawn up in cities and villages. The role of land management is reduced to the design of decisions made by local governments in connection with the redistribution, redivision of land and agreements of citizens with landowners. No attention is paid to scientific and methodological support of land management, one of the main tools of spatial planning is not fully used – the satellite state geodetic network (Aleksandrova and Pedak, 2019).

It is no secret that cadastral activities in Ukraine have been and still are carried out with insufficient cooperation of various agencies and often in conditions of fierce competition between different state institutions. In particular, this applies to the topographic and geodetic support of the State Land Cadastre. Correction of numerous existing errors of topographic surveys of land boundaries, achieving full consistency of boundaries without overlaps and gaps requires the performance of works simultaneously in a single effort. This essentially means the transition from the essence of "plot of land" to the essence of "totality of land plots" as a single land cadastral coverage. Understanding that the totality of land plots as a single whole allows to reach a logical conclusion: the ultimate goal of topographic and geodetic works on land inventory is the formation of a continuous land cadastral cover for the whole territory (Karpinskyi, 2015).

The implementation of such large-scale projects is a small part of the examples of using the State Geodetic Network of Ukraine to solve its applied problems.

2 Aim of the study

Using open source data on the spatial position of the DGM points by means of GIS-technologies to assess the geodetic support by comparing three methods. The first method is to construct the radii of the circles around the geodetic points (creation of spatial objects from other objects) in accordance with regulatory requirements. The second involves the construction of a hexagonal grid of specified polygon sizes in accordance with regulatory requirements for the study area (spatial statistics). Third, the construction of polygons around the point objects of the DGM network in such a way that for any position within the polygons the distance to the central point object is always less than to any other object of the network under consideration (tools of Proximity group).

Compare the obtained results of the assessment of topographic and geodetic support with the data of previous studies. Identify and justify priority places for further development of the State Geodetic Network of Ukraine.

3 Previous research on the subject

Geographic information systems and technologies have become a convincing alternative to traditional means of cartographic modeling of geosystems, as for the complex modeling of the most complex spatial objects and phenomena in modern GIS the whole arsenal of numerical methods and powerful software tools for computer processing, space-time modeling, information visualization, including using global information systems are used (Karpinskyi and Liaschenko, 2011).

Currently, geoinformation analysis is a common and effective technology for estimating the distribution of geospatial objects, including points of the DGM of Ukraine. Thus, the study of the spatial distribution of points of the geodetic network was carried out (Karpinskyi and Stopkhai, 2010). The purpose of this study was geoinformation analysis of the squares of the scheme of construction of DGM of the 1st class, proposed by Krasovskiy and the 1st class network scheme, based on which the state geodetic reference network USK-2000 with conclusions on geospatial distribution of points was constructed.

Prof. Yu.O. Karpinskyi and prof. A.A. Lyashchenko launched in Ukraine the scientific direction of development of the national infrastructure of geospatial data, which provides the transition from the infrastructure of cartographic production to geoinformation production and complies with Directive of European Parliament and Council 2007/2/EU of 14 March 2007 establishing a geospatial information infrastructure in the European Community (INSPIRE). A set of researches on development of the basic directions of normative-legal and institutional maintenance is executed, structure and principles of formation of basic sets of geospatial data, functions of formation of metadata and principles of creation of profile data sets are defined. The obtained results of scientific research are practically realized in the developed national standard of Ukraine DSTU 8774: 2018 "Geographical information. Rules of Geospatial Data Modeling", which is the Ukrainian profile of 14 international standards of ISO 19100 "Geographic Information/Geomatics", which ensures Ukraine's integration into international structures in terms of forming an open information society and a single European geospatial data infrastructure and Global geospatial data infrastructure.

On January 2, 2013, the specialists of the Research Institute of Geodesy and Cartography created a new geoinformation online resource – the geoportal of the State Geodetic Network (hereinafter the geoportal of DGM); http://dgm.gki.com.ua. The information resources of the portal are a database of metadata about DGM points, information from the Geodetic Data Bank of Ukraine, digital and electronic maps, space images of the country (Cherin and Horkovchuk, 2013).

Since May 14, 2015, the second version of the Geoprtal "State Geodetic Network of Ukraine" has been opened. As a result, not only the functionality has been expanded, but also the amount of initial data on DGM points has been increased, which undoubtedly creates preconditions for their further analysis (Geoportal, 2022).

It should be noted that one of the methods of assessing the possibility of creating topographic maps and plans was proposed (Bilokrynytskyi, 2001) and tested (Bilokrynytskyi, 2016) in studies of topographic and geodetic support of Chernivtsi oblast.

