Space observations in the tasks of geoecological researches of coastal arctic shelves

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Abstract. The article discusses the tasks of creating a digital platform for integrated geoecological research based on space observations of the effects of natural and man-made sources of pollution of coastal marine areas. Data on the state of pollution of estuaries of the northern seas are given. Methods are proposed for identifying sections of surface water pollution from survey data using Landsat -8 space station. In this work, studies were conducted on the selection of spectral ranges of surveys in the tasks of isolating pollution of coastal surface waters. Examples are presented that illustrate the capabilities of satellite imagery in the tasks of identifying contaminated sites for estuarine areas of the marine areas of the Arctic Ocean. Recommendations are given on choosing the spectral ranges of surveys when conducting geoecological studies of marine waters.

1. Introduction
The active development of the continental Arctic shelf of Russia, which has been going on since the beginning of the 2000s, has led to a significant increase in marine activity in these areas. It is accompanied by the need to ensure the geoecological safety of the Arctic seas by controlling the level of their anthropogenic pollution. The solution to this problem must be carried out taking into account the geoeconomic risks that are caused by:

- intensified exploration and production of oil on the continental shelf, the construction of oil terminals and increased oil transportation by sea;
- reduction of complex expeditionary scientific research necessary for the reproduction of the resource base;
- wastewater from rivers and bays to the seas of the Arctic Ocean;
- lack of systems for continuous monitoring of natural and technogenic processes in the tasks of environmental control of global and regional scales.

Ensuring the safety of the marine environment requires the improvement of methods and tools for integrated research of the oceans [1]. This involves the creation of a multidisciplinary system for monitoring the state of marine water areas and the atmosphere on the basis of a single digital platform for the integration of ongoing geoecological research. Its important element is the aerospace monitoring system for observations of the state of the ocean and atmosphere. Their use provides a transition from a sectoral approach to planning marine activities to systemic solutions. This refers to comprehensive geoecological studies focused on assessing the control of the physical, chemical and biological effects on the state of surface waters.
Studies conducted at the Murmansk Marine Biological Institute of the Kolsky Scientific Center of the Russian Academy of Sciences (MMBI KSC RAS) showed that economic activity in the waters of the seas and on the adjacent land is a source of impact anthropogenic pollution of the marine environment of regional and local scale. It has a focal character and is associated with the formation of technogenic pollution zones in the estuarine areas of large rivers and port infrastructure.

Integrated geoecological studies, which were based on hydrological and hydrochemical observations of the state of river runoff at river mouths, were carried out by MMBI as part of the project “Biological resources of the Arctic seas of Russia: current status, the impact of natural changes and anthropogenic impacts, scientific foundations and prospects for use”. They were carried out in the Barents, Kara, East Siberian seas and the Laptev Sea. An important result of the research was a map illustrating the areas of influence of river flow and its pollution level (Figure 1) and Table 1 [2].

Figure 1. Removal of pollutants by rivers into the seas of the Russian sector of the Arctic [2]

Table 1. Type and quantity of pollutants (t/year) (2014)

| River basin    | Oil products | Cu  | Ni  | Pb  | Zn   | Mn  | SPAV | Phenols |
|---------------|--------------|-----|-----|-----|------|-----|------|---------|
| Ob            | 400 000      | 2150| 2100| 12000| 112550| -   | 1560  |
| Yenisei       | 63 000       | 4720| 2700| 4290 | -    | -   | 3400  |
| Lena          | 385 000      | 2400| -   | -   | -    | -   | 610   |
| Severnaya     | 2 400        | 168 | -   | 936 | -    | -   | 39    |
| Dvina         | 2 400        | 168 | -   | 936 | -    | -   | 39    |
| Pechora       | 6 900        | 290 | -   | 2120| -    | 0,4 | -     |
| Mezen         | 400          | 13,0| -   | 398 | -    | -   | -     |
| Kola Bay      | 160          | 31  | 49  | 7,7 | 297  | -   | -     |
| Teriberka     | 34,7         | 7,9 | 7,4 | 1,5 | 24,0 | 35,7| -     |
The influence of river runoff in quality is a determining source of pollution in the seas of the eastern sector of the Arctic. This is due to the presence of oil and gas facilities in the catchment areas of the northern rivers of this region. In the western sector of the Arctic (Barents and White Seas), the main source of pollution is water transoceanic and airborne transboundary transport of pollutants. In the open sea, the content of heavy metals, pesticides and radionuclides in aquatic organisms remains low.

