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THE ISSUE OF DETERMINING OF THE GEODESIC CENTER OF UKRAINE IN THE CONTEXT OF EVOLUTION OF CENTROGRAPHIC RESEARCH

Aim. The aim of the proposed research is to substantiate the scientific and practical significance of calculating centers of states and regions territories , to conduct a historical review of centrographic research in Ukraine and in the world in the context of evolution of their methodology, to establish geodetic coordinates of the set of points lying on the line of the land state border and coastlines along the seas, and to determine the center of dead weight of the territory of Ukraine as the center of gravity of the broken polygon formed by state territory contours (geodesic center of Ukraine). Methods. In calculating the geodesic center of Ukraine, the authors used a method (in their own interpretation) of determining the center of gravity of the territory, proposed by Jean-Georges Affholder and tested by him in establishing the center of Europe. Results. The history of centrographic research is more than 250 years old, but only in the last-half century they have acquired a proper scientific character, becoming a solid geodesic base. The main milestones in the formation of the centrographic dimension in context of determining the centers of a number of leading world countries and the evolution of research methods are presented. It is established that it is necessary to distinguish the geometric, geographical and geodesic centers of territories, which differ in method of definition and level of accuracy stipulated by calculations requirements. Each of the recognized centers of the territory of Ukraine has its own significance and justification. Scientific novelty. A historical review of definition of the territories centers in the world and in Ukraine has been made. A method of calculating the center of territory gravity of Ukraine as the center of a broken landfill formed by its contours, including the land state border and coastline, is proposed. The concept of "geodesic center" has been introduced to denote the center of territory gravity, which describes a polygonal, including irregular, figure. The location and exact coordinates of the geodesic center of Ukraine, located in the Novoukrayinsky district of Kirovohrad region, has been established. Practical significance . Specifying the location of territories centers is important in terms of optimizing location of manufacturing facilities and infrastructure, as well as potential tourism facilities. The methods used in calculating territories centers of Ukraine can be used not only in conducting similar studies for administrative regions, but also in newly created districts, united territorial communities, etc.

Key words: centrographic research, geographical center, geodesic coordinates, gravity center of territory, gravity center of broken polygon, geodesic center of Ukraine.

Subject Statement and Sources Review

During past decades, the interest of scientists and public to the topic of defining geographical centers of territories of states and their administrative-territorial entities, as well as macro-regions of the world has significantly grown. In our opinion, the reason for this, are, in particular, a significant increase of number of sovereign states on the planet in the last-half century and the rapid development of tourism as a profitable economics' sector as well. The latter provoked an increased interest to the above-mentioned issue, including in highly developed countries, where quite recently the geographical coordinates of the centers of administrative-territorial units of the first and second order have been calculated [Affholder, 2003; Mittelpunkt Deutschlands].

As for Ukraine, we think, the growing interest in centrography is due to both of the above reasons. At the same time, attempts to calculate geographical centers are not limited to the territory of Ukraine as a whole, recently similar measurements have been conducted for individual regions [Ostapchuk, & Nimkovych, 2017].

To solve that from modern scientific standpoint, the issue of establishing geographical centers of territories, including improvement of theory and methodology of centrographic research, the most

significant contribution was made by foreign geographers and surveyors Jean-Georges Affholder, Christian. Bischoff, Hans. Brunner, Stefan. Wagenknecht, and Ukrainian scientists – Vikor Shevchenko, Yurii Karpinsky, Yaroslav Kudlyk, Volodymyr Hrytsevych, Anatolii Kornus, Oleh Pechenyuk and others. From theoretical and globalistic aspects, the scientific achievements of a French scholar and engineer Jean-Georges Affholder [Affholder, 1991; 2003], who introduced his own method of calculating the center of the territory, which is about calculating the center of gravity of the surface of the ellipsoid, as close as possible to the Earth's surface. His proposed method, improved by Ukrainian scholars, shaped the basis of our calculations, designed to bring a stronger geodetic base to current research carried out mainly by geographers.

The **aim** of the research is to determine the center of gravity of the Ukrainian territory as the center of gravity of a broken landfill formed by the land state border and seas' coastline (geodetic center of Ukraine).

The main objectives of the research:

– to define the goal of defining the territories' centers;

– to conduct a historical review of centrographic research in Ukraine and in the world in the context of the evolution of their methodology;

– to determine the geodetic coordinates of points on the line of the State Border of Ukraine;

– to calculate the center of gravity of the territory (geodetic center) of Ukraine on the basis of the received coordinates of points.

Presentation of the main points

Centrography of countries and territories is a scientific issue that is at the intersection of object-subject areas of science which study the Earth – geography and geodesy.