The state of geodetic support for the needs of land cadastre and the peculiarities of its use during work in settlements and beyond were considered (Scherbak and Bryn, 2017). The authors substantiated the need to move to a single geodetic coordinate system, which in the form of the State Geodetic Reference Coordinate System USK-2000 of December 2, 2016 Order №509 of the Ministry of Agrarian Policy and Food of Ukraine was introduced as mandatory for use by all land management entities.

Estimation of the state of geodetic support of the territory of Ukraine using spatial analysis by constructing buffer zones of radii of circles of normatively established sizes and zoning of the territory by Thyssen-Voronnyi polygons is given in (Hutsul and Pusarenyuk, 2017). The data of 15127 points 1,2,3 classes of DGM of the territory of Ukraine are used without taking into account the territories of the Autonomous Republic of Crimea and the temporarily occupied territories.

For the first time since the time of independent Ukraine, a full-scale analysis of the state of preservation of points of 1,2,3 classes of DGM in the regions of Ukraine was conducted (Trevoho et al., 2019). Losses of points of the 1st class amounted to – 36 items; 2nd – 485 items; 3rd – 1008 items. Other 3164 items need instrumental search.

Works on inspection and updating of DGM points in accordance with the Procedure for construction of the State Geodetic Network, approved by the resolution of the Cabinet of Ministers of Ukraine of August 7, 2013 №646, are carried out both systematically and periodically. The results of the survey, updating and restoration of geodetic points are periodically published on the geoportal of the State Geodetic Network. In particular, in December 2020, the Research Institute of Geodesy and Cartography completed work under an agreement with the State Service for Geodesy, Cartography and Cadastre №64-G of October 20, 2020 "Services for survey, update and restoration of geodetic points of the State Geodetic Network" on sheets of a map of scale 1: 200 000: M-34-VI, XII, and M-35-I, II, III, VII, VIII, IX, as a result of which 60 points were built (restored) and 865 were inspected (State Geodetic Network of Ukraine, 2020).

On January 1, 2021, the Verkhovna Rada adopted and the President signed the Law of April 13, 2020 №554-IX "On the National Infrastructure of Geospatial Data". In it, the State Geodetic Network, including geodetic points and level benchmarks are listed among the sets (types) of geospatial data. The law stipulates that the State Geodetic Network and topographic database are the geodetic and cartographic basis for the State Land Cadastre, Urban Planning and other cadastres.

4 Methodology

The initial data were the information part of the national infrastructure of geospatial data – Geoportal DGM. The use of selection tools available on the site allowed to collect information fragmentarily on the names and indexes of points. It should be noted that the field of indices by that was unique.

The copied data were moved to the Microsoft Office Excel 2007 spreadsheet environment, where a single directory was formed. Since the copying was carried out with longitudinal and transverse overlap, respectively, this led to the appearance of repetitions. The duplicate removal function contributed to the uniqueness of the values in the spreadsheet environment.

To further collect and systematize attribute information, the principle of the parser was used, which consisted of reading a previously formed tabular file with unique indexes and loading identical URLs of web-pages. Further, in the automatic mode the search for and comparison of the corresponding html-elements of syntax with the necessary data was carried out. The result of the query was written as a data tape to a *.csv file.

The DGM geoportal contains information on 31 969 points of the planned network. From among all set according to the Order of construction of the state geodetic network of values 17 851 records corresponding to points of a geodetic planned network of 1-3 classes are selected. The obtained data can be integrated into any GIS in the form of a table. We will construct point objects according to the available coordinates (rectangular or geographical).

The cartographic support of the study took into account the changes in the administrative-territorial structure of Ukraine in 2020. The concept of reforming local self-government has led to transformational changes at the level of rayons and territorial communities. The Ministry of Communities and Territories Development of Ukraine promotes the openness of geospatial data. Therefore, layers of boundaries of oblasts, rayons and territorial communities are available for download (Ministry for Communities and Territories Development of Ukraine, 2020). A separate cartographic layer was "administrative-territorial units of the temporarily occupied territories of Ukraine" (Hutsul and Pysarenok, 2015). This feature is due to the lack of initial data on the territory of the latter and the desire to prevent imbalances in the analysis and further interpretation of the results.

4.1 First method

The implementation of the first method (method I) was based on the fact that the density of geodetic points is considered as circles (buffer zones) created around geodetic points (see Figure 1).

