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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

REMOTE SPECTROMETRIC METHODS AND MEASURING TOOLS FOR

COASTAL POLLUTANTS

Specialty: 3337.01 Information-measuring and control systems (in environmental monitoring)

Field of science: **technical sciences**

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GENERAL CHARACTERISTICS OF THE WORK

Relevance and thoroughness of the topic. For sustainable development of coastal areas and environmental protection in these regions, reliable monitoring of coastal zones is a major task. The task of controlling the degree of pollution of seawater in large geographic areas, taking into account the high information content of such an indicator of water spaces as the color of seawater, is of particular relevance. Remote sensing methods allow monitoring the synthesis of new models for determining the chlorophyll content in seawater. Coastal monitoring is essential for sustainable coastal development and environmental protection in these regions. The study of the long-term and seasonal dynamics of the coastlines of various water bodies is of particular importance.

The coastline is the most important temporal characteristic of the earth's surface. Almost 44% of the world's population live within 150 km of the ocean and according to the IPCC https://www.ipcc.ch/ forecasts, the ocean water level will rise from 19 cm to 50 cm by 2099.

In India alone, a 1-meter rise in ocean water levels will lead to the displacement of a population of 7 million. All this indicates the relevance of studying the issues of determining the dynamics of changes in the coastline of the seas and oceans. The shape of the coastline is influenced by factors such as hydrography, geology, climate and plants. When studying the pollution of coastlines with oil, from an environmental point of view, it is relevant to calculate the volume of oil that can be accumulated in the coastline zone; study of differences between such separate types of oil as light oil, heavy oil; development of a methodology for assessing oil accumulated on the coastal zone, etc. When carrying out remote measurement of organic substances dissolved in water in shallow areas of coastal waters and rivers, the main problem is the influence of the reflection of the measuring beam from the bottom of the reservoir. Optical radiation reflected from the bottom during remote sensing should be taken into account in shallow coastal zones of water bodies.

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Determination of the state of the study of turbidity of coastal waters is one of the tasks of environmental control. For this purpose, various satellite and aircraft means of remote sensing can be used, and stationary turbidimeters can be used to validate the results obtained.

The study attaches particular importance to the long-term and seasonal dynamics of the coastlines of various water bodies. For a certain time interval, the concentration of chlorophyll and suspended particles under stable conditions of environmental pollution of sea basins in the coastal zone is constant.

In the presence of reliable space data on the chlorophyll content in water, it becomes possible to study the absorption and scattering properties of suspended marine solid particles. Water turbidity is defined as the decrease in transparency due to attenuation of the optical beam passing through the water due to absorption, scattering and reflection from suspended solids.

Phytoplanktons carry out more than 50% of the total volume of the photosynthesis process on Earth by absorbing light and CO2, generating oxygen. The absorption of sunlight by phytoplanktons leads to a change in the color of sea waters from blue to green, while chlorophyll is the main light-absorbing pigment in phytoplankton.

In a water column with a height of 4000 m, organic carbon is 100 g/m2. In total, the total mass of such particles in the oceans is 2x1016 g.

The transmission of light in the water column is significantly influenced by suspended particles and, therefore, these particles affect the optical and biological properties of sea waters. In particular, they affect the coefficient of diffuse attenuation of light at a wavelength of 490 nm, the concentration of chlorophyll, as well as the productivity of sea waters.

The quality of life of millions of people living in coastal areas can be affected by total suspended solids, which is an indicator of water quality and the purity of sea waters. Traditionally, the 645 nm MODIS channel (36 channel VIS / IR spectroradiometer) as well as the 545 nm and 840 nm channels of the SPOT satellite are used for remote sensing.

Various data sources can be used to study coastline dynamics, such as cartographic data, satellite imagery (SPOT-PX / XS, Landsat-TM, Corona), and aircraft data. The solution to such issues is taken after analyzing the scale of coastline pollution, in particular, the dependence of the length of the polluted part of the coastline on the volume of crude oil poured into the sea.

Colored dissolved organic matter (CDOM) is detected in water as photoactive fractions of dissolved organic matter in the ultraviolet (UV) range. The optical absorption coefficient of these substances is high and decreases to zero in the red zone of the electromagnetic spectrum.

For this reason, 440 nm is often used for remote CDOM measurements. The concentration of CDOM is often presented as an indicator of the distribution of organic carbon in the aquatic environment; therefore, it is important to study the carbon cycle in the space of interaction between the aquatic and terrestrial environment. remote measurement of CDOM (Colored dissolved organic matter).The purpose and objectives of the study. The aim of the thesis is to develop new methods for remote sensing to increase the reliability of assessing the state of the environment in the coastal zone.

To achieve this goal, the following main tasks are formulated and solved in the dissertation:

1. Development of a two-wave method for determining the concentration of suspended solids in seawater, providing for joint two-wave measurements of a parameter that depends on the

experimental conditions, the concentration of chlorophyll and suspended solids.

2. Development of a method for classifying suspended particles by the magnitude of the absorption coefficient of optical radiation, which makes it possible to classify these particles by their structural composition.

3. Drawing up a model for evaluating signals from satellite spectroradiometers for the case of anomalous air pollution by aerosol and a multi-wavelength method for determining the coastline.

4. Improvement of the three-channel criterion for detecting the coastline, implemented on the basis of measurements of channels B1, B2, B3 of the SPOT XS and X1 equipment, by transforming it into an index-channel criterion.

5. Solving the problem of determining the amount of suspended solids depending on the turbidity of water in the zones of river deltas and in the coastal zones of the seas using turbidometric measurements. Development of one-wave and two-wave methods for determining the total amount of suspended solids and the type of investigated waters.

6. Development of a modified criterion for the selection of methods for remote sensing of dissolved organic matter in the coastal zones of the seas. Solving the problem of optimizing the measurement of the concentration of dissolved organic carbon in the coastal zones of mixing of sea and river waters.

7. Development of a method for the information balance of dispersive and non-dispersive measurement signals used, respectively, for basic and validation measurements for exploration of oil fields using onboard hyperspectrometers.

Methods of research. In the process of solving the problems posed, the corresponding provisions of atmospheric optics, mathematical analysis, optimization theory and spectral measurements were used. In order to confirm the theoretically obtained results, model and experimental studies were carried out using laboratory samples of photometers.

The main provisions for the defense.

1. The proposed two-wave method for determining the concentration of suspended solids in seawater, providing for joint two-wave measurements, as well as a modification of this method, when the concentration of suspended particles is measured autonomously, using slightly shifted wavelengths.

2. The proposed method for the classification of suspended particles by the magnitude of the absorption coefficient of optical radiation, which makes it possible to carry out the classification of these particles by their structural composition in the formed space of the main functional indicators.

3. The proposed model for evaluating signals from satellite spectroradiometers for the case of anomalous air pollution by aerosol, as well as a multi-wavelength method for determining the coastline, developed on the basis of this model.

4. The proposed index - channel criterion, developed on the basis of the well-known three-channel criterion for coastline detection, implemented on the basis of measurements of channels B1, B2, B3 of the SPOT XS and X1 equipment.

5. The solved problem of carrying out turbidometric measurements and the proposed methods for determining the amount of suspended solids depending on the turbidity of the water in the zones of river deltas and in the coastal zones of the seas.

