RESEARCHING THE GEODETIC WORKS IN FORECASTING THE LEVEL OF THE BLACK SEA COASTLINE

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Abstract

Black Sea coasts are important targets for preventing the adverse effects of climate change due to their sensitivity to temperature and climate changes. Also, coastal zone is of enormous economic importance to countries of Black Sea basin. Research proves that in order to prevent the negative economic and social consequences caused by the destruction of economic and natural objects located in the coastal strip, it is necessary to monitor its condition and changes in the coastline. Appropriate researches should be carried out using measurement methods that allow to obtain necessary accurate and reliable information about current and permanent changes, taking into account the need to make a long-term forecast. The object of study is the Black Sea coastline. The subject of the study is surveying observations of changes in the Black Sea coastline and their impact on the surrounding areas. The aim of the research is to develop proposals for modernizing the effectiveness of research and monitoring of coastline changes. As a result of the study, the historical stages and the current state of the network of observation points and space data of the Black Sea level study are determined; the relevance of using the photogrammetric method of forecasting changes in the Black Sea coastline on the basis of data obtained by unmanned aerial vehicles (UAV) is substantiated; the classification of UAV on various signs is formed; the advantages of UAV use for the updated topographic and geodetic support for forecasting changes in the Black Sea coastline are substantiated.

Keywords: geodetic monitoring, unmanned aerial vehicles, topographic and geodetic observations, coastline, state of the Black Sea.

INTRODUCTION

The history of observations of the Black Sea has a century and a half period. The complete bibliography of works in which various aspects of its variability are considered, includes more than 300 names. In the last 25 years, a new direction in studying the variability of the Black Sea level has been put on the agenda - the study of its fluctuations and the forecast of future changes. It is largely due to the current global rise in the oceans, resulting in flooding of low coastal areas, as well as the active reshaping of coasts with negative consequences.

Therefore, understanding the causes of rising or falling sea levels, as well as monitoring these fluctuations is of great economic importance, in particular, in the construction of shore protection and port facilities, the development of marine recreational areas and other. This problem may become even more relevant in connection with the expected acceleration of ocean level rise in the XXI century.

MATERIALS AND METHODS

The methodological basis of the work is a system of classical provisions of topographic and geodetic support of the study of territories, including scientific works of domestic and foreign scientists to determine the organizational, institutional and scientific justification of geodetic observations. In the process of research to achieve this goal the following methods of scientific knowledge were used: induction and deduction; economic-statistical and graphoanalytical methods; logical generalization, synthesis, comparison, system and spatial analysis.

RESEARCH RESULTS

Thorough observations of the Black Sea level began in the middle of the XIX century. They were conducted on level rails (footposts) installed in several ports, mainly by the Directorate of Lighthouses and Lots of the Black and Azov Seas and partly by the Port Authorities. Data from these observations have not been preserved. In the second half of the XIX century, systematic observations of fluctuations in Black Sea levels were organized, and level posts were established in the ports where the fleet was based and on the coastal lighthouses of the Hydrographic Service.

For a long time, the results of observations at these posts remained the only material on the basis of which the first scientific data on the level regime of the Black Sea was obtained. These materials were used for the practical safety of navigation, hydrographic, geodetic research and port needs.

Systematic observations were organized in 1873. The most relevant have been preserved for Ochakov (since 1874), Odesa and Sevastopol (since 1875). At the initial stage, level observations in Odesa were conducted in parallel on two upper-zero rails installed in 1874 near Richelieu, and in 1875 – near Vorontsov lighthouses. From April 1892, after the closure of the Richelieu lighthouse, observations were made only on the level rail of the Vorontsov lighthouse, where a tide gauge station was created, on which a recorder recorded the sea level.

In 1881, the corps of military topographers began systematic work on laying lines of precise leveling in the European part of Russia. These works were intended to equip the territory with a network of major altitude points necessary for mapping the country and for communication at altitude of the Baltic, Black and Azov seas. Data on the leveling of these lines was used in compiling the first in Russia "Catalog of heights of the Russian leveling network from 1871 to 1893", known as the "Rilke Catalog", named after the military surveyor who directed in those years leveling work, which formed the basis for determining and linking the average long-term levels of the Baltic, Black and Azov Seas. This allowed to perform accurate bindings of water meter posts, including the post of the Odesa port **[1]**.