The results of observations of the hydrohydrochemical network of Roshydromet showed that there were no significant changes in the level of pollution of surface water in the Arctic zone of the Russian Federation for the period 2011-2018 years. The number of cases of extremely high (EHZ) and high (EZ) levels of surface water pollution in this region in 2018 amounted to 229, which is 33.9% higher than in 2017 and 2.7% higher than in 2010.

Extremely high pollution of surface waters determines the level of pollution that exceeds the maximum permissible concentrations (MPC) by 5 or more times for substances of hazard classes 1 and 2, and 50 and more times for substances of classes 3 and 4. High contamination of surface waters corresponds to a 3–5 times excess of MPC for substances of hazard classes 1 and 2, 10–50 times for substances of classes 3 and 4, and 30–50 times for oil products, phenols, manganese ions, copper and iron.

In 2018, extremely high pollution levels were observed at 17 water bodies in 83 cases, high pollution levels at 23 water bodies in 146 cases. In particular, in the Severnaya Dvina there were 16 cases of water pollution and 1 case of EVZ [3].

Assessing the state of pollution of the mouths of river flows by conducting natural geoecological studies has limitations due to the absence:

- of a representative sample of data from an existing network of hydrological stations;
- of control the spread of contaminants in the event of an accident;
- of automatic localization and determination of the composition of pollutants.

2. Materials and methods

To eliminate the existing limitations in the tasks of complex geo-ecological research, it is proposed to use satellite imagery materials. Currently, they are used to control the ice situation, search and control the sources of natural and anthropogenic impacts in marine areas [4-9]. In most cases, for this purpose are used for radar survey, which does not depend on the time of day or weather conditions. However, these images do not allow to assess the nature of the pollution of the studied water areas.

The purpose the work is to assess the possibilities of using optical space-based observation systems in the tasks of conducting complex geoeological researches of the spread of pollutants in the estuarine areas of the water areas.

To achieve the goal during the research, the following was carried out:

- preparation of data sets of satellite imagery for the studied estuaries of the sea areas of the Arctic zone of the Russia;
- assessment of the capabilities of the spectral channels of satellite images of the Landsat-8 system at test sites;
- search of contaminated sites at the mouths of the northern rivers.

The main attention is paid to assessing the possibilities of conducting complex geoeological studies based on multispectral optical images obtained from the Landsat-8 spacecraft (SC). It provides simultaneous image acquisition in 11 spectral ranges (table 2).

| Band | Wavelength (μm)         | Band              |
|------|------------------------|-------------------|
| B1   | Band 1: 0.43 - 0.45    | Coastal aerosol   |
| B2   | Band 2: 0.45 - 0.51    | Blue              |
| B3   | Band 3: 0.53 - 0.59    | Green             |
| B4   | Band 4: 0.64 - 0.67    | Red               |

Table 2. Spectral channels of the spacecraft “Landsat-8” [10]
Band 5: 0.85 - 0.88 Near IR
Band 6: 1.57 - 1.65 SWIR 1 (SWIR)
Band 7: 2.11 - 2.29 SWIR 2 (MIR)
Band 8: 0.50 - 0.68 Panchromatic
Band 9: 1.36 - 1.38 Cirrus
Band 10: 10.60 - 11.19 Thermal Infrared (TIRS)
Band 11: 11.50 - 12.51 Thermal Infrared (TIRS)

During the research were used as test plots:
- Kola Bay and Teriberka (survey date: 2019-08-01; survey time T = 03:57:33);
- Northern Dvina River (survey date: 2019-06-20; survey time T = 08:45:03);
- Pechory (survey date: 2019-08-13; survey time T = 08:07:03);
- the Kara Bay (Kara) (survey date: 2018-07-31; survey time T = 07:28:44);
- Lena (survey date: 2018-08-08; survey time T = 03:20:48).

The key place during the work was given to identifying the boundaries of the distribution of river flows of estuaries of the northern rivers and the Kola Bay. For these purposes, we used the original images obtained directly by the shooting camera in the above channels of the electromagnetic wave ranges.

Along with highlighting direct indicators of electromagnetic radiation emanating from the water surface, indirect indicators obtained during image operations are of interest. In particular, they include spectral indices that allow strengthening indicators of the studied properties of water bodies [11,12].