6. Modified criterion for selection of methods for remote measurement of dissolved organic matter in the coastal zones of the seas. The formulated and solved problem of optimizing the measurement of the concentration of dissolved organic carbon in the coastal zones of mixing of sea and river waters.

7. The proposed method for the information balance of dispersive and non-dispersive sounding signals used, respectively, for basic and validation measurements for the purpose of exploration of oil fields using onboard hyperspectrometers.

Scientific novelty of research. The scientific novelty of the research is as follows:

1. A two-wave method has been developed for calculating the concentration of suspended solids in seawater, which consists in carrying out joint two-wave measurements of a parameter that depends on the experimental conditions, the concentration of chlorophyll and suspended solids, as well as an autonomous two-wave measurement of the concentration of chlorophyll. The possibility of implementing a variation of this method, when the concentration of suspended particles is measured separately, using several shifted wavelengths, is shown.

2. A method has been developed for the classification of particles suspended in seawater by the magnitude of the absorption coefficient of optical radiation, on the basis of which it is possible to classify these particles by their structural composition.

3. A model has been developed for evaluating signals from satellite spectroradiometers in relation to the case of anomalous air pollution with aerosol, on the basis of which a multi-wavelength method for identifying the coastline has been developed, which makes it possible to eliminate the aerosol error of the known two-wave method.

4. An improvement is proposed for the well-known three-channel criterion for coastline detection, implemented on the basis of measurements of channels B1, B2, B3 of the SPOT XS and X1 equipment. The specified criterion for conversion to a channel index criterion is more sensitive to a change in B1 / RED than to a change in NDVI.

5. Single-wave and two-wave methods are proposed for determining the amount of suspended solid particles and the type of water under study, depending on the turbidity of the water, determined using two wavelengths.

6. An improved criterion for the selection of methods for remote sensing of dissolved organic matter in coastal zones has been developed. Formulated and solved the problem of optimizing the measurement of the concentration of dissolved organic carbon in coastal zones, where the mixing of sea and river water occurs.

7. A method has been developed for the information balance of dispersive and non-dispersive sounding signals, which are implemented, respectively, for basic and validation measurements for exploration of oil fields using onboard hyperspectrometers. An expression is obtained for determining the signal-to-noise ratio in the system for calculating the correlation between the narrow-band oil index and the broad-band signature indicator of the presence of anomalous concentration of heavy metals.

Theoretical and practical significance of the research.

1. The theoretical possibility of using these channels B1, B2, B3 of spectroradiometer SPOT XS and X1 to determine the coastline, by forming the proposed index - channel criterion, is shown. The properties of the considered three-channel criterion were found, which consists in high sensitivity to changes in B1 / RED than to changes in NDVI.

2. The results of the optimization of the measurement of the concentration of dissolved organic carbon can be used to study the degree of pollution of the coastal sea zones of mixing of sea and river waters.

3. The proposed method of information balance in relation to signals of dispersive and non-dispersive measurement can be applied in the exploration of oil fields or places of pollution with carbohydrates, on the basis of anomalous concentration of heavy metals.

4. The developed measures to increase the efficiency of three-level measurement of water turbidity allow in practice to study in more detail the dynamics of the distribution of water masses in the mouth of the river and sea coastal zones.

5. The proposed method and the improved criterion for determining the coastal zone make it possible to eliminate the aerosol error of the known two-wave measurement method and to increase the sensitivity to spectral indices.

Approbation and application.

The main provisions and results of the dissertation work were reported at the Research Institute of Aerospace Informatics and discussed in the following International Scientific and Practical Conferences:

1. Scientific and technical conference dedicated to the 95th anniversary of Heydar Aliyev, AzTU, Baku; 2018;

2. 2nd Caspian International Conference on Water Technologies “Methods of protection of drinking water from pollution in the Republic of Azerbaijan”, Baku, April 11, 2014;

3. 7th International scientific-practical conference "Actual problems of ecology and labor protection" Kursk, мay, 2015;

4. 10th International Scientific and Technical Conference "Actual Problems of Ecology and Labor Protection" Yugo-Zap. State University, Kursk, 2018;

5. International scientific conference "Transformation of ecosystems under the influence of natural and anthropogenic factors" Vyatka State University. Materials, Kirov April 16-18;

6. International conference "Opportunities for implementation and prospects of information technologies and systems in Azerbaijan", Institute of Systems and Management of ANAS, Baku, July 05-06, 2018;

7. 1st International Conference “Problems and Perspectives (MIMCS'2019)” ADNSU-UBFC July 01-02, 2019, Baku, Azerbaijan p-191.

In addition, the main provisions of the dissertation work are implemented in research work («Dəniz səthində neft təbəqəsinin qalınlığının məsafədən yüksək dəqiqliklə təyin edilməsi üçün fluorescent və üsullarının işlənilməsi» .Baku,-2020,-46s.) carried out in the Research Institute of Aerospace Informatics.

Considering the urgency of the problems solved in the thesis on this subyect («Dəniz səthində neft təbəqəsinin qalınlığının məsafədən yüksək dəqiqliklə təyin edilməsi üçün fluorescent və kolorimetrik üsullarının işlənilməsi») in 2020 there was an agreement on scientific and technical cooperation signed between the Ministry of Ecology and Natural Resources of closed sount Complex Casipan.Environmental Monitoring Department. In accordance with the concluded agreement, an Act was drawn up on the work performed and the implementation of the result obrained in the dissertation/

The name of the organization in which the dissertation work is carried out:

The dissertation work was carried out at the Research Institute of Aeros ace Informatics of the National Aerospace Agency.

The total volume of the thesis by the number of characters, indicating the volume by structural units of the thesis separately

The dissertation work consists of an introduction, four chapters, main conclusions and a list of references. The work is presented on 190 pages of typewritten text, contains 14 tables, 35 figures and a list of references, including 148 titles. The volume of the dissertation is 161,733 characters (without spaces, tables, figures, graphs, appendices and references), including the introduction consists of 14,078 characters, Chapter I consists of 41,947 characters, Chapter II consists of 27,879 characters, III the chapter consists of 35,462 characters, the IV chapter consists of 44,367 characters.

Published works on the topic of the dissertation. On the topic of the dissertation, 23 scientific articles and conference materials were published (including 15 papers in peer-reviewed scientific and technical journals abroad).

SUMMARY OF THE WORK

In the remote study of waters on the coastal expanses of the sea, simple semi-empirical algorithms are used to restore water pollution indicators from satellite data. when considering the problem of pollution of coastal waters, the task of research becomes quite complicated. Coastal waters contain components such as phytoplankton, mineral suspension and dissolved organic matter. The combined optical influence of all these components as a result determines the optical properties of coastal waters.

This circumstance significantly complicates the restoration of the content of a single component and there is a need to develop and apply algorithms that can simultaneously restore the concentrations of all the above components separately. At the same time, under stable conditions of environmental pollution of marine basins, the thesis that the concentration of chlorophyll and suspended particles in the marine coastal zone is constant for a certain period of time can be accepted as an initial assumption.

With this assumption, it becomes possible to carry out space onboard measurements using previous reliable space data on the content of chlorophyll in water in order to study the absorption and scattering properties of suspended marine solid particles.

Reliable monitoring of coastal zones is the most important task for the sustainable development of coastal territories and environmental protection in these regions. At the same time, the study of the long-term and seasonal dynamics of the coastlines of various reservoirs is of particular importance.

