The Use of Spectral Characteristics of Satellite Images to Assess Water Pollution after Dike Breaking on the Irelyakh River

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Abstract. An urgent problem in the modern world is the pollution of water bodies with waste water that enters the reservoir after insufficient filtration, or with industrial effluents, in our case related to the mining works. In any case, this pollution negatively affects both the state of the environment and the health of the population forced to use water from polluted sources. And for inhabitants of the Far North remote areas this is fraught with poisoning of fishery resources. The method of remote sensing and processing of satellite images allows you quickly assessing the degree of contamination of reservoirs after man-made emergencies and timely warning the population from exposure to dangerous pollutions. On the basis of decoding the spectral characteristics of pollution, it is possible to track timely the size and speed of its spread, significantly reduce the number of samples taken, field research and ensure regular monitoring of a risen extreme situation. In this work, we used methods of preliminary digital processing of space images: geometric, radiometric and atmospheric correction. The thematic processing of the ERS was carried out. The ERS is a method of image enhancement that includes modification of contrast, noise reduction, boundary detection.

An assessment of water pollution in the territory of the Republic of Sakha (Yakutia) after the dyke breaking on the Irelyakh River in August 2018 was carried out using the interpretation of satellite images by spectral analysis on the ENVI software system. The use of this method is relevant for remote hard-to-reach areas and, if necessary, rapid assessments of pollution, as well as for tracing the forecast of the process flow.

1. Introduction

At present, water pollution is a global problem, and its state is of prime importance for the development of the region. The monitoring using the sampling method and laboratory analysis is not always possible due to the inaccessibility of sampling sites, high material costs and does not allow determining the extent of contamination [1, 2]. In addition to the above, observation and sampling methods characterize the presence and scale of pollution only at a given time, and it is more convenient to track the dynamics of changes using the methods of Earth’s remote sensing (ERS).

The modern technologies of ERS make it possible to analyze and evaluate the geo-ecological state of water bodies and the environment as a whole. Their use makes it possible to record the state of vast territories almost simultaneously, with the same observation conditions for all monitoring sites, track and analyze the processes of environmental change, and ensure regular observation that especially...
important under conditions of a shortage of ground-based observations [3]. Studies on the assessment of the state of geo-ecology of the territory, the assessment of water pollution by remote sensing methods have been carried out by many Russian and foreign authors. So, in the research [4] the method of assessing pollution by coal industry enterprises is considered, in [5] - by oil and gas enterprises. However, as noted in [1], the nature of pollution from various sources has its own specifics and does not allow using fully a single methodology for evaluating various pollutants.

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2. Methods and materials

Spectral characteristics of spatial objects provide a more subtle analysis of the object's state and properties. As a whole, these characteristics allow identifying spatial objects of pollution in the images and monitoring the dynamics of changes in pollution, predicting the spread of pollutants, and ranking river sections by the degree of pollution [7]. In this work, the goal is to use the interpretation of satellite images by spectral analysis to assess the pollution of water bodies. The area of the Irelakh, the Malaya Botuobuya and the Vilyui rivers was chosen as the object of applicability of these methods of space images digital processing because waters of these rivers were subjected to large-scale contamination by waste from diamond mining enterprises as a result of the dams failure on testing grounds.

On August 19, 2018, at the "Irelakhskaya rossyp'" ("Placer deposit of the Irelakh") field of the Mirninsky mining complex of ALROSA company of the Republic of Sakha (Yakutia), the abnormal precipitation led to the failure of four dams of dredging foundation pits which caused large-scale contamination of water bodies on the Irelakh, the Malaya Botuobuya and the Vilyui rivers. One of the dams was broken in 390 meters from the branch of the Irelakh riverbed.

According to the results of laboratory studies as a result of the dam break, the maximum permissible concentration standards were significantly exceeded: suspended substances by 728.6 times, iron by 38.7 times, and copper by 27.6 times. Significant damage was caused to the environment and infrastructure of the region. It should be noted that this force majeure occurred due to natural factors, and is not a consequence of the production activities of ALROSA.

According to meteorologist, on August 17, 82.1 mm of precipitation fell in the Mirnyi district, which is 60 percent above the monthly norm, on August 16, 0.216 thousand cubic meters of water passed through the Irelakh waterworks facility, on August 18 – 4,053 thousand m³, on 19 Aug –5.93 thousand m³. Further, these figures gradually decreased but nevertheless remained high. On August 19, there was a break in the dam of testing grounds, benthic deposits were removed of bottom sediments and the ingress of suspended substances into the Irelakh, the Malaya Botuobuya and the Vilyui rivers took place.

The damage is 11 million 190 thousand rubles on the Irelakh river, 4 billion and 67 million rubles for the Malaya Botuobuya river. The damage for the Vilyui River was calculated by the Federal Service for Supervision of Natural Resource Usage Department for the Republic of Sakha (Yakutia) and amounted to 27 billion rubles [6].

When decoding water pollution, the spectral features are used that allow analyzing variations in optical densities caused by solutions and suspensions of organic and inorganic substances in certain ranges of electromagnetic waves which makes it possible to determine the degree of water pollution.

In this work, we used methods of preliminary digital processing of space images: geometric, radiometric and atmospheric correction. Once the remote sensing data is processed, it can be used for creating of high-quality cartographic products. The thematic processing of ERS methods data was carried out. These methods enhance images including modification of contrast, noise reduction, and boundary detection with method [7-9].
3. Results and discussion

To study water pollution, the method of spectral analysis was used on the ENVI software package. Radiometric and atmospheric correction was performed, and then the classification with training by the spectral angle method was made [5-7]. 3-4 images were studied for each region and the average value for each spectrum was calculated. The compiled database of satellite images covered the territory of Suntarskyi, Verkhnevilyuisky, Vilyuisky, Nyurbinskyi, and Kobyayskyi districts.