Various methods were used to determine the centers of territories, including average coordinates, equal areas, integral estimates, etc. [Ostapchuk, & Nimkovych, 2017]. The method of determining the center of gravity of the figure is the most common and most recognized in the world scientific practice [Ostapchuk, & Nimkovych, 2017].

However, the above-mentioned methods, although quite satisfactory from a geographical point of view, are still not accurate enough in terms of geodesy, because they do not fully take into account the true shape of the planet, different not only from the sphere but also from the ellipsoid of rotation – they do not take the spatial differentiation of the Earth gravitational field to attention.

The method of determining the center of the territories, which takes into account the heterogeneity of the Earth gravitational field, proposed by the French geodesist Jean-Georges Affholder [Affholder, 2003]. He used it in many centrographic studies in France and abroad.

Defining geographical center of states over the past century and a half has become one of seemingly unofficial signs of the nation's sovereignty and importance in the world community. In particular, the geographical center of the United States was measured and re-measured (in connection with the annexation of Alaska and Hawaii in 1959) (excluding territorially separated states), according to the measurements and calculations of Julius Erasmus Hilgard [Hilgard, 1872], held in 1872, located in Lebanon, Kansas, and, including Alaska and Hawaii – west of Castle Rock, South Dakota) [Department of the Interior Geological Survey, 1964].

In the former Russian empire, an attempt to determine the geographical center of the then state was first made by the eminent scientist Dmitriy Mendeleev [Mendeleev, 2002]. In 1984, the above-mentioned Jean-Georges Affholder, using his own method, calculated the geographical centers of France (separately with and without Corsica; in the first case, the center is located in the commune of Vesdun, in the other – in the settlement of Nassigny) [Affholder, 1991]. The geographical center of reunified Germany in 1990, located in the village of Niederdorla (Vogtei community, Thűringen) [Mittelpunkt Deutschlands]. Similar examples can be given for many countries.

Attempts to determine the geographical center of Europe have a particularly long history. The first of them was made in 1755, when the Polish cartographer Szymon Sobiekrajski, based on research performed by the methods of the time, claimed that it was located on the market square of the town of Suchowola, 52 km from Bialystok [Suchowola (Poland)]. Later, interest in this problem was awake in the late twentieth century. in connection with modern processes of European integration. In particular, in 1989, scholars at the French National Institute of Geography, supervised by the above-

mentioned Jean-Georges Affholder by calculating the center of mass of the geometric figure of Europe, its center (in fact, in our opinion – the geodetic center) was found in Lithuania, namely – in the village of Purnuskes, 25 km north of Vilnius [Kokmeijer, 2008]. Further attempts to "clarify" the location of the geographical center of Europe were largely subjective, as evidenced by the inevitable "location" of such a center in the territories of the countries where the study was conducted (Hungary, Slovakia, Belarus, etc.). A memorial in the village of Dilove, Rakhiv district of Zakarpattia region, where in the late XIXth century there was an inscription made in Latin, which testified to the establishment of the coordinates of the point made in Austria-Hungary by high-precision (for that time, of course) devices [Zastavny, 1994]. Thus, there was no mentioning of the "center of Europe" and, in our opinion, the attitude to such a common interpretation of this sign in our time should be cautious.

In Ukraine, the issue of defining the geographical center of the territory was first raised about a hundred years ago in the wake of the national liberation revolution of 1917–1921, attempted to solve this problem by calculating the methods known at the time to the geographical center of the UkrSSR (which did not include the western regions) and locating it near Nikopol [Rudnytskyi, 1994]. After the Soviet government curtailed the policy of "Ukrainization," the arrest and execution of Stepan Rudnytskyi himself and many of his colleagues, this issue was long forgotten. Centrography research of Ukraine was raised again only during the latest national upsurge in the late 1980s. Since then, centrographic research has been started by Yurii Karpinsky and Anatolii Liashchenko, geographers Viktor Shevchenko, Volodymyr Hrytsevych, a mathematician Yaroslav Kudlyk.

The first attempt to establish the geographical center of Ukraine in its modern borders in 1989 was made by professor of Kyiv University Viktor Shevchenko. According to his calculations, this is a point on the northeastern outskirts of the village of Dobrovelychkivka (near the "Cossack well") of Kirovohrad region with coordinates 48°23'05" of northern latitude and 31°10'37" of eastern longitude, where in 1990 a memorial was erected. These coordinates were calculated using the analog-cartometric method, which takes into account the complex configuration of the territory of Ukraine and its considerable length from north to south and from west to east, as well as the sphericity of its surface. The extreme points of the territory of Ukraine were taken as a basis for determination [Shevchenko, 2006]. Almost immediately, it became clear that the results of Shevchenko's research (despite its exceptional significance in history of the formulation and solution of the issue) need to be clarified.

