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Remote Monitoring of the Environmental Condition of Oil Producing Areas in Western Siberia

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Abstract

The paper deals with opportunities of remote probing as a method to assess the environmental condition of hard-to-reach areas. The dynamics of changing the condition of the vegetation cover of anthropogenically disturbed areas of the Tomsk region under conditions of the negative impact of oil recovery was investigated using freely distributed satellite MODIS images of medium spatial resolution. Vegetation cover condition was assessed according to the value of the normalized difference vegetation index (NDVI). Condition dynamics for vegetation cover in the vegetation season was analysed over the 9-year period from 2010 to 2018. The work stepwise stated the processing algorithm of satellite data using geographic information system ArcGis 10.2.2. Analysis was performed for NDVI values of the background territory of the Oglatsky wildlife reserve and five territories of oil and gas fields in the Tomsk region. The latter include Luginets, Olenie, Lomovoye, Katylginsky, and West Katylginsky fields. As determined, the trend of changing index values for all investigated areas is single-type: high and minimum magnitudes in 2016 and 2012, respectively. As demonstrated by the analysis of the dynamics of changing average NDVI values during vegetation, there are improved but significantly reduced NDVI magnitudes in all investigated areas from 2012 to 2016 and 2016 to 2018, respectively.

Key words: vegetation dynamics, satellite data, vegetation index, geoinformation systems, oil fields, environment

INTRODUCTION

Western Siberia is the most developed region of Russia being rich in oil and gas. The West Siberian oil and gas basin is situated in the area of West Siberian Plain and covers such Russian regions, as Novosibirsk, Omsk, Tyumen, and Tomsk regions, and also Yamalo-Nenets and Khanty-Mansi Autonomous Districts. The Tomsk region is an oil-producing region of Russia and Western Siberia, third according to importance. According to recent estimates, (based on the geological prediction), the volume of oil resources not yet explored is higher than the explored ones by about 1.8 times. That allows concluding that oil recovery in the Tomsk region is likely to proceed for many years to come [1].

Official authorities are responsible for monitoring and ensuring compliance with environmental legislation, and also for developing strategies for the energy sector. However, resulting from the privatization of the oil sector, the responsibility for the past and current environmental and social impacts of the oil and gas sector has passed to the management of Russian and foreign oil companies that exploit fields [2].

Currently, various techniques to gain information are used. They involve ground observations, air survey, and satellite data. However, numerous territories of Western Siberia are referred to so-called hard-to-reach areas, whereat there are difficulties with ground observations because of economic reasons [3]. Due to the above peculiarities of the investigated areas, vegetation cover condition may be assessed using available satellite data.

The objective of this research was to carry out analysing and monitoring vegetation cover condition for oil producing areas of Western Siberia. Research is based upon satellite images of average spatial resolution that combine advantages of free (no-charge) access to data and the quality acceptable to detect changes in vegetation cover condition.

EXPERIMENTAL

Using normalized difference vegetation index

The characteristics of the Moderate Resolution Imaging Spectroradiometer (MODIS) meet the requirements listed above. It is installed on board of Terra and Aqua satellites. Shooting is carried out in 36 spectral channels in the optical spectrum range at a resolution between 250 and 1000 m. Two of them (at a resolution of 250 m) are found in the red and near-infrared ranges [4]. A wide band of surveillance guarantees an opportunity for the retrospective analysis of the area condition of the Tomsk region during 2000–2016. This research used specialised MOD13Q1 products that maintained NDVI (Normalized Difference Vegetation Index) values that were formed once in 16 days [5].

The calculation of the NDVI is premised on a difference of reflection in the near infrared and red regions of the electromagnetic spectrum [6, 7]:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

where NIR and RED are reflection coefficients in the near infrared and red regions of the spectrum, respectively.

Areas with photosynthetically active vegetation absorb much more radiation in the red portion of the electromagnetic spectrum than in regions without vegetable life or photosynthetically inactive vegetation. That is linked to the presence of pigments in leaves, needles, *etc*. Thus, the difference in reflectance makes it possible to single out the following areas: without vegetation cover, and also photosynthetically inactive and active vegetation. In order to interpret the calculated values, there is used the discrete scale, whereat NDVI values are varied in the range between −1 and 1. The NDVI values for green biomass of high and average activity degrees are fluctuated between 0.4 and 1.0 and may not be lower than 0.2 [6, 7].

Thus, in addition to determining areas with oppressed vegetation, the analysis of NDVI values allows the additional determination of changes of phytomass volumes in the investigated area.

TABLE 1

Number of equipment failures in the investigated hydrocarbon fields of the Tomsk region.

Fields	Failures number (per year)						
	2010	2011	2012	2013	2014	2015	2016
Luginetskoe	43	28	44	26	15	10	4
Olenie	26	22	20	7	7	22	5
Lomovoye	43	28	44	26	15	10	4
Katylginsky	40	69	26	13	9	5	2
West Katylginsky	10	25	15	3	6	3	2

Methodological issues of remote monitoring

The remote monitoring of environmental condition was carried out for territories of five oil and gas fields of the Tomsk region, such as Luginets, Olenie, Lomovoye, Katylginsky, and West Katylginsky. In order to check the correctness of the technique proposed, the background territory of the State nature reserve of regional importance “Oglatskiy” (Oglatskiy reserve) in the Kargasokskiy district of the Tomsk region was selected. The reserve is a mixed forest with an area of 100 000 ha.