The coastline is the most important characteristic of the earth's surface, which has temporal dynamics. The use of remote spectral sensing in order to determine the coastline is based on the properties of the aquatic environment of the absorption of optical radiation in the infrared region and the strong reflection of this radiation by soil and vegetation. These spectral properties of the components of coastal zones cause the use of visible and infrared images to solve the problems of mapping coastlines.

Dissolved organic matter (DOM-Dissolved organic matter) plays an important role in marine waters as a source of carbon and energy for various microbes, as well as for higher-order consumers who feed on microbes or directly on these organic substances.

Turbidity of reservoirs is defined as a decrease in transparency due to the attenuation of the optical beam passing through the water due to absorption, scattering and reflection from suspended solids.

At the same time, the vertical distribution of suspended particles in the water column in the area of the estuary depends on the displacement of river and sea waters. It is obvious that the turbidity of the water mass also depends on a number of meteorological factors, including the strength of the wind driving the water mass in motion. The vertical distribution of suspended matter slightly depends on the processes of storing soil on the marine environment during dredging and sedimentation.

The first chapter of the thesis is devoted to the spectral method for determining the concentration of sea water pollutants. At the beginning of the chapter, a proposed two-wave method for determining the concentration of suspended solids in seawater is presented, which provides for joint two-wave measurements of a parameter that depends on the experimental conditions, the concentration of chlorophyll and suspended solids, as well as an autonomous two-wave measurement of the concentration of chlorophyll [15, p.191]

The possibility of implementing a certain variation of the method, when the concentration of suspended particles is measured autonomously, is shown using somewhat shifted wavelength values. In this case, the results obtained during the implementation of the proposed methods can be monitored by a trial determination of the parameter depending on the experimental conditions [6, т. 136, №4, с.24-27].

Further, in the first chapter, information optimization of the known models for calculating Chl in seawater is carried out when considering the remote sensing data obtained from the SeaWİFS satellite as a basis. On the basis of the known models for calculating the Chl content DC4V4 and CSM01, a new model has been synthesized, which has an information content equal to that of in situ measurements.

The first chapter also describes a method for classifying suspended particles according to the magnitude of the absorption coefficient of optical radiation. A graphic interpretation of the proposed method is given. The proposed method allows for the classification of these particles by their structural composition in the $\left\{\frac{POC}{SPM}, \alpha_P(400)\right\}$ space.

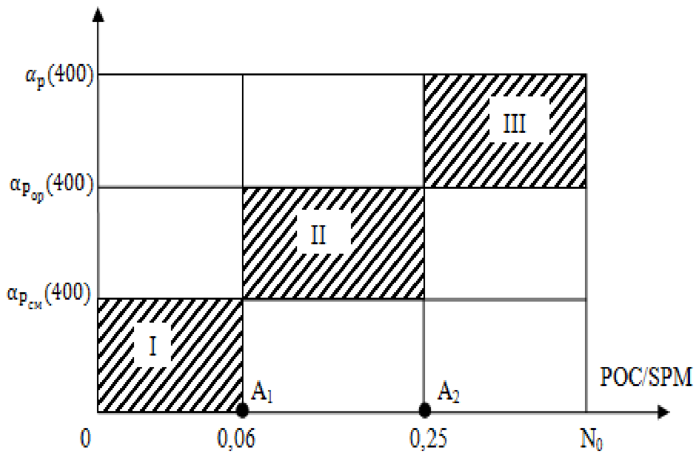

Figure 1. Graphical diagram of the classification of suspended particles [6, т. 136, №4, с.24-27]

The second chapter of the dissertation is devoted to the proposed method for determining sea coastlines using measuring systems. At the beginning of the chapter, a model for evaluating signals from satellite spectroradiometers for the case of anomalous air pollution with aerosol is proposed. On the basis of the proposed model, a multiwave method for determining the coastline has been developed, which makes it possible to eliminate the aerosol error of the known two-wave method [12, c.195-199].

The expediency of multichannel methods for determining the coastline is shown, the results of the three-channel method implemented on the basis of measurements of channels B1, B2, B3 of the SPOT XS and X1 equipment are analyzed. The well-known three-channel coastline detection criterion has been converted into an index-channel criterion. It is analytically shown that the considered three-channel criterion is more sensitive to changes in B1/RED than to changes in NDVI. It is graphically shown that the sensitivity of the test used to B1/RED is at least two times higher than to NDV[7, №3, c.107-112].

Taking into account the above, we propose a multiwave method for determining the coastline in conditions of strong aerosol pollution. Taking into account the model, the aforementioned b_2/b_5 ratio, the aquatic environment is more than one, and less for the land [14, №4 (21), c.49-54].

The essence of the proposed method is to use the well-known three-wave technique applied to b_2 ($\lambda 2$) and b_5 ($\lambda 5$) to eliminate the influence of $\tau_{a.a.}(\lambda_2)$ *and* $\tau_{a.a.}(\lambda_5)$, respectively. According to the three-wave technique, an intermediate indicator is introduced which is defined as

$$\gamma_1(b_2) = \frac{F_1(\lambda_{1^+})^{K_{11}} \cdot F_1(\lambda_{2^-})^{K_{21}}}{F_1(\lambda_2)} \tag{1}$$

Where $\lambda_{2+} = \lambda_2 + \Delta\lambda$; $\lambda_{2-} = \lambda_2 - \Delta\lambda$

Repeating all the procedures of the three-wave method for $b_5(\lambda_5)$, we obtain

$$\gamma_1(b_5) = \frac{F_1(\lambda_{5^+})^{K_{12}} \cdot F_1(\lambda_{5^-})^{K_{22}}}{F_1(\lambda_5)} \tag{2}$$

Where $\lambda_{5+} = \lambda_5 + \Delta\lambda$; $\lambda_{5-} = \lambda_5 - \Delta\lambda$

Given the expressions (1) and (2), we can write

$$\chi = \frac{\gamma_1(b_5)}{\gamma(b_2)} = \frac{C_1 \cdot F_1(\lambda_2)}{F_1(\lambda_5)} \qquad (3)$$

where C_1=const.

Returning to the solved problem of determining the coastline by the two-wave method, the criterion, based on expression (2), can be reformulated as follows: the ratio $\frac{C_1 \cdot F_1(\lambda_2)}{F_1(\lambda_5)}$ in relation to the aquatic environment is greater than C_1 and less than C_1 for land. Thus, the analysis performed makes it possible to improve the known two-wave technique in the sense of eliminating the influence of anomalous values of atmospheric aerosol

The possibility of constructing a hyperspectral measuring system based on the WISOIL index using a controlled liquid crystal filter is considered. The requirement for the speed of movement of the carrier of the measurement system is formulated. The operating mode of the meter has been optimized in the sense of reducing the redundancy of information by introducing an adaptive measurement mode.

The decrease in time of the length of the polluted part of the coastline after the spill of crude oil in the volume of 1 barrel under the influence of wind and water currents was investigated. after the spill. The optimal mode of accounting for influencing factors has been determined, at which the minimum route pollution is achieved along the entire length of the coastline.

The third chapter of the dissertation is devoted to the development of measuring systems and new methods for the study of pollution in sea coastal zones. At the beginning of the chapter, the issues of constructing a system for three-level measurement of the turbidity of coastal waters are considered.