A significant contribution to further research of the problem was made by Yurii. Karpinsky, Anatolii Liashchenko and Andrii Dyohtyar, which on the basis of their own measurements and calculations localized the geographical center of Ukraine in Cherkasy region, namely near the town of Shpola [Karpinsky, et al., 2002].

The study of the question was continued by Lviv scientists – geographer Volodymyr Hrytsevych and mathematician Yaroslav Kudlyk. They proceeded from the position that the geographical center should be calculated as the center of gravity of a flat figure bounded by the borders of Ukraine. The point, calculated from the average values of latitude and longitude of the extreme northern, southern, western and eastern points of Ukraine, has coordinates of 48°22'58" of northern latitude and 31°10'56" of eastern longitude and is located on the northern outskirts of the village of Maryanivka between the former district center – the town of Shpola – and the village of Matusiv [Hrytsevych, 2003].

In 2005, based on the results of the above-mentioned centrographic studies of Viktor Shevchenko, Yurii Karpinsky, Volodymyr Hrytsevych and others the order of the State Committee for Natural Resources of Ukraine No. 95 "Regarding the specified location of the geographical center of Ukraine" was prepared and issued, which confirmed that the geographical center of Ukraine is located in the village. Maryanivka, Shpola district, Cherkasy region, and it is stated: "in reference, statistical, educational and other official publications, a certain center of the territory of Ukraine is used0" [Laws of Ukraine. Information and legal portal].

However, the significance of the above-mentioned results of Viktor Shevchenko's research has not been diminished, and the village of Dobrovelychkivka is now interpreted as the "geometric center of Ukraine" [Shevchenko, 2019] or the "geographical middle of Ukraine" [Hrytsevych,

2002]. It should be emphasized that Viktor Shevchenko also has important theoretical generalizations on the issues of centrography [Shevchenko, 2006].

We emphasize that the position of the geometric center of a figure of complex shape (polygon) can be defined as the arithmetic mean of the coordinates of the points. That is:

$$B_0 = \frac{\sum_{i=1}^{n} B_i}{n}; \quad (1)$$

$$L_0 = \frac{\sum_{i=1}^{n} L_i}{n}, \quad (2)$$

where B_0, L_0 are geodetic coordinates of the angles of rotation of the landfill sides. .

We have determined the geodetic coordinates of 1500 points of the State Border and the coastline of Ukraine (such a number of points that prevents the appearance of rectilinear sections of the border with a length of more than 5 km, we consider sufficient). For these points, the position of the geometric center of our state, defined as the arithmetic mean, is characterized by the following coordinates:

B_0geom = 47°44'53.3";

L_0geom = 32°13'22.8".

But this method is not unambiguous [Gashkov, 2015], in particular in the presence of small almost rectilinear sections of the figure. In this case, the geometric center will be shifted. To simplify the illustration of this process, consider the right-angled coordinates of the ordinary triangle ABC and the "degenerate" quadrilateral AVKS, in which the point K will lie on one of the sides of the triangle ABC (Fig. 1).

The coordinates of the points of these figures are given in Table 1.

Table 1

Coordinates of points of flat figures

	A	B	C	K
X	0	40	0	4
Y	0	0	30	27

In this case, the geometric center of the figure ABC has the coordinates:

X_0geom = 13.33 Y_0geom = 10.00.

And the geometric center of the figure AVKS has coordinates:

X_0geom = 11.00 Y_0geom = 14.25.

That is why geodesy recommends calculating the centers of complex shapes as the center of gravity of the polygon [Affholder, 2003]. In the use of a "degenerate" quadrilateral as a polygon, we see our own interpretation of the above-mentioned method of Jean-Georges Affholder.

To establish the coordinates of the center of gravity of a broken polygon of complex (unextended) shape, well-known formulas are used [Pechenyuk, 2006]:

$$X_0 = \frac{\sum_{i=1}^{n} X_i}{n+1}; \quad (3)$$

$$Y_0 = \frac{\sum_{i=1}^{n} Y_i}{n+1}, \quad (4)$$

where n is the number of vertices of the angles of rotation of the polygon boundary.

It is obvious that this formula will work not only for rectangular coordinates X and Y, but also for spherical coordinates, in particular geodetic B and L, provided that they were determined by cartographic materials, which take into account corrections for the curvature of the Earth. Calculated according to the following formula, the coordinates of the center of landfill gravity , limited to 1500 points of the State Border and the coastline of Ukraine on the Black and Azov Seas, were:

B_0geod = 48°20'51.0";

L_0geod = 31°27'36.8".