To assess the possibilities of their use in the tasks of identifying pollution zones of estuaries of northern rivers, the following indices were considered in the work [13-18]:

- **Normalized Differentiated Water Index (NDWI)_1**
  \[
  NDWI_1 = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}}
  \]  

- **Normalized Differentiated Water Index (NDWI)_2**
  \[
  NDWI_2 = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}}
  \]  

- **Modified Normalized Difference Water Index (MNDWI)**
  \[
  MNDWI = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}}
  \]  

- **Normalized Difference Turbidity Index (NDTI)**
  \[
  NDTI = \frac{\text{RED} - \text{Green}}{\text{RED} + \text{Green}}
  \]  

### 3. Results and analysis

To highlight the boundaries of the flow distribution of the estuarine sections of the northern rivers, test sections of multispectral images were prepared: in the panchromatic channel B8, of channels in RGB (4-3-2), infrared channels B5 (Near IR), B6 (SWIR 1, SWIR), B7 (SWIR 2, MIR), B10 and B11 (Thermal Infrared, TIRS) (Table 3). It should be noted that channels B5, B6 and B7 receive reflected solar radiation, and channels B10 and B11 receive own thermal radiation from objects.

The images show that the contaminated areas are clearly distinguished in the visible channels B5, R-G-B (B4-B3-B2), as well as the thermal ranges of the electromagnetic spectrum B10 and B11 (Thermal Infrared, TIRS) in almost all sections of rivers. In the water area of the Kola Bay, only heat-affected areas are distinguished, which are clearly visible in the images in the ranges B10 and B11 of the thermal...
IR channel. This is because the mouth of the bay has a deep fairway, where muddy suspensions of ground bottom rocks are practically absent.

On the images of the infrared channels B5 (Near IR), B6 (SWIR 1, SWIR), B7 (SWIR 2, MIR), the water surface of river channels and coastal marine areas is well displayed. This information makes it possible to increase the efficiency of studies of channel processes occurring in these territories.

| B:8 | RGB, B: 4-3-2 | B: 5, B:6 | B:7 | B:10, B:11 |
|-----|---------------|-----------|-----|------------|
| ![Image](image1) | ![Image](image2) | ![Image](image3) | ![Image](image4) | ![Image](image5) |

Kola Bay, Tuloma River

Severnaya Dvina River

Pechora River

Kara Bay, Kara River

Lena river

**Figure 3.** The allocation of pollution of water bodies in the original spectral ranges of the images SC "Landsat-8"
The use of spectral indices in classifying the state of water areas of the mouth of northern rivers has shown the effectiveness of a normalized differentiated water index (NDWI_1) and a normalized difference turbidity index (NDTI) in problems of identifying the distribution of contaminated effluents on surfaces of marine waters. In almost all test sites, color spectral contrasts of pollution of river flows are visible. Synthesized images displaying these indicators can be used to map the areas of contamination of the estuarine sections of the rivers of the sea shelf.

Images created based on the spectral indices NDWI_2 and MNDWI provide a good color contrast of the coastal lines of river channels and the sea coast. This property of the obtained images allows them to be used in structural and morphometric studies of channel processes.
4. Conclusion
The article presents the results of research on the use of space observational materials in the tasks of complex geoeological studies of the surface waters of the northern rivers of the Russian Arctic. Existing approaches used to assess pollution of coastal shelf zones of marine areas based on marine expeditions and stationary stations are considered. To eliminate the limitations associated with insufficient coverage of the area with observation points, it is proposed to supplement them with the results of space observations using orbiting satellites.

The paper assesses the possibilities of using multispectral space images for zoning pollution of the estuarine sections of the northern rivers and ongoing channel processes. To solve these problems, the images obtained by the Landsat-8 spacecraft were used.

The research results showed that when using the source images:

- in the visible ranges B8 (panchromatic, black-and-white) and synthesized color R-G-B (B 4-B 3-B2), shallow-water near-surface pollution of the estuarine sections of marine areas is clearly distinguished;
- in the thermal ranges B10 and B11 (Thermal Infrared, TIRS), zones of temperature thermal gradations of marine water areas are clearly distinguished in almost on all areas;
- in the infrared channels B5 (Near IR), B6 (SWIR 1), B7 (SWIR 2), the water surface of rivers and coastal marine areas is clearly displayed, which makes it possible to increase the efficiency of investigations characteristics of channel processes on these regions.