In the considered three-level scheme for measuring turbidity and the total amount of suspended matter (OOB) in seawater, the aircraft sensor plays the role of a link for a better comparison of data from satellite measuring instruments and ground-based meters. At the same time, the light-engine aircraft used can fly at different altitudes to search for the optimal sensing mode with maximum information content.

The issues of constructing a three-level system for determining the turbidity of sea waters and, in particular, the issue of determining the conditions for achieving the optimal mode of operation of an aircraft sensor in the sense of determining the optimal flight altitude are considered

The possibility of constructing and optimizing a three-level complex for remote sensing of sea water turbidity using satellite and aircraft means and a ground-based turbidimeter (Fig. 2).

The following transcendental equation for calculating the optimal flight altitude is obtained.

$$L_h' \cdot \ln(S_0 + S_h' \cdot h(t_0)) + \frac{[L_0 + L_h' \cdot h(t_0)] \cdot S_h'}{[S_0 + S_h' \cdot h(t_0)] \cdot \ln 2} = 0 \qquad (4)$$

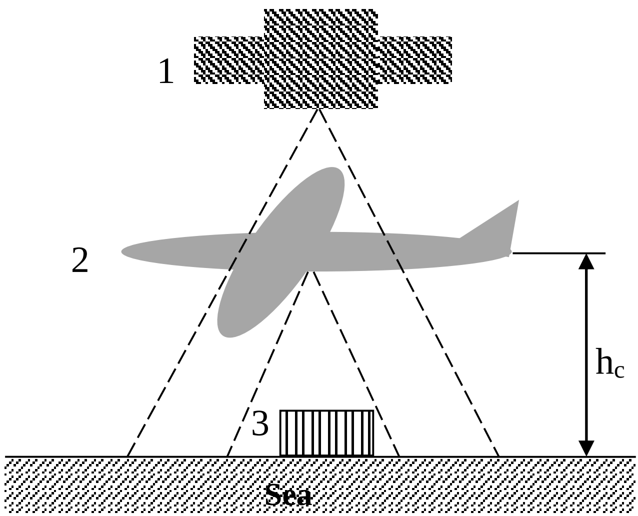

Figure 2. Schematic representation of a three-tier system remote sensing and validation of measurement results

Under known conditions, $L'_h, S_0, S'_h, L_0, L'_h$,using the obtained transcendental equation (4), it is possible to calculate the optimal value of h(t), at which M(t0) reaches an extreme value, i.e. the results of aircraft sounding are as informative as possible

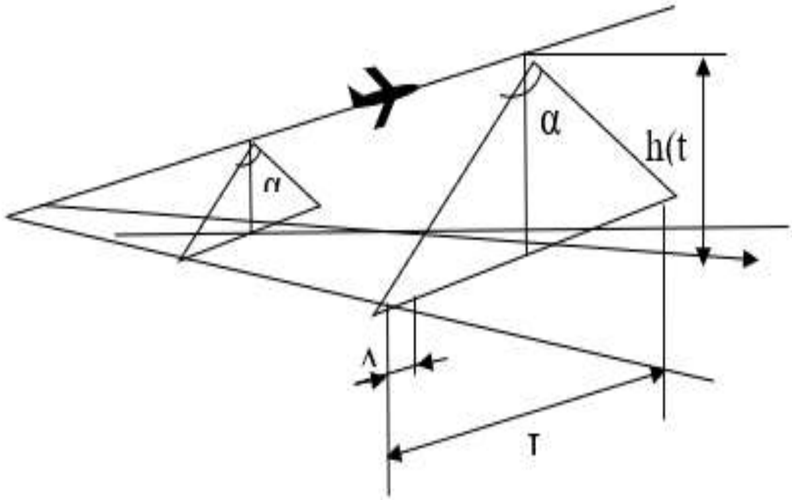

Figure 3. Schematic representation of a marine survey water using a spectrometric device installed by light aircraft

A ground-based method for measuring the total suspended matter in the zone of the estuarine seaside has been developed The measurement of the turbidity of seawater can be carried out using a simple device, the block diagram of which is shown in Fig. 4.

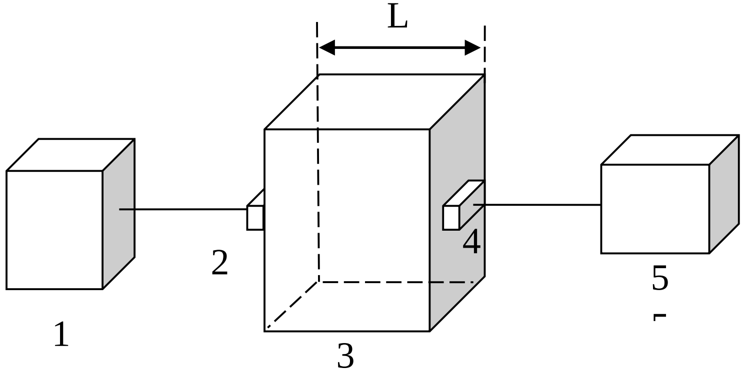

Figure 4. Block diagram of the turbidimeter:

1-Digital voltage meter; 2 - photodetector; 3-a vessel for filling sea water; 4 - emitting diode; 5 - stabilizer of the emitter power supply; L is the distance between the emitter and the receiver, or the length of the optical base

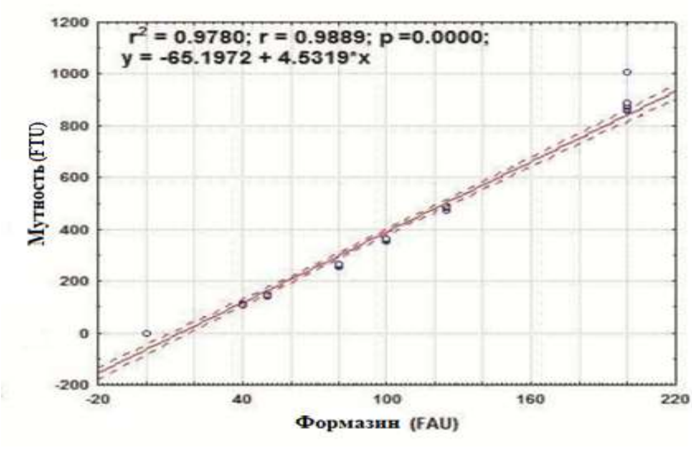

Figure 5. Calibration curves of a turbidimeter calibrated using a formazin solution in the range (0 ÷ 200) FAU.
(FAU) - Unit of radiation attenuation by formazin solution

General view of the calibration curves of the turbidimeter manufactured in [19, т.22. №2. с.63-68].are shown in Fig/ 5.

A turbidimeter calibrated in the above way allows us to obtain relative estimates of the turbidity of seawater in units of FTU. At the same time, the question remains open: how to determine the total suspended matter (TSM), which caused the turbidity of the water.

To solve the above problem, a new ground-based method is proposed, based on the results of studies of estuarine seashore zones using the first channel of the MODIS medium-resolution spectroradiometer installed on the AQUA and TERRA satellites.