In 1912, the Department of Commercial Ports of the Ministry of Trade and Industry approved the "General Program for the Development of the Hydrometeorological Service in Commercial Ports and Sea Coasts of European Russia." Previously interrupted observation posts were restored and new level posts were organized.

During the civil war of 1918-1920, the work of many level posts was interrupted, the rails were partially damaged and partially destroyed. In 1920, the Central Station of the Hydrometeorological Service of the Black and Azov Seas, located in Feodosia, carried out extensive work to restore the network of stations and its expansion in accordance with the program of 1912.

Before the Great Patriotic War (1940), the Sevastopol Department of Hydrometeorological Service opened 17 more posts and 2 posts in various parts of the Black and Azov Seas Coast – the Hydrographic Department of the Navy.

During the Great Patriotic War, many level posts were completely or partially destroyed and no observations were made. Posts located on the Caucasus coast were also affected, where surveillance, although continuing, was intermittent due to damage to the level rails during aerial bombardment. During the occupation there was a level post in Yalta. Since 1944, the network of level posts began to be restored, reconstructed and expanded. Sea level recorders were installed at many posts.

In the mid-50's, the geodetic service made a lot of work on the precise leveling of geodetic points, which allowed to bring all the benchmarks to a single system of heights and make the data comparable. Prior to that, each item had its own zero post. In 1977, the USSR's Main Elevation Base was introduced into the Baltic Altitude System, which dates back to the 1977 and is still in use.

Much work has been done in preparing the "Catalog of observations in the Black and Azov Seas" **[2]**: errors from previous observations were excluded, the data was reduced to a single altitude system. In total, in different years on the territory of the former USSR on the Black Sea there were 44 level posts, data from which survived until 1985 inclusive, summarized in **[3]**. This work contains brief information about the posts and their height reference (benchmarks). Since 1992, the network of stations has moved to the newly independent states. In Constanta and Sulina (Romania) observations have been made since 1858, and complete series have been preserved. In Bulgaria, sea level monitoring began in 1881 (Varna), and later the stations Nessebar (1924) and Burgas (1928) were opened. On the Turkish coast during 1949-1962, observations were made in Eregli, Trabzon (1956-1983) and Samsun (1961-1983). In Turkey, the network of stations belongs to the hydrographic service of the Navy.

Currently, the network of Black Sea level monitoring points includes 30 stations. Of these, 13 belong to Ukraine, 5 – to the Russian Federation, 4 – to the Republic of Bulgaria, 3 – to Romania and the Republic of Turkey, 2 – to Georgia. Thus, on average, one station has 120 km of coastline. However, the stations are located very unevenly. The densest network on the west coast is half of all stations. The rarest network on the southern – Turkish coast (only 3 stations).

In Ukraine, 12 out of 13 stations were transferred to the State Committee for Hydrometeorology (currently the Hydrometeorology Department, which is a subdivision of the staff of the State Emergency Service of Ukraine), and one (Katsiveli village) was transferred to the National Academy of Sciences. Some information on sea level observation points in Ukraine is summarized in table. 1.

Table 3.1. Data on Black Sea level monitoring points in Ukraine

№ p / p	Item	Number of terms of observations	Availability of recorders	The beginning of observations
1	Ust-Dunaisk	4		1983
2	Primorsko	2		1951
4	Chernomorsk	4	+	1960
5	Odesa	4	+	1875
6	Jugne	4		1980
7	Ochakiv	2	+	1874
8	Horley	4		1923
9	Black Sea	3		1927
10	Evpatoria	3		1917
11	Sevastopol	4	+	1875
12	Katsiveli		++	1949
13	Yalta	3	+	1927
14	Theodosia	2	+	1912

Source: **[4]**.

Due to the destruction of footstools, no observations were made for several years in Horly, the Black Sea and Evpatoria. The unsatisfactory condition of the network was caused by the decision of a group of MedGLOSS project experts to install a tide gauge in the organization of the National Academy of Sciences of Ukraine – Experimental Department of the Marine Hydrophysical Institute in Katsiveli (Southern coast of Crimea).