The size of the area of such circles must meet regulatory requirements. For geodetic support of topographic survey the following norms of density of points and benchmarks of DGM for surveys are established:

- on a scale 1:25 000 and 1:10 000 – 1 point per 30 km^2 and 1 benchmark per a trapeze on a scale of 1:10 000;
- on a scale 1: 5 000 – 1 point per 20-30 km^2 i 1 benchmark per 10-15 km^2;
- on a scale 1: 2 000 and more – 1 point per 5-15 km^2 and 1 benchmark per 5-7 km^2;
- in built-up areas the density of points of the state geodetic network must be not less than 1 point per 5 km^2 (The main provisions, 1998).

When applying this method, the circle area formula is used. Since the area is a given value, you can determine the value of the radius. From here we get:

$$R = \sqrt{\frac{S}{\pi}} \tag{1}$$

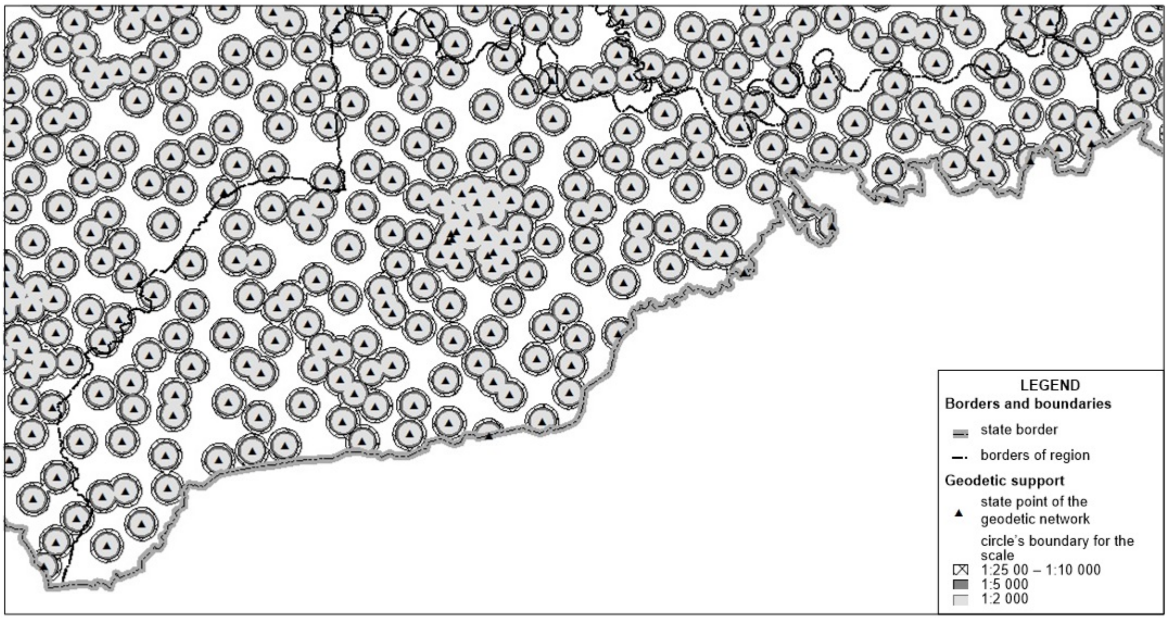

Figure 1. Schematic representation of geodetic support by the method of construction of buffer zones (fragment)

Table 1. Values of the radii of the circles for topographic maps and plans of the scale range 1:25 000 – 1:2000

Scale	Area S, [km^2]	Radius R, [km]
1:10 000 – 1:25 000	30	3.10
1:5000	20	2.52
1:2000	15	2.19

The calculated values of the radii of the circles for topographic maps and plans of the scale range 1: 25 000 - 1: 2000 are shown in Table 1.

Applying this method, you need to use the base with the geodetic points located on it. From the points of DGM, we draw the defined radii of the circles mentioned above. As a result, we obtain a schematic image (Figure 1), which will depict the intersection of the radii of the circles drawn from the respective centers of geodetic points. In this scheme, the formation of "white spots" is possible, i.e. places that do not overlap with the radii of the respective circles. Such "white spots" show that topographic maps (plans) of a particular scale can not be created for a given area without violating regulatory requirements.

Areas of "white spots" were deducted from the total area of the region, and the obtained value was translated into a relative indicator and entered into the general table (Table 2).