In the NIR range, there is a linear relationship between the near infrared reflectance Rrs (NIR) and turbidity.

$$T(FTU) = 17693 \cdot R_{rs}(859)-13.483 \qquad (5)$$

It is also known that the reflection coefficient from the seas and rivers obtained using the first *MODIS* channel, hereinafter referred to as $R_{rs}(B_1)=x$ allows you to determine turbidity (T) and OBB using the following regression equation

$$OBB = 12.450x^2 + 666.1x + 0,48 \qquad (6)$$

$$T(B_1) = 26.110x^2 + 604.5x + 0,21 \qquad (7)$$

The proposed method for determining the RHV OBB value, taking into account the expressions 5, (6), (7):

The block diagram of the algorithm of the proposed first technique is shown in Fig.6.

Further in the third chapter, the proposed new criterion for the selection of remote sensing methods for dissolved organic substances in coastal waters is presented.

Special methods and algorithms for remote sensing are known both in deep-water areas and in coastal shallow-water zones. A special indicator is known, called the bottom effect index (abbreviated BEI), which allows to determine optically deep waters from optically shallow ones with a certain accuracy]. However, as the conducted studies show, when using this indicator in practice, a large spread of its values is found, which creates uncertainty when choosing remote sensing methods in one environment.

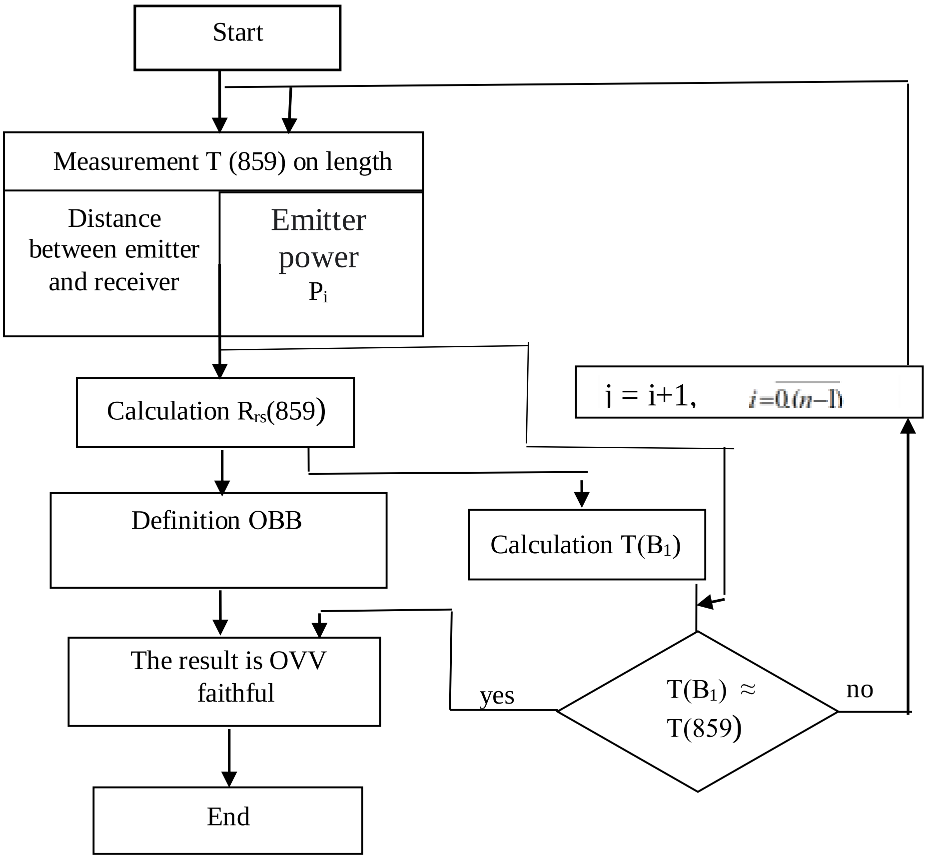

Figure 6. Block diagram of the algorithm for the implementation of the proposed method for determining OBB in the waters of the estuarine coast

Further in the third chapter, the proposed new criterion for the selection of remote sensing methods for dissolved organic substances in coastal waters is presented.

Special methods and algorithms for remote sensing are known both in deep-water areas and in coastal shallow-water zones. A special indicator is known, called the bottom effect index (abbreviated BEI), which allows to determine optically deep waters from optically shallow ones with a certain accuracy [91]. However, as the conducted studies show, when using this indicator in practice, a large spread of its values is found, which creates uncertainty when choosing remote sensing methods in one environment.

New modified bottom influence coefficients have been developed to reduce the above uncertainty. The Known Bottom Influence Factor (BEI) is defined as

$$BEI = \exp\left[-\left(\frac{R_{rs}(\lambda_1)}{R_{rs}(\lambda_2)} \right) \cdot H \right] , \tag{8}$$

where: H – water depth; $R_{rs}(\lambda)$ is the optical radiation reflected from the aquatic environment; λ_1 = 690 nm; λ_2 = 555 nm.

According to known calculations, more than 90% of the total reflected optical radiation during remote sensing of a shallow water environment is reflected from the bottom radiation and reflected from the water thickness optical radiation.

The above first component is determined by the following well - known formula:

$$R_{rs}^{b} \approx 0{,}17 \cdot \rho \cdot \exp\left[-(1{,}5 + (D_d))\alpha \cdot H \right] , \tag{9}$$

where: p is the reflection coefficient (albedo) of the bottom; D_d is the function of the distribution of the light field in the downward direction; α is the total absorption coefficient; H is the height of the water layer.

At the same time, it is obvious that with increasing distance to the shore, the depth of sea waters will increase. Thus, expression (6) can be rewritten as

$$R_{rs}^{b} \approx 0{,}17 \cdot \rho(l) \cdot \exp\left[-(1{,}5 + (D_d) \cdot \alpha \cdot H(l))\right] . \tag{10}$$

Let's examine the expression (7) on the extremum.

by the method of derivative analysis we find:

$$l_{экс.} = \frac{1}{D_d \cdot \alpha \cdot H_l'} - \frac{\rho_0}{\rho} \quad . \tag{11}$$

Thus, at a distance of $l_{экс}$ from the shore, an extremum in value can be expected R_{rs}^{b}.

It should be noted that the detected extreme nature of the radiation reflected from the bottom is also confirmed by the results of well-known experimental studies.

The ways of minimizing the influence of the extreme nature of radiation reflected from the bottom on the BEI indicator are analyzed. The task of the study is formulated as follows: under what kind of function

$$H = H(\rho) , \tag{12}$$

the contribution R_{rs}^{b} to the total reflected signal may become minimal. To solve this problem, let us consider a simplified case when it is legitimate to use a dual model of the function H(p) in the form

$$H = H_{\rho}' \cdot \rho , \tag{13}$$

$$H = H(\rho)_{\max} - H_{\rho}' \cdot \rho . \tag{14}$$

Taking into account the binary model (10), (11), we form the following restrictive condition with respect to the function *H = H(p)*

$$F_1 = \int_{\rho_{\min}}^{\rho_{\max}} H(\rho) d\rho = c \tag{15}$$

It is necessary to calculate such a functional dependence *H(p)* at which F_2 would reach the minimum value.The above problem can be solved by the method of unconditional variational optimization, for which the following goal functional is formed:

$$F_3 = \frac{1}{\rho_{\max} - \rho_{\min}} \int_{\rho_{\min}}^{\rho_{\max}} 0{,}17 \cdot \rho \cdot \exp\left[-(1{,}5 + D_j \cdot \alpha \cdot H(\rho))\right] d\rho + \lambda \left[\int_{\rho_{\min}}^{\rho_{\max}} H(\rho) d\rho - c \right]$$

.(16)

where: λ is the Lagrange multiplier.