The use of spectral indices for image synthesis allows you to:

- on the basis of the normalized differentiated water index NDWI_1 and the normalized differential turbidity index NDTI, to choose the color contrasts of the areas of pollution of river flows and map the areas of pollution of the estuarine sections of the sea shelf;
- through the synthesis of images displaying the spectral indices NDWI_2 and MNDWI, can to receive a clear color contrast of the coastal lines of river channels and the sea coast in problems of mapping the structural and morphometric characteristics of channel processes.

The results obtained showed the possibility of using satellite imagery in geoeological researches of the pollution of the estuarine sections of the shelf zones of marine waters caused by runoff of northern rivers.

References
[1] 2019 Strategy for the development of maritime activities of the Russian Federation until 2030 Approved by order of the Government of the Russian Federation of August 30 2019 N 1930
[2] Matishov G et al 2014 Biological resources of the Arctic seas of Russia: Current status, the impact of natural changes and anthropogenic impacts, scientific foundations and prospects for use. Search fundamental scientific research for the development of the Arctic zone of the Russian Federation for 2014 Available from: http://www.ras.ru/viewstaticdoc [Accessed 20 March 2020]
[3] On the State and Environmental Protection of the Russian Federation in 2018 (Mocow: Ministry
8

of Natural Resources of Russia; NPP "Cadastre") p 844

[4] Aleksanin A, Kubryakov A, Levin V, Stanichnyy Since 2014 Problems of satellite remote sensing while ensuring economic activity on the shelf of the Arctic seas. Searching basic scientific research in interests of the development of the Arctic zone of the Russian Federation Available from: http://www.ras.ru/viewstaticdoc [Accessed 20 March 2020]

[5] 2018 Kola Bay and oil: biota, vulnerability maps, pollution (SPb: Renome) p 520

[6] 2016 Satellite-based radar monitoring of the Kola Bay: spatiotemporal distribution of film pollution and their main sources Ecology and industry of Russia 20(7) 46-53

[7] Terleeva N, Ivanov A 2017 Liquid shiploads and wastes, causes of ship spills at sea and problems of their remote sensing Ecology and Industry of Russia 21(8) 13-19

[8] Bondur V., Kuznetsova T 2012 Investigations of natural oil and gas occurrences on the sea surface from space images Aerospace monitoring of oil and gas facilities (Moscow.: Scientific World)

[9] Akovetsky V G 2019 Space monitoring observations of oil manifestations of marine areas: geological and geoecological aspects Actual problems of oil and gas 4(23)

[10] Zanter K 2015 Landsat 8 (L8) Data Users Hand Book Available from: landsat@usgs.gov [Accessed 20 March 2020]

[11] Akovetsky V, Afanasyev A, Vaseha M 2020 Automation of Aerospace Observations of Manifestation of Oil and Gas in Marine Areas International applied research conference «Biological Resources Development and Environmental Management», KnE Life Sciences 95-108 DOI 10.18502/klss.v5i1.6029

[12] Feyisa G, Meilby H, Fensholt R, Proud R 2014 Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery Remote Sensing of Environment 140 23-35

[13] Tulbure M, Broich M 2013 Spatiotemporal dynamic of surface water bodies using Landsat time-series data from 1999 to 2011 ISPRS Journal of Photogrammetry and Remote Sensing 79 44-52

[14] Liu Z, Yao Z , Wang R 2016 Assessing methods of identifying open water bodies using Landsat 8 OLI imagery Environmental Earth Sciences 75(10) 1-13

[15] Rokni K, Ahmad A, Selamat A, Hazini S 2014 Water feature extraction and change detection using multitemporal Landsat imagery Remote Sensing 6(5) 4173-4189

[16] Moradi M, Sahebi M, Shokri M 2017 Modified optimization water index (MOWI) for Landsat-8 OLI/TIRS/ The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL III-4/W4

[17] Elhag M, Gitas I, Othman A, Bahrawi J, Gikas P 2019 Assessment of Water Quality Parameters Using Temporal Remote Sensing Spectral Reflectance in Arid Environments, Saudi Arabia Water 11(556) 1-14 doi:10.3390/w11030556 Available from: www.mdpi.com/journal/water [Accessed 20 March 2020]

[18] Lacaux J, Tourre Y, Vignonlles C, Ndione J, Lafaye M 2007 Classification of ponds from high-spatial resolution remote sensing: Application to Rift Valley Fever epidemics in Senegal Remote Sens. Environ. 106 66-74