4.2 Second method

The second method (method II) was used to create regular grids of hexagons (Figure 2) with the area shown in Table 1. The choice of hexagons is not random, because regular grids can consist of equilateral triangles (for example, the same triangulation during the development of DGM networks), squares (for example, delineation of nomenclature sheets of different scales) and regular hexagons (hexagons). Hexagons have a geometry close to a circle, and unlike circles, they can be folded into a mosaic to form a uniformly filled grid. The classic definition of DGM involves the uniform placement of points in the territory of the country and their consolidation on the ground by special centers that ensure their preservation and stability in plan and height for a long time (The main provisions, 1998).

In contrast to squares, hexagons are characterized by equal distance in all six directions. Finding a neighborhood using a hexagonal grid is the most optimal. For each hexagonal grid object, more neighbors (adjacent DGM points) will be calculated than with other regular grids (Birch et al., 2007).

To create a hexagon grid, you can use the "Generate Tesselation" tool, available in the ArcGIS GIS Data Management suite. The result will be a mosaic grid of regular polygons (triangles, squares or hexagons), which will cover a given extent. In the settings you can specify the type of objects to be created, their size (in this case, the area), spatial reference.

The hexagonal grid should be cut along the contour of the administrative boundaries. Use the spatial query to select polygons where there is at least one point that corresponds to the DGM point. From the total area of the region we will subtract the area of selected polygons with available DGM points. The obtained value is translated into a relative indicator and entered in the general Table 2.

4.3 Third method

The implementation of the third method (method III) involves the construction of Thissen-Voronoipolygons (Figure 3). In practice, it is the division of territory into a set of districts to determine spatial associations and interactions. This type of analysis is widely used for surface distribution based on user-defined criteria and attributes.

It should be noted that on the constructed map of the spatial distribution of the variable under study, the latter undergoes a discontinuity break at the boundaries of the polygons, which, as a rule, contradicts reality. In addition, the nature of the simulated spatial distribution largely depends on the spatial location of network nodes.

In this regard, the method is recommended for interpolation of point values at:

- relatively small range of changes of this variable (placement of DGM points – static);
- spatial homogeneity of conditions of formation of its field (requirements to spatial arrangement of points are provided by regulations);

The construction of polygons and further analysis of the network was carried out in the GIS environment MapInfo Pro 15. The geo-

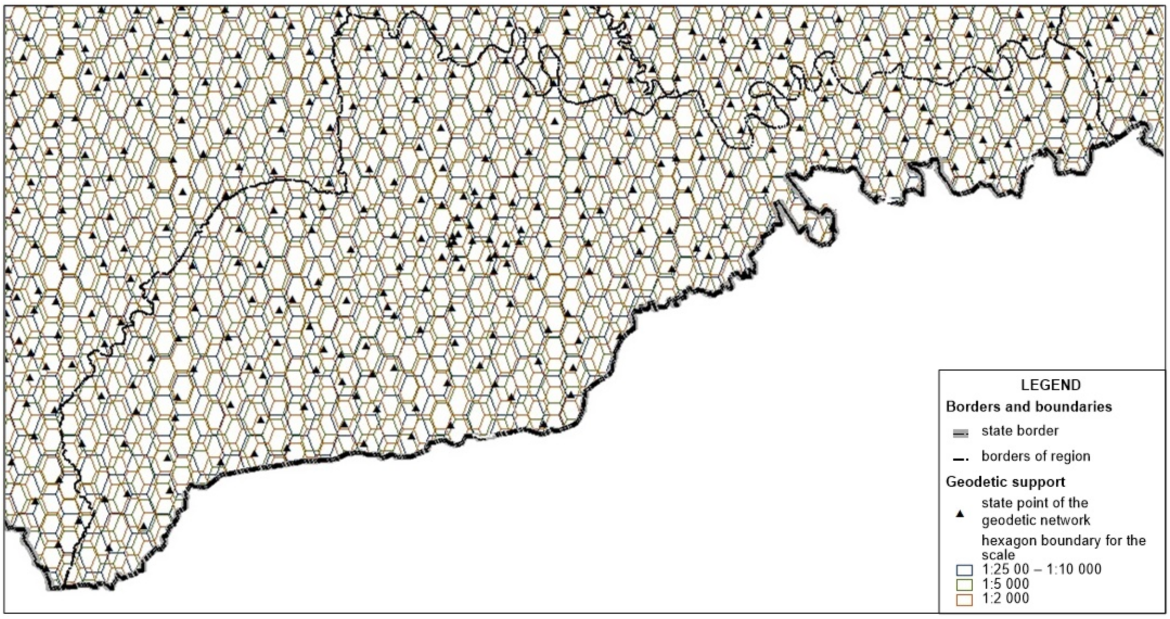

Figure 2. Schematic representation of geodetic support by the method of construction of a hexagonal grid (fragment)