The solution of the optimization problem by the Euler – Lagrange method gave the following expression at which F_3 reaches a minimum

$$H(\rho)_{opt} = \frac{\ln\left[\frac{0{,}17 \cdot \rho \cdot D_d \cdot \alpha}{\lambda_0(\rho_{\max} - \rho_{\min})}\right] - 1{,}5}{D_d \cdot \alpha}, \qquad (17)$$

where: λ_0 is a constant value, the value of λ calculated taking into account condition (16) and the derivative of the functional integrand (17) set equal to zero.

Thus, as follows from the above, in order to minimize the contribution to R_{rs}, it is necessary to carry out measurements at those points of the shallow coastal zone of the sea where the logarithmic dependence of H on p is observed and then average the obtained values of the measured values by the number of measurements taken.Such minimization will make it possible to more accurately determine the value of the *BEI,* which is the criterion for classifying the marine coastal zone into deep and shallow areas. Taking into account the above , the well -known index *BEI* can be modified and written in the following form

$$BEI_{\text{mod}} = \exp\left[\frac{-\left(R_{rs}^{w}(\lambda_1) + R_{rs.\min}^{b}(\lambda_1)\right)}{\left(R_{rs}^{w}(\lambda_2) + R_{rs.\min}^{b}(\lambda_2)\right)}\right], \qquad (18)$$

where: $R^{b}_{rs.\min}(\lambda_i) = F_{3\min}(\lambda_i); \quad i = \overline{1,2}$

where: is the minimum value of F3 calculated taking into account the function (15).

The fourth chapter is devoted to spectral methods for studying soil contamination in coastal zones.

It is shown that for the detection of oil contamination of soil in oil-producing regions by remote sensing based on existing spectral indices (signatures), high reliability of the results can be obtained with proper organization of validation measurements. The well-known fact of accumulation of heavy metals in oil production zones makes it possible to use the sign of an anomaly of heavy metals as a methodological basis for organizing validation measurements. At the same time, the channels of validation measurements, combined in groups, in the amount of m, make it possible to carry out non-dispersive validation measurements with high reliability due to the summation of signals in a group. The requirement for information disparity in the channels used to form narrow-band and broadband spectral features of oil and heavy metals, respectively, allows you to form requirements for the signal-to-noise ratio in the system for further calculation of the degree of correlation between the calculated indices. the degree of oil pollution on the intensity of the reflected signal.

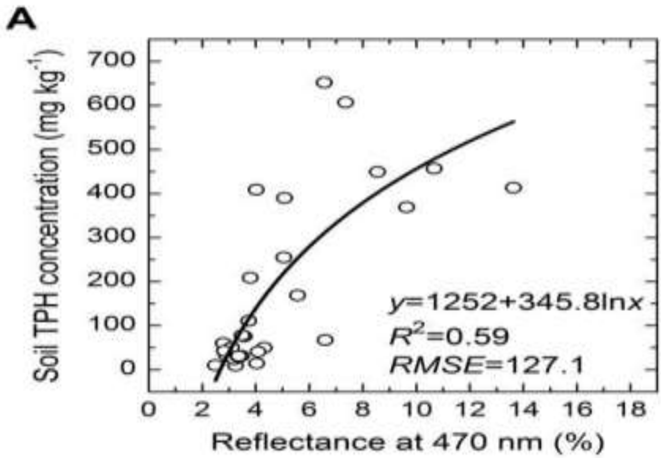

Figure 7a- Curve of the correlation dependence of the TPH concentration on the reflection signal at a wavelength of 470 nm

The question of using inverse signal ratios in practice to reduce measurement errors inherent in single-wave measurement methods by switching to a two-wave measurement mode is considered. It is shown that the presence of the above inverse relationships allows achieving the following advantages when switching to the two-wave measurement mode:

1. Increasing the dynamic range of measurements;
2. Reducing random errors

In view of the foregoing, it seems expedient to switch to a two-wave method for determining the TRN from the reflective spectrum of plants. In this case, the wavelengths must be chosen in such a way that the above difference signals would be bipolar, thereby providing partial or complete compensation for the influence of the presence of a difference signal.

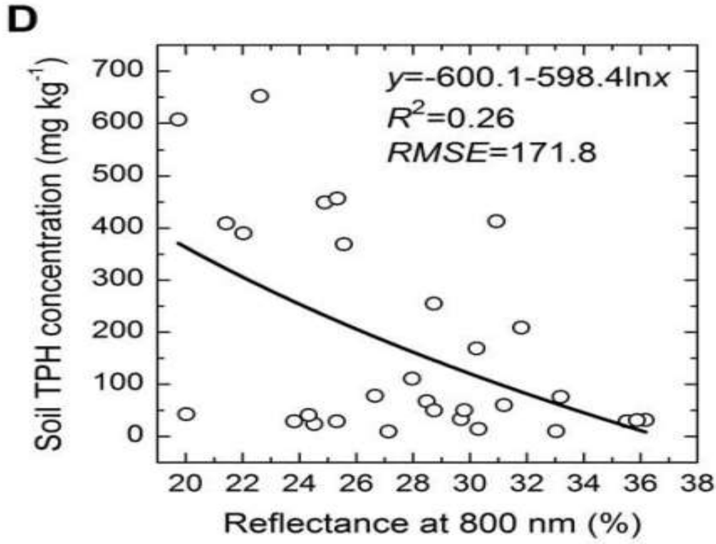

Figure 7b. Curve of the correlation dependence of the concentration of TPH in the soil from the reflection signal of vegetation at a wavelength of 800 nm.

On fig. Figures 7a,b show the correlation curves of the relationship between the concentration of TPH in the soil and the spectral reflection at wavelengths λ1 = 470 nm and λ2 = 800 nm, obtained in the study of Phragmites australis vegetation using an ASD Fieldspec FR spectroradiometer [76].

Taking into account the data given in Fig. 7 a,b the regression equations shown in them can be expressed as

$$Y_1 = a_1 + a_2 \ln x\,. \tag{19}$$

For λ=470 нм;
where: a_1=1252; a_2=345,8

at

$$Y_1 = Y_0 \pm \sigma_{Y_1}, \qquad (20)$$

where : Y_0 – реальная концентрация нефтяного загрязнителя в фиксированной точке;

σ_{Y_1} - с.к.о. случайной погрешности измерения Y_1

$$Y_2 = b_1 - b_2 \ln x. \qquad (21)$$

For λ=800 нм;

where: b_1= – 600,1; b_2=598,4

At

$$, Y_2 = Y_0 \pm \sigma_{Y_2} \qquad (22)$$

where : σ_{Y_2} - s.c.o. random measurement error Y_2

The proposed method for determining the TPH by the reflection spectrum of vegetation, conventionally named as the multiplication method, is as follows. Taking into account expression (25) for the wavelength λ=470km, we obtain:

$$x_1 = \exp\left[\frac{Y_p - a_1}{a_2}\right]. \qquad (23)$$

From expression (28) for a wavelength of 800 nm, we obtain

$$x_2 = \exp\left[-\frac{Y_a - b_1}{b_2}\right], \qquad (24)$$

$$kx_1^2 = \exp\left[\frac{Y_0}{a_2} - \frac{Y_0}{b_2}\sqrt{\frac{\sigma_{Y_1}^2}{a_2^2} + \frac{\sigma_{Y_2}}{b_2^2}} - \frac{a_1}{a_2} + \frac{b_1}{b_2}\right]. \qquad (25)$$

$$Y_0 = \frac{2\ln x_1 \pm \sigma_y \sqrt{\frac{1}{a_2^2} + \frac{1}{b_2^2}} + \frac{a_1}{a_2} - \frac{b_1}{b_2}}{\frac{1}{a_2} - \frac{1}{b_2}}. \qquad (26)$$

Thus, the resulting formula (32) makes it possible to determine the TPH depending on the results of measurements of the reflection signal at wavelengths of 479 and 800 nm. In this case, as can be seen from expression (32), a twofold decrease in random errors is achieved.