Figure 1 shows on the map the location of the studied sections of the Vilyui River which intersects sequentially the territories of these districts. Distance between test sections is 1 and 2 ~170 km, 2 and 3 ~ 120 km, 3 and 4 ~ 100 km, 4 and 5 ~160 km.

The Vilyui River is the longest major left tributary of the Lena. The length of the Vilyui is equal to 2450 km, the basin area is 454 thousand sq km. The alimentation of the river is mixed, with a slight predominance of snow. The average annual temperature of the basin is about minus 8° C. The freezing-up period takes place in mid-October, and the river becomes open in mid-May. The source of the Vilyui River is located on the middle Siberian plateau (Vilyui plateau) near the Lower Tunguska river basin. The upstream flow has a direction from the North to the South, then together with the waters of the Chon River, the Vilyui angles to the East and maintains this direction until the mouth (near the settlement of Sangar), only in one place it bends in a loop to the South (Suntar bend). On the upper course the river is very meandering. Crossing the marshy-lake plain, it flows lower along a valley with mountainous nature. Most of the river’s slopes are wooded and steep, and there are rapids in the riverbed. The valley of the river lower course extends along the Central Yakut lowland, and below the settlement of Suntar it expands. In a wide valley, the river flows from the city of Vilyuisk to the mouth. Here, the Vilyui has a branched channel with islands, the largest of which is Khochenakh that has a length of up to 15 kilometers.

![Map showing the location of the studied sections of the Vilyui River](image1)

Figure 2 shows the spectral curves of water in the studied areas after the dam break at various times, corresponding to the movement of the pollution flow from Suntarskyi to Kobyaiskyi ulus. For comparison, the graph shows the spectral curve of water corresponding to the state of the object before and after the dam break. Exceeding the amount of suspended particles in water increases the reflection in the near IR-zone of the spectrum, and organic substances (such as petroleum products, phenols, etc.) - in the middle IR-zone. The analysis of the spectral characteristics of water in the studied areas, presented in Fig. 2, shows that the degree of contamination gradually decreases from the accident site.
to the last section along the river course but remains much higher than in the background. The amount of suspended particles in the water exceeds the background by 2-3 times.

![Endmember Collection Spectra](image)

**Figure 2.** Spectral curves of the studied sections of the river after the dam break at various times. 1 - Suntarskyi 28-08-2018, 2 - Nyurbinskyi 29-08-2018, 3 - Verkhnevilyuskyi 01-09-2018, 4 - Vilyuiskyi 03-09-2018, 5 - Kobyayskyi 05-09-2018, 6 - background 06-08-2017.

Based on the study results, the maps of differences were created for the river studied sections. To do this, the data was preliminarily processed using normalization and standardization methods. The comparison of the obtained results showed that normalization gives a more accurate result, since the entire range of values is used, while standardization uses the average brightness value and standard deviation [8]. As an example, Fig. 3 shows a map of differences in the state of water on the river section in the area of Nyurbinskyi ulus made as the result of a multi-time composition of images on 14-09-2017 and on 29-08-2018. The positive changes are shown in red shades (from gray to zero change to red for the largest positive change). The negative changes are shown in shades of blue (from gray for zero change to bright blue for the largest negative change).

**Figure 4** shows the comparison of spectral curves graphs showing the changes in the state of water in the river before the dam break, 9 days after the accident, and a month later on the example of a section of the river located in the Suntarskyi district. In the Suntarskyi district, the amount of suspended particles increased by 2.4 times after the dam break (compared to August 2017), and even a month later, the level of suspended particles remains 1.5 times higher than the background level. Fig. 4 also shows how much the water quality in the river differs from the standard; the spectrum of Lake Baikal is highlighted in red as the standard.
Figure 3. Map of differences in the area of Nyurbinskyi ulus, made as the result of a multi-time composition of images on 14-09-2017 and 29-08-2018, where Fig. b) shows an enlarged image of the river section. The negative changes are shown in shades of blue.

Figure 4. Spectral characteristics of water in the area of Suntarskyi ulus. 1 is the spectrum before the dam break on 19-08-2017, 2 is the spectrum after the dam break on 28-08-2018, 3 is the spectrum after the dam break a month later on 19-09-2018, and the spectral curve of Lake Baikal is selected as a standard.
4. Conclusion
The results of the research show that the use of spectral characteristics allows us to track the presence of suspended particles in the water, assess the degree of contamination using archival background images, and determine the change in the water state in the river sections over time from satellite images. The example of the Irelakh river section shows that the degree of pollution gradually decreases from the accident site to the last section downstream the river course but remains much higher than in the background. The amount of suspended particles in the water exceeds the background by 2-3 times.

The use of the composition of multi-time images allowed creating a map of differences in the state of water in the river section. This helps assess visually the degree of contamination throughout the study area. The use of satellite images makes it possible to significantly reduce the performance of ground-based experimental work and ensure regular observation, especially within the conditions of ground-based observations shortage.

The proposed method can be used to assess the state of reservoirs and in cases of their contamination in conditions of inaccessibility – swampiness, remoteness, lack of opportunities for conducting ground research. Using modern methods of ERS, it is possible to quickly identify areas of water pollution by analyzing the main characteristics of the display on images such as: changes in the optical characteristics of the water column, changes in the properties of a film of surface active agents, changes in the spectral characteristics of a display, etc.

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