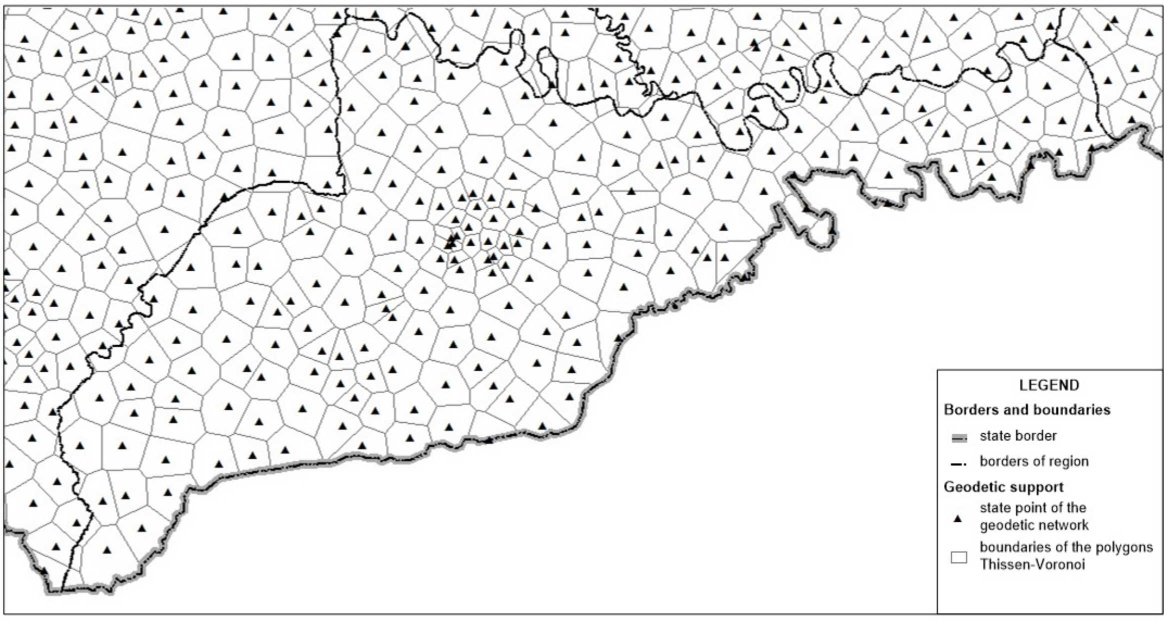

Figure 3. Schematic representation of geodetic support by the Thissen-Voronoi method (fragment)

graphical operator Contains allowed to take into account only those polygons within the region that contain a point of DGM. The value of the area returned to the polygons. The normative values of the areas provided for different scales were deducted from the value of the total area. The values completely satisfying the condition were selected from the generated values on the basis of SQL-queries. The total number of points whose polygons exceed the allowable area was multiplied by one of the normative values and added to the previously obtained area. Thus, the total area of geodetic support for the territory was established, which was translated into a relative indicator and entered in Table 2.

In essence, the buffer zones that are formed around each of the DGM points in the form of a polygon are the most efficient zones for topographic and geodetic works with its use. In addition, if we construct circles of different radii on the obtained Thissen-Voronoi polygons (Figure 4), we can find a pattern: in places of "white spots" the boundaries of several polygons intersect, which allows us to state the possibilities of effective modeling of network development by 1-3 classes in these places.

To the situation shown in Figure 4, you can add a layer of hexagonal grid of appropriate scale. The intersections of the boundaries of the Thissen-Voronoi polygons with the boundaries of hexagonal objects can be considered optimal for the establishment of new points of 1,2,3 class or bit geodetic networks of the DGM of Ukraine.