The second proposed two-wave method, named by us as the "zero method" is as follows. Taking into account expressions (31) and (32), we obtain the following transcendental equation

$$\exp\left[\frac{Y_0 - a_1}{a_2}\right] - k\exp\left[-\frac{Y_0 - b_1}{b_2}\right] = 0 \quad . \tag{27}$$

From expression (33) for k=1 we obtain the following transcendental equation.

$$Y_0 = \frac{\dfrac{a_1}{a_2} + \dfrac{b_1}{b_2} \pm \sqrt{\dfrac{\sigma_{Y_1}^2}{a_2^2} + \dfrac{\sigma_{Y_2}}{b_2^2}}}{\dfrac{1}{a_2} + \dfrac{1}{b_2}} \quad . \tag{28}$$

Thus, the “zero” method provides for the sequential implementation of the following steps:

1. Obtaining a specific expression for the transcendental equation (33).

The value of the parameter k is determined, under which condition (34) is satisfied.

The value y0 is calculated by solving the transcendental equation (28)

The mathematical foundations of the proposed method of information balance are stated. Let us assume that the measurements are carried out by a hyperspectrometer with the number of channels equal to N_n. Let us assume that N_0 channels are consumed to measure uninformative reference values in the reflection spectrum [23, №7, c.50-52].

In this case, the number of channels used for narrow-spectrum measurements required for calculating hydrocarbon indices is equal to N_n, let's assume that N_0 channels are consumed to measure non-informative reference values in the reflection spectrum. while the number of channels used for narrow-band measurements required to calculate hydrocarbon indices is N_d; therefore, for non-dispersive measurements, N_{n1} - N_d channels are used, where $N_{n1} = N_n - N_o$. The main provision of the information balance method is the equality of the amount of information obtained during basic and validation hyperspectrometric measurements [17, №4 (34), c.50-52].

He amount of information extracted as a result of dispersive measurements is defined as

$$M_d = N_d \log_2 \frac{U_d}{\sigma} \ , \tag{29}$$

where::U_d - is the range of the measured signal

σ – noise of one channel

The amount of information extracted as a result of non-dispersive measurements of heavy metals is defined as

$$M_{nd} = m \cdot \log_2 \left(\sqrt{\frac{N_{n1} - N_d}{m}} \right) \cdot \frac{U_d}{\sigma} \quad , \tag{30}$$

where: m – he number of outputs, or groups, into which the channels of the hyperspectrometer are combined in the amount $\frac{N_{n1}-N_d}{m}$

The main position of the method, yes, the information balance is the equality of the amount of information obtained during the main and validation hyperspectrometric measurements.

This position can be justified as follows:

If $M_d > M_{nd}$, then we get insufficiently confirmed measurement information;

If $M_d > M_{nd}$, then we get a lack of confirmed measurement information and an excess of validation information.

There fore, taking into account (19) and (20) the condition of information balance has the form

$$\mathrm{M_d} = M_{nd} \ , \tag{31}$$

or

$$N_d \log_2 \frac{U_d}{\sigma} = m \cdot \log_2 \left[\sqrt{\left(\frac{N_{n1} - N_d}{m}\right)} \frac{U_d}{\sigma} \right] . \qquad (32)$$

From expression (22) we obtain

$$\left(\frac{U_d}{\sigma}\right)^{N_d} = \left(\frac{N_{n1} - N_d}{m}\right)^{\frac{m}{2}} \left(\frac{U_d}{\sigma}\right)^{m} , \qquad (33)$$

From expression (23) we find the following expression for the required value of the signal/noise ratio ψ, which provides the information balance condition

$$\psi = \frac{U_d}{\sigma} = \sqrt[m-N_d]{\frac{1}{\left(\frac{N_{n1}-N_d}{m}\right)^{\frac{m}{2}}}} \qquad (34)$$

Thus, it has been shown that for the detection of oil contamination of soil in oil-producing regions by remote sensing based on existing spectral indices (signatures), high reliability of the results can be obtained with proper organization of validation measurements.

The known fact of accumulation of heavy metals in oil production zones allows using the sign of heavy metals anomaly as a methodological basis for organizing validation measurements.

In this case, the channels of validation measurements, united in groups, in the number of m, allow to carry out non-dispersive validation measurements with high reliability due to the summation of signals in the group. At the same time, the requirement to dilute information in the channels used to form narrow-spectrum and broadband spectral features of oil and heavy metals, respectively, makes it possible to form requirements for the signal-to-noise ratio in the system for further calculating the degree of correlation between the calculated indices. the degree of oil pollution from the intensity of the reflectedsignal.

As noted in the Commonwealth of Independent States at present there is no single methodology for assessing the content of heavy metals in bottom sediments. According to [18, т.144,№12, с.62-65], it is advisable to study foreign criteria for assessing the quality of bottom sediments, to recommend them for use on the territory of your country. At the same time, it makes sense to carry out their modification in order to further ensure the receipt of information on the state of water and biological resources. One of the indicators of pollution widely used in world practice is the geoaccumulation index, developed by G. Müller in Germany 18, т.144,№12, с.62-65]. This index is based on the classification of water pollution developed by the international research association IAWR. The geoaccumulation index is calculated by the formula

$$I_{geo} = \log_2\left(\frac{C}{1{,}5\ Cf}\right), \qquad (35)$$

where: C - is the concentration of a chemical element in the composition of bottom sediments;

C_f - is the geochemical background value of the concentration of a chemical element.

When calculating by formula (6), the concentration of heavy metals in bottom sediments of fine-grainedfractions (<20 μm) is taken into account. There are 7 levels of pollution (Table 1) [18, т.144, №12]. At the same time, the lack of a mathematical basis for the US EPA, (United States Environmental Protection Agency) method, the impossibility of a separate assessment of the groups of strong and weak human health of heavy metals, as well as the lack of the possibility of developing a single quantitative indicator for such groups creates certain problems in assessing the pollution of water sediments.

Table 1

Contamination level of bottom sediments

Geo-accumulation index value	Class of geoaccu-mulation	Contamination level of bottom sediments
>0	0	Practically to moderately contaminated
>0-1	1	Uncontaminated to moderately contaminated
>1-2	2	Moderately polluted
>2-3	3	Medium contaminated
>3-4	4	Heavily contaminated
>4-5	5	Heavily soiled to excessively soiled
>5	6	Overly contaminated

Evaluation of the concentration of base metals is carried out according to *Igeo* classes .

According to [18, т.144,№12, с.24-27], this method does not allow obtaining a comprehensive assessment of the level of pollution of a water body. This issue was partially resolved by the USEPA staff (USA).