Installed in 2003, the tide gauge is part of the MedGLOSS Network and operates in a mode close to real-time (online mode). So data from it is posted with a slight delay on the relevant site (medgloss.ocean.org.il). This tide gauge works in parallel with the tide float of the tide gauge, which is at a distance of about 400 m. In addition to sea level (measured by a pressure sensor), it records the sea water temperature, which is extremely important in terms of monitoring the effects of level changes. The same tide gauge is installed in Constance. The MedGLOSS network also includes Tuapse and Burgas stations, but data from them arrive in the off line mode **[4]**.

Various methods are usually used to assess the condition of the coastal strip. In the conditions of research of a coastal strip of the Black Sea it is possible to offer use of the following research methods (fig. 1).

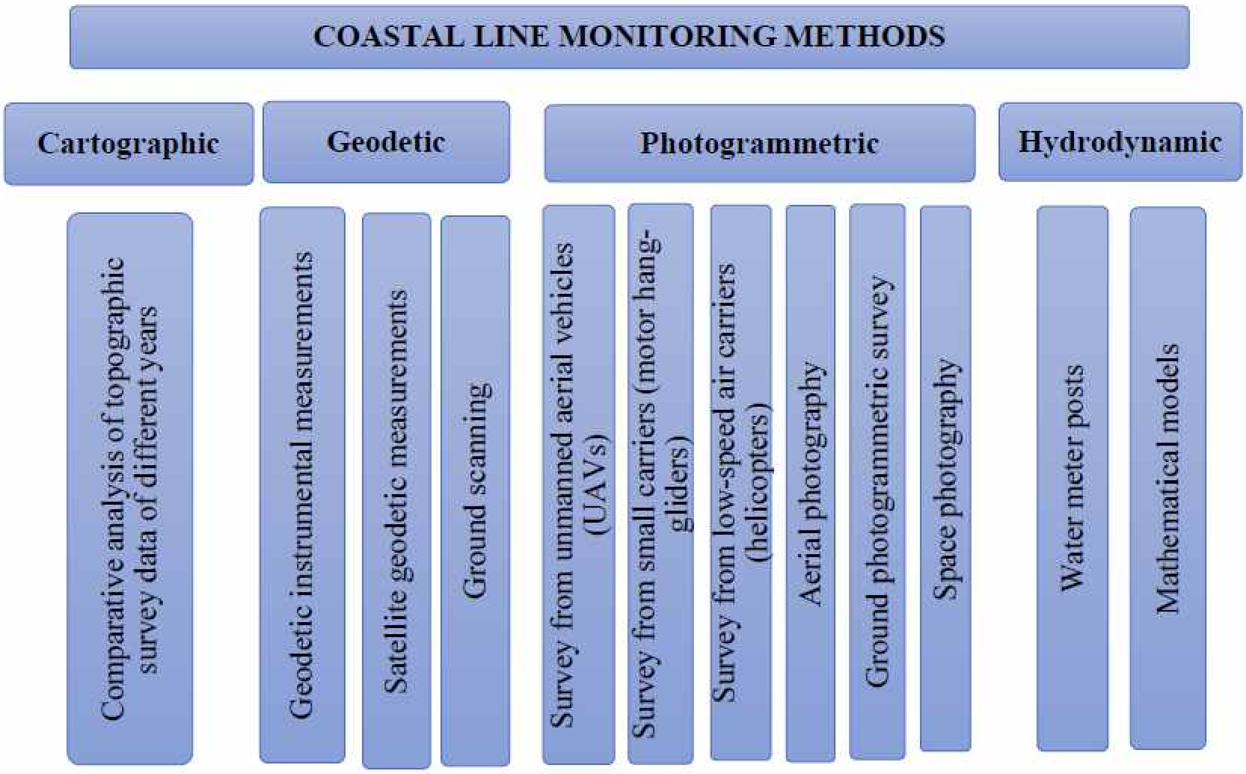

Fig. 1. Coastal line monitoring methods

The above methods have different degrees of suitability for monitoring the dynamics of the coastline.