It is clear that, for an objective, general comparison of data obtained in Table 2, an overall rating indicator should have been used. The proposed calculation was to use scales of different values. The scale was determined by the principle of delineation of cartographic works. In the scale under study, 1: 2000 is the largest in content and accuracy. Accordingly, 9 sheets of scale 1: 2000 make 1 sheet of scale 1: 5000. In turn, 4 sheets of the plan 1: 5000 form a topographic map of 1:10 000. In addition, it should be noted that smaller scales can be always obtained from a larger scale by generalization. Thus,

Table 2. Assessment of geodetic support of the regions of Ukraine by different methods for 2022

Region	Total area, region in km^2	% of the territory with the possibility of geodetic support for different scales without violating regulatory requirements by different methods									General rating assessment of geodetic support		
		I method			II method			III method					
		1:10 000 1:25 000	1:5000	1:2000	1:10 000 1:25 000	1:5000	1:2000	1:10 000 1:25 000	1:5000	1:2000	I method	II method	III method
Autonomous Republic of Crimea[1]	26081	—	—	—	—	—	—	—	—	—	—	—	—
Vinnytsia obl.	26513	66.16	48.13	37.62	72.50	51.92	40.15	63.37	46.96	37.07	59.51	64.04	58.13
Volyn obl.	20144	70.14	55.05	45.04	80.09	63.57	52.68	67.32	51.43	43.12	68.69	79.77	65.66
Dnipropetrovsk obl.	31974	69.24	51.35	40.41	76.34	55.77	43.56	66.18	51.10	39.88	63.43	68.84	62.10
Donetsk obl.[2]	18366	71.87	55.97	44.48	80.77	60.77	48.22	69.75	53.27	43.02	68.67	75.16	66.38
Zhytomyr obl.	29832	69.69	51.69	40.90	78.62	58.52	46.24	65.60	49.54	39.79	64.07	72.40	61.69
Zakarpattia obl.	12777	59.61	41.86	32.20	63.87	43.64	33.00	55.98	40.16	31.96	51.75	53.82	50.42
Zaporizhzhia obl.	27180	75.86	59.49	48.38	84.87	67.83	55.49	72.99	59.93	48.12	73.96	84.24	73.03
Ivano-Frankivsk obl.	13928	66.51	48.43	37.92	74.36	53.22	41.05	64.30	48.77	37.81	59.93	65.55	59.30
Kyiv obl. (without Kyiv)	28131	70.99	54.60	44.22	79.07	61.91	50.80	67.22	53.04	42.87	68.03	77.45	65.57
Kirovohrad obl.	24588	70.36	51.57	40.31	77.07	55.76	43.15	69.67	50.47	39.90	63.63	68.61	62.93
Luhansk obl.[3]	18218	63.29	45.35	35.16	69.26	48.23	36.81	60.05	44.28	34.07	56.02	59.48	54.00
Lviv obl.	21833	67.56	50.02	39.50	75.63	55.54	43.38	64.17	48.69	38.73	61.95	68.46	60.18
Mykolaiv obl.	24598	64.03	46.26	36.10	70.27	50.09	38.85	62.04	46.02	36.29	57.25	61.98	56.91
Odesa obl.	33310	66.29	48.84	38.46	72.91	53.48	42.10	67.07	49.35	38.94	60.46	66.27	61.19
Poltava obl.	28748	69.40	52.53	42.06	76.96	58.19	46.56	66.23	50.13	40.70	65.25	72.27	62.83
Rivne obl.	20047	62.50	45.68	35.88	69.60	51.38	40.28	58.86	42.76	33.71	56.58	63.39	53.18
Sumy obl.	23834	71.28	54.38	43.43	78.88	60.14	48.09	66.80	51.02	40.84	67.29	74.49	63.21
Ternopil obl.	13823	72.33	53.98	42.52	79.90	59.09	46.39	68.31	52.07	40.79	66.60	72.93	63.65
Kharkiv obl.	31415	64.78	47.27	37.08	71.00	50.69	39.37	62.17	46.03	35.72	58.53	62.75	56.38
Kherson obl.	28461	63.21	48.17	38.65	71.73	52.06	43.95	63.31	48.52	38.83	59.80	67.67	60.05
Khmelnytskyi obl.	20645	64.62	46.34	35.96	70.55	49.39	37.72	63.07	44.96	34.62	57.26	60.85	55.38
Cherkasy obl.	20900	65.02	47.81	37.70	72.09	52.29	40.73	62.30	46.08	36.79	59.27	64.56	57.49
Chernivtsi obl.	8097	60.21	42.53	33.04	65.45	45.89	35.33	55.80	40.89	32.05	52.82	56.79	50.54
Chernihiv obl.	31865	61.82	44.75	35.12	67.27	48.35	37.83	58.43	41.90	32.86	55.55	60.02	52.12
Kyiv	839	94.33	87.31	79.81	81.91	81.37	80.78	81.36	77.29	64.53	100.00	100.00	93.46
Sevastopol[4]	864	—	—	—	—	—	—	—	—	—	—	—	—

Note: [1,4]Data are absent. [2,3]Excluding the temporarily occupied territories.

we obtain the formula:

$$r = \chi_1 + \frac{\chi_2}{9} + \frac{\chi_3}{4} \qquad (2)$$

where: r – overal rating value; χ_1 – the value of the scale 1:2000; χ_2 – the value fo the scale 1:5000; χ_3 – the value of the scale 1:10 000–1:20 000

Since each of the relative values cannot exceed 100%, it is possible to calculate the maximum possible value of the rating by substituting the corresponding values for Equation 2. The calculated values for convenience will also be expressed in relative terms.