Note that when calculating the center, we did not take into account the islands located in the Black Sea (Berezan, Dzharilhach, Zmiiny, etc.), because, in our opinion, they are too small to affect the location of the center of gravity of Ukraine. It should also be noted that when determining the coordinates of points on the shoreline, its inequalities were taken into account, including in the area of the Dnipro - Buh and Dnister estuaries, which are the deepest in the land.

Our established point, which we propose to call the geodetic center of Ukraine, is located near the village of Zvirivka in the Novoukrainka district of the Kirovohrad region (Fig. 2; 3).

Conclusions

Centrographic studies are of great scientific and practical importance, because, firstly, the definition of centers of gravity of territories contributes to the optimal location of enterprises and industries, infrastructure, general planning, etc. And, secondly, such centers can become important objects of tourism.

Although, the attempts to find the centers of territories in different countries have been going on for over 250 years, a sufficiently strong geodetic scientific base for such research has been brought up in the last-half century, in which the French geographer and surveyor Jean-Georges Affholder, had made a significant impact In Ukraine, in accordance with the principles of centrographic research developed and accepted in the world, the geometric, geographical and geodetic centers of the territory of the state are calculated.

To calculate the center of landfill gravity formed by the land state border of Ukraine and the coastline of the Black and Azov Seas, the coordinates of 1500 points lying on the line contouring the territory of the state were determined. Using the formulas, the coordinates of the geodetic center of Ukraine, located within the Novoukrainsky district of Kirovohrad region, were obtained.

We associate prospects for further centrographic research in Ukraine with the definition of geographical and geodetic centers of administrative regions (for some relevant measurements and calculations have already been carried out [Kornus, 2011; Ostapchuk, & Nimkovich, 2017], as well as newly formed enlarged areas and united territorial communities. The quarantine restrictions on long-distance migration caused by the Covid-19 pandemic are of particular importance to local tourist destinations, which, in our opinion, may occupy a prominent place among the centers of territories.

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ПРОБЛЕМА ВИЗНАЧЕННЯ ГЕОДЕЗИЧНОГО ЦЕНТРУ УКРАЇНИ В КОНТЕКСТІ ЕВОЛЮЦІЇ ЦЕНТРОГРАФІЧНИХ ДОСЛІДЖЕНЬ

Метою досліджень є обґрунтування наукового й практичного значення обчислення центрів територій держав і регіонів, проведення історичного огляду центрографічних досліджень у світі й в Україні в контексті еволюції їх методики, встановлення геодезичних координат множини точок, що лежать на лінії сухопутного Державного кордону і береговій лінії морів та визначення центру ваги території України як центру тяжіння ламаного полігона, утвореного контурами території держави (геодезичного центру України). Методи. При обчисленні геодезичного центру України використано, у власній інтерпретації авторів, методику визначення центру ваги території, запропоновану Ж.-Ж. Аффольде й апробовану ним при встановленні центру Європи. Результати. Історія центрографічних досліджень нараховує понад 250 років, але тільки в останні пів сторіччя вони набули власне наукового характеру, ставши на міцну геодезичну базу. Наведено основні віхи у становленні центрографічного напрямку в контексті визначення центрів територій низки провідних держав світу й еволюції методики досліджень. Встановлено, що необхідно розрізняти геометричний, географічний і геодезичний центри територій, що розрізняються за способом визначення й рівнем точності, продиктованим вимогами до проведення обчислень. Кожен із визнаних центрів території України має власне значення та обґрунтування. Наукова новизна. Здійснено історичний огляд визначення центрів територій у світі й в Україні. Запропоновано метод обчислення центру ваги території України, як центру ламаного полігона, утвореного її контурами, в тому числі сухопутним Державним кордоном і береговою лінією. Запроваджено поняття “геодезичний центр” для позначення центру ваги території, що описує багатокутну, в тому числі неправильну, фігуру. Встановлено місце розташування й точні координати геодезичного центру України, локалізованого в Новоукраїнському районі Кіровоградської області. Практичне значення. Уточнення місцезнаходження центрів територій має значення з погляду оптимізації розміщення об’єктів виробництва та інфраструктури, а також як потенційних об’єктів туризму. Методики, застосовані при обчисленні центрів території України, можуть бути використані не лише при проведенні аналогічних досліджень для адміністративних областей, а й новоутворених районів, об’єднаних територіальних громад тощо.

Ключові слова: центрографічні дослідження, географічний центр, геодезичні координати, центр ваги території, центр тяжіння ламаного полігона, геодезичний центр України.

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