Cartographic method

The cartographic method is suitable for studying its dynamics only in the long run, as the period of updating cartographic materials is calculated in years. The cartographic method is based on the study of maps of coastal areas created in different periods. The accuracy of obtaining information about the coastal strip in this method depends on the scale of the topographic map used, and the relevance of the information - from the time of creation of the map. The requirement for the accuracy of the map (the degree of conformity of the location of objects on the map to their location in reality) is that the objects depicted on it must maintain the accuracy of their location, geometric shape and size according to the scale of the map and its purpose. Therefore, the cartographic method is used to obtain only primary information about the state of the coastal strip. The order of renewal of cartographic materials is accounted in years and depends on many factors, because the map is essentially the product of a set of astronomical and geodetic data, remote sensing data, field observations and measurements, text sources. In this regard, this method of monitoring in itself does not meet the input parameters of the monitoring.

Geodetic method

The geodetic method is a topographic survey of the coastal strip. When surveying the coastal strip, traditional technologies for topographic surveying are used. For regular observation of the territory, it is advisable to use geodetic networks and thickening networks as a basis for repetitive measurements. Deformation marks or integrated sensors are used to study the dynamics. The geodetic method has a high accuracy, but due to the high complexity and high cost, this method should be used only for monitoring small areas of the coast.

Satellite technologies play a role of supporting other technologies. The essence of satellite technology is to use the Global Navigation Satellite System (GNSS) and computer processing system (computers and software) to obtain the coordinates and heights of points in the area. The location of the point when using satellite technology is determined by measuring the time of the signal coming from the Earth's satellites.

GPS receivers are geodetic devices that allow you to quickly perform a topographic survey of the shoreline. The results of the recordings can be recorded directly by GPS in the field, and then transmitted to a computer in the office, and can be viewed either using software provided by the manufacturer, or in a GIS for processing. The GPS standard has an accuracy that can vary from 1 to 10 meters (X, Y) depending on the location, equipment, etc. The value (Z) is not used due to its large inaccuracy. Using multiple satellites provides better accuracy. At least four satellites must be involved **[5]**.

The advantages of GPS are that it allows executors to take measurements quickly and easily. It is an affordable tool, easy to use and relatively accurate (depending on the need, when it is not necessary to have high accuracy). The disadvantages of GPS are that this technology in some cases provides very low accuracy (10 m or more). For surveying along rocks (below) or under vegetation cover, GPS may have some limitations due to the difficulty of capturing satellites.

Photogrammetric methods include a wide range of technologies: unmanned aerial vehicles (UAVs), surveying from small carriers (motorized hang gliders), surveying from low-speed air carriers (helicopters), aerial photography, ground photogrammetric surveying, space photography, radio photography. The photogrammetric method involves the use of remote sensing data using air or space-based imaging equipment, which includes aerial photography and subsequent photogrammetric processing of the images, as well as aerial laser-location imaging. Remote sensing is the observation of the Earth's surface by aircraft and spacecraft equipped with various types of imaging equipment **[8].**

During aerial photography, the media equipped with the camera flies at a fixed height above the coastal zone. With the help of the camera, images that provide overlapping images for further stereo processing are obtained. Currently, GPS records the coordinates of each image when using UAV. Aerial photography allows to determine the geometry of the shoreline and then have access to its dynamics. An important condition is the comparison of surveying conditions, which in practice is difficult to perform. Aerial photography can be combined with digital terrain modeling, which creates augmented reality. Analyzing the data processing process, it should be noted that in general, processing of any remote sensing data obtained from the air consists of the stages of pre-processing, photogrammetric processing and subsequent decoding. However, each type of surveying has its own characteristics [9].

The photogrammetric method requires high surveying heights due to the high speeds of modern aircraft. High altitudes reduce image blur, which always occurs when surveying from a moving subject. Photogrammetric information is always relevant, but its accuracy depends on the height of the shot and the speed of the media. The photogrammetric method can be used as a supplement to the geodetic method.