5 Results

A comparison of the results obtained in Table 2 can be made with the data from 2017, presented in the study (Hutsul and Pusarenyuk, 2017). The state of geodetic support of the territory of Ukraine by the II method for 2017 will be calculated according to the method given in the work on the data on the points of DGM for that period of time. We will form the final Table 3, which will try to analyze the difference in the level of geodetic support by three methods between 2017 and 2022. Positive values will indicate an increase in the number of DGM points in a particular region, and as a result positive dynamics of coverage density. Negative values, on the other

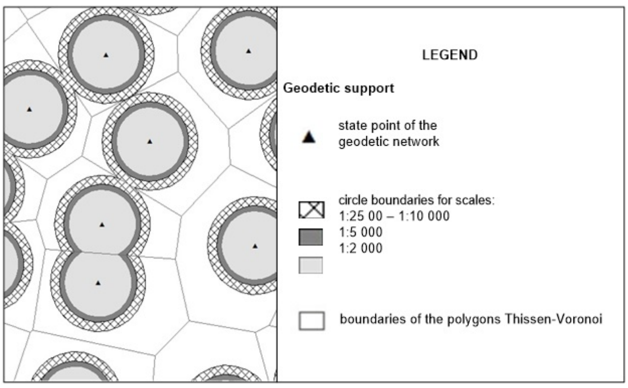

Figure 4. Possibility of modelling of spatial locations of future points

Table 3. Dynamics of changes in the level of geodetic support of the regions of Ukraine for 2017-2022

Region	Total area, region in km²	level change (±) of geodetic support of the territory (%) to enable the creation of topographic maps of various scales without violating regulatory requirements								
		I method			II method			III method		
		1:10 000 1:25 000	1:5000	1:2000	1:10 000 1:25 000	1:5000	1:2000	1:10 000 1:25 000	1:5000	1:2000
Autonomous Republic of Crimea[1]	26081	—	—	—	—	—	—	—	—	—
Vinnytsia obl.	26513	2.27	2.41	2.16	3.38	3.27	3.36	1.66	2.04	2.13
Volyn obl.	20144	9.54	11.43	11.19	13.73	17.38	17.85	9.88	10.47	10.72
Dnipropetrovsk obl.	31974	1.04	1.32	1.30	1.19	1.78	2.45	1.03	1.19	1.38
Donetsk obl.[2]	18366	-2.16	1.06	0.89	1.17	1.2	2.01	1.03	0.85	0.66
Zhytomyr obl.	29832	6.44	6.83	6.27	10.14	11.03	10.31	5.90	6.70	6.32
Zakarpattia obl.	12777	-12.30	-0.01	0.00	0.04	-0.01	0.11	0.01	0.00	0.00
Zaporizhzhia obl.	27180	1.22	1.50	1.51	1.10	2.17	4.02	0.99	1.32	1.29
Ivano-Frankivsk obl.	13928	0.54	0.68	0.63	0.96	1.15	1.34	0.75	0.71	0.67
Kyiv obl. (without Kyiv)	28131	5.89	6.35	5.97	7.77	9.26	10.07	5.79	6.90	5.97
Kirovohrad obl.	24588	0.31	0.40	0.42	0.39	0.67	1.24	0.16	0.45	0.34
Luhansk obl.[3]	18218	1.05	0.78	0.63	0.74	0.83	0.89	0.99	0.56	0.52
Lviv obl.	21833	3.42	3.71	3.38	4.62	5.47	5.44	3.02	3.12	3.44
Mykolaiv obl.	24598	2.62	2.70	2.43	3.43	3.66	3.68	2.85	2.40	2.45
Odesa obl.	33310	1.37	1.36	1.20	1.48	1.58	2.12	1.23	1.11	1.08
Poltava obl.	28748	1.38	1.58	1.51	1.44	2.1	3.17	1.15	1.36	1.63
Rivne obl.	20047	5.34	5.46	4.92	8.68	9.37	8.59	5.24	4.80	4.40
Sumy obl.	23834	0.40	0.46	0.44	0.61	0.69	1.82	0.00	0.46	0.24
Ternopil obl.	13823	1.52	1.61	1.46	2.09	2.3	2.92	2.12	1.60	1.29
Kharkiv obl.	31415	0.12	0.13	0.12	0.23	0.31	0.68	0.19	0.03	0.16
Kherson obl.	28461	0.65	0.63	0.54	2.14	-1.5	2.14	0.53	0.42	0.67
Khmelnytskyi obl.	20645	2.28	2.20	1.96	3.14	3.18	2.92	2.62	2.21	1.86
Cherkasy obl.	20900	0.39	0.48	0.48	0.95	0.86	1.43	0.43	0.10	0.35
Chernivtsi obl.	8097	0.16	0.13	0.12	0.30	-0.02	0.23	0.00	0.00	0.00
Chernihiv obl.	31865	2.47	2.70	2.62	2.96	3.79	4.12	2.20	2.26	2.35
Kyiv	839	0.00	0.02	0.02	-0.10	-0.27	0.99	0.00	0.00	0.00
Sevastopol[4]	864	—	—	—	—	—	—	—	—	—