In this article, we will consider the possibility of forming such a single indicator based on the known geoaccumulation index. Let us assume that all heavy metals are divided into groups of the degree of impact on human health, so, for example, Cd and Hg are assigned to the first group, Pb and Cu in the second group, Ni and Cr in the third group, etc. For any of the selected groups, in relation to heavy metals included in this group, we calculate the sum of the geoaccumulation indices

$$\sum_{i=1}^{n} I_{geoi} = \log_2\left(\frac{C_{ekv}^{(n)}}{\left((1{,}5) * \mathrm{C}_{\mathrm{fekv}}^{(\mathrm{n})}\right)}\right) \qquad (36)$$

Thus, the proposed indicator Cekvn allows one to characterize the complex pollution of bottom sediments at the design, i. e. calculated indicators   Next, we will consider the issue of the possibility of using the proposed integrated indicator to assess the state of pollution of some lakes on the territory of the Absheron Peninsula. As noted in [7], the area of Absheron is about 200,000 hectares, but more than 60% of all continental oil production in Azerbaijan is produced in this peninsula.

This circumstance inevitably led to a high degree of contamination of the lands of the Absheron Peninsula with heavy metals.

The location of the Boyukshor and Bulbula lakes is shown in Fig. 6.

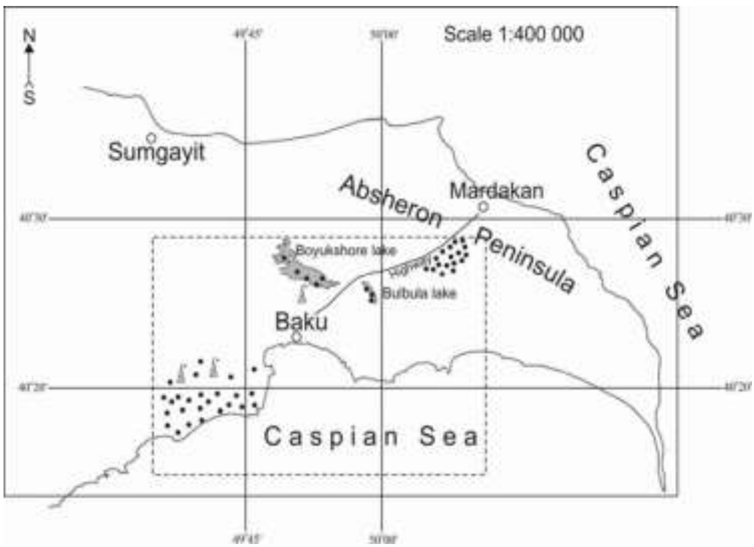

Figure 6. Location of lakes Boyukshor and Bulbula on map of Absheron

The measured values of I_{geo} for various heavy metals in these lakes are shown in Table 2.

Table 2

Measured value I_{geo} for various heavy metals in the specifie lakes

Boyukshor lake					**Bulbula** lake			
Ele-ments, %	Concentration			I_{geo}	Concentration			I_{geo}
	Min.	Max.	Ave-rag.		Min.	M a x	Max.	
Cd	1,0	1,7	1,7	1,4043	0,5	1,4	0,6	-2,9668
Cr	15,6	25,1	4,2	1,2572	11,3	28,9	17,7	-1,7612
Cu	10,6	14,7	4,9	3,3510	13,4	35,0	22,6	-2,7315
Hg	0,004	00015	0,04	6,1413	0,002	0,029	0,006	-6,6438
Pb	16,7	285	0,9	0,0740	6,9	30,2	18,4	0,7052
Zn	20,3	86,8	3,8	0,2746	6,6	36,8	20,3	-2,3708
Mn	213,4	355	--	--	179,4	636,0	376,2	--

Due to the absence of bottom ones about the values

Cf = ì; (м = 1, n) calculate the relative indicator for lake Boyukshor:

$$\gamma_1 = \frac{C_{ekv}(n)}{C_{fekv}(n)} = 1.5 * 2\left(\frac{\sum_{i=1}^{n} I_{geoi}}{n}\right) = 1,5 * 2^{-2,08} \quad (37)$$

Let′s calculate the relative indicator for Bulbula lake:

$$\gamma_2 = 1.5 * 2\left(\frac{\sum_{i=1}^{n} I_{geoi}}{n}\right) = 1,5 * 2^{-2,85} \quad (38)$$

As can be seen from the calculated expressions (37) and (38), the pollution of the Bulbula lake is less polluted than the Boyukshor lake. Let us calculate the coefficient of the degree of multiplicity of purity of the Bulbula lake in comparison with the Boyukshor lake:

$$\eta = \frac{\gamma_1}{\gamma_2} = \frac{1{,}5 * 2^{-2{,}08}}{1{,}5 * 2^{-2{,}85}} = 2^{0{,}77} \qquad (39)$$

Thus, we can conclude that Lake Bulbula is $2^{0.77}$ cleaner than Lake Boyukshor. Therefore, the proposed complex indicator allows you to compare the degree of pollution of various water bodies. In conclusion, we will formulate the main conclusions and provisions of the study: A new complex indicator of the pollution of bottom sediments and water bodies is proposed, which makes it possible to take into account the influence of various heavy metals. Estimates of the complex pollution of the Boyukshor and Bulbula lakes are given.

MAIN CONCLUSIONS

1. Ways of conducting separate or aggregate measurements of separate components of sea water have been investigated. A two-wave method for determining the concentration of suspended solids in seawater is proposed, which provides for joint two-wave measurements of a parameter that depends on the experimental conditions, the concentration of chlorophyll and suspended solid particles, as well as an autonomous two-wave measurement of the chlorophyll concentration. A modification of this method is described, when the concentration of suspended particles is measured autonomously using several mixed values of wavelengths.
2. The problem of the classification of suspended particles by the magnitude of the absorption coefficient of optical radiation has been solved, which makes it possible to classify these particles in space by their structural composition.

3. A model for evaluating signals from satellite spectroradiometers for the case of anomalous air pollution with aerosol has been developed, on the basis of which a multiwave method for determining the coastline has been developed, which allows eliminating the aerosol error of the known two-wave method.

4. The possibility of transformation of the known three-channel criterion for coastline detection, implemented on the basis of measurements of channels B1, B2, B3 of the SPOT XS and X1 equipment, into an index-channel criterion has been investigated. It was found that the considered three-channel criterion is more sensitive to changes in B1 / RED than to changes in NDVI.

5. The problem of carrying out turbidometric measurements and determining the amount of suspended solids depending on the turbidity of water in the zones of river deltas and in the coastal zones of the seas has been solved. Single-wave and two-wave methods have been developed for determining the total amount of suspended solid particles and the type of water under study, depending on the turbidity of the water, determined at two wavelengths.

6. An average integral estimate of the optical radiation reflected from the bottom in the coastal zones is given. The extreme nature of this radiation was found, depending on the distance to the coast.

7. A modified criterion for the selection of methods for remote sensing of dissolved organic matter in the coastal zones of the seas is proposed. The problem of optimizing the measurement of the concentration of dissolved organic carbon in the coastal zones of mixing of sea and river waters is solved.

8. A method has been developed for the information balance of dispersive and non-dispersive sounding signals used, respectively, for basic and validation measurements for the exploration of oil fields using onboard hyperspectrometers. index and broadband signature of anomalous concentration of heavy metals.

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