Aerial surveying is a technology that uses an on-board laser scanner installed on board an aircraft or helicopter. On the carrier board, the return time of the laser pulse and the difference between the radiation time and the reflection time are calculated. The lidar covers large areas and has decimeter accuracy. Two types of onboard sensors are used: topographic and bathymetric. Topographic sensors are used to obtain models of the earth's surface. Bathymetric sensors are used to probe the water surface. Many bathymetric lidars simultaneously measure the height and depth of water, providing an aerial laser scan of the water surface. Topographic leaders record changes in the shoreline regardless of water level, vegetation boundaries or rock microerosion, all of which can be easily identified and presented for diachronic analysis. The lidar method can be used as a supplement to the photogrammetric method for capturing stationary situations and stationary objects.

Unmanned aerial vehicles (UAVs) are of two fundamentally different types: aircraft and helicopter type. Modern UAVs have the ability to carry imaging equipment that provides a spatial resolution of 2 cm at a safe flight altitude, the width of the capture band is on average 110 m, and the flight range is about 60 km. Manufacturers give a guarantee for 80 flights, respectively, during the year you can receive data every 1 to 4-5 days. This provisional permit indicator is the best of all monitoring methods available today. In terms of reasonable labor and economic costs, as well as the compliance of the input parameters of the monitoring, this method of shoreline monitoring is the best. It should be noted that the use of UAV survey data allows to create three-dimensional terrain models with high accuracy, which, of course, should be used as part of a comprehensive methodology for monitoring the dynamics of the coastline **[10].**

Space photography is used to monitor large areas. One space image can replace up to 1000 aerial photographs. With the help of space aerial photographs it is possible to obtain information about both the terrain and the state of the coastline, but to obtain information about the terrain it is necessary to use a couple of images. Analysis of the parameters of artificial satellites of the Earth, which capture the Earth's surface, shows that currently the ability to obtain images with a spatial capacity of 30 cm among the space-based imaging systems has two spacecraft (SP) - WorldView 3 and WorldView 4. The main amount of space survey data is performed with a capacity of 50-60 cm. In most cases, the height error in such data is close to

1.5-2 pixels - is 75-100 cm. The error in the plan usually is 2-3 pixels - 1-1.5 m (in the presence of a high-quality relief model and a sufficient number of reference points) **[11]**. Space survey materials are generally suitable for creating large-scale contour plans (2D), but do not provide the required accuracy of altitude for this scale. Thus, we can conclude about a fairly high accuracy, which corresponds to the input parameters of the monitoring. An important parameter of any satellite imaging system is the temporary resolution or repeatability of the same area.

Water meter measurements

The modern scientific literature describes methods and algorithms for modeling phenomena related to the oceans. Thus, the most dynamic oceanic natural phenomena, such as storm surges, are subject to modeling. The modeling is performed using various hydrodynamic models, for example, ADCIRC (ADvanced CIRCulation model for oceanic, coastal and estuarine waters), with correction for observations obtained at water meter posts. Similarly, less dynamic oceanic natural phenomena, such as coastal abrasion, can be simulated.

According to the design and method of the device there are water meter posts:

- simple, at which the height of the level is measured by a water meter rail (rail foundation, mixed (rail-foundation));
- transmitters, at which the height of the level is measured and transmitted by transmitting devices;
- automatic, at which water level fluctuations are continuously and automatically perceived by the sensor (float, manometer, etc.) **[12]**.

The choice of a particular type of water meter depends on climatic and local conditions, as well as requirements for the accuracy of the results of observations. Currently, the most modern and accurate type of water meter posts is automatic. Water metering data combined with a three-dimensional shoreline terrain model (created (and regularly updated) based on UAV aerial photography data) can have a significant impact on improving the quality of coastal abrasion forecasting in the most coastal problem areas characterized by near-coastline retreat speeds 20 m / year.

CONCLUSIONS

As a result of research on shoreline monitoring methods, we can conclude:

1. The optimal method for forecasting the level of the Black Sea coastline is the photogrammetric method using unmanned aerial vehicles with small-format cameras or medium-format air cameras.
2. The geodetic method of instrumental measurements and the method of satellite geodetic measurements correspond to the input parameters of the monitoring in terms of accuracy, but do not correspond in terms of repeatability of the survey in terms of high economic costs and use of large human resources.
3. Space survey materials can be used to monitor the long-term dynamics of sea shores. A common method for estimating coastline dynamics currently used by researchers is retrospective analysis of space images.

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