Note: [1,4]Data are absent. [2,3]Excluding the temporarily occupied territories.

hand, will indicate a decrease in the level of geodetic support caused by the loss of DGM points due to their destruction.

Compared to 2017, the number of points of DGM of Ukraine of 1,2,3 classes has increased by 2742 units. And this is not surprising, because only for 2020-2021, according to the Budget Request Form 2019-3, it was planned to restore 1,523 points (among them: 1-st class – 61; 2-nd class – 473; 3-rd class – 989). Among the leaders in the number of new points – the northern regions of Ukraine (Volyn, Kyiv, Zhytomyr and Chernihiv oblasts). It should be noted that Volyn, Zhytomyr and Chernihiv oblasts used to have some of the lowest indicators of geodetic support in Ukraine.

Studies of the rate of "aging" of geodetic networks are given in the works Shevchuk (1978); Tatarenko (1986). In particular, the percentage of loss of geodetic points "is 1.1% per year for forested areas and 1.9% per year for steppe areas". The overall increase in points over the five-year period was 18%, or an average of 3.6% for the year. Thus, the DGM of Ukraine is developing steadily.

Usually, such growth rates often do not meet the dynamic needs, such as the opening of agricultural land commerce on July 1, 2021. It is estimated that the moratorium covered 66% of Ukraine, most of which was owned by peasants.

In such circumstances, the further development of the State Geodetic Network of Ukraine should be compared with the localization of a significant number of potentially interested persons. To do this, you can determine the population within the hexagons and sort it separately in descending order for hexagons without the DGM point.

6 Conclusions

The state of geodetic support of the territory of Ukraine has been generally characterized by positive dynamics for the last five years. The number of points of DGM of 1,2,3 classes in Ukraine has increased. Irregularity of the location of points gives grounds for their assessment by various methods, in particular – geoinformation analysis. The first method using buffer zones seems the simplest. However, there are many questions about the "white spots" or remnants of the territory between the circles of the specified radii, on which it is impossible to create a map of a certain scale without violating regulatory requirements. Often such gaps are very small, so the development of the network is relevant only in the future, given the demand for cartographic works of more detailed scale.

The use of Thissen-Voronoi polygons can be justified only under the condition of the optimal uniform development of the geodetic network within the regulatory requirements. It allows to carry out geodetic works with greater optimality and to determine the effective zone around each of the points. However, the situation when the area of the polygon formed as a result of the analysis exceeds the normative one seems somewhat abstract at the modeling stage. The combination of this technique together with the buffer zones makes it possible to spatially see the presence of zones to identify places that need network development.

The organization of space and development of the DGM network using a hexagonal grid is optimal. Of course, the location of points far from the centroid can be criticized, but this is offset by the trend towards satellite methods of determining coordinates. For example, the average radius of "service" of one reference station in Europe is 55 km, while the radius of the circumcircle of one hexagon varies from 2.4 km to 3.4 km, depending on the scale studied in the article. In addition, by using a base of hexagons it is technically easier to implement geodetic bit geodetic networks.

Comparing the results of the assessment by different methods, a high and very high degree of correlation (according to the Chaddock scale) is observed between all of them, which increases with the transition to smaller scales in all cases.

Priority places for further development of the State Geodetic Network can be determined by sorting hexagons with missing points and available population density within the polygon.

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