According to the open information annually provided from state reports regarding the condition and the preservation of the environment of the Tomsk region, the major pollution of lands and water bodies is due to accident rate in hydrocarbon deposits [8]. Oil and gas production facilities witnessed the 61st non-categorical failure in 2016. It took place in at Tomskneft VNK OJSC facilities (52 failures in oil pipelines, 9 – in water pipelines). The major number of failures occurred resulting from pipes corrosion and increased operation rate of fields. Table 1 reports data about the number of failures in oil and gas producing facilities between 2010 and 2016.

The entire process of data processing and analysis can be presented as an algorithm of subsequent actions.

The first step assumes the collection formation of satellite data for a multi-year period. The Research Information Centre of the Institute of Petroleum Chemistry (IPC), Siberian Branch Russian Academy of Sciences, collected MODIS satellite data for Tomsk region area over a period of 2000–2018. The calculations used MOD13Q1 data for 2010–2018 that covered the investigated area in the Tomsk region.

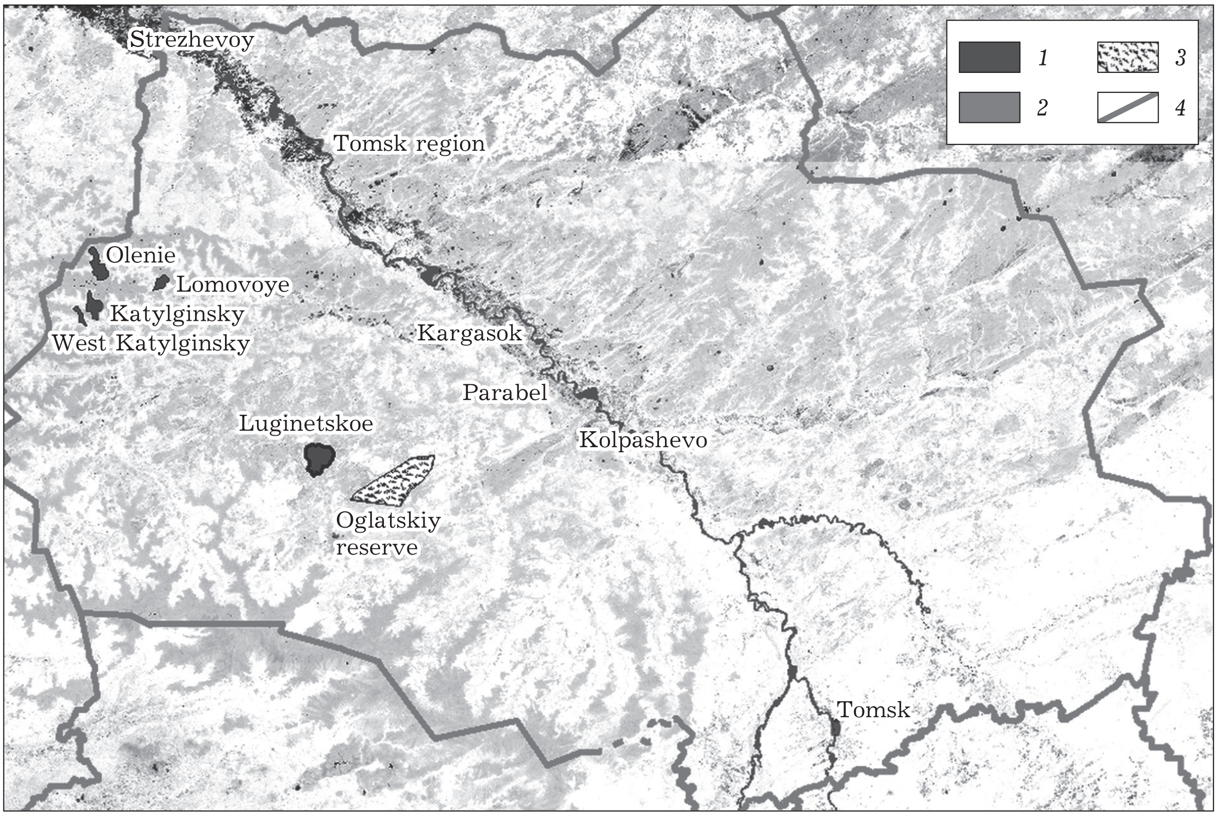

Fig. 1. Investigated territories of the Western Siberia deposits: *1* – oil and gas-oil; *2* – large rivers; *3* – settlements; *4* – borderlines of administrative-territorial formations.

The second step included the analysis of environmental reports and statistical data about emergency situations in the territories of hydrocarbon deposits and the formation of the list of the latter, the territory of which required the assessment of the condition of their vegetation cover.

The third stage suggests making polytonal vector layers using the ArcGis10.2.2 geoinformation system. This paper reports analysis results for vegetation cover condition of territories of five hydrocarbon deposits in the Tomsk region from 2010 to 2018 (Fig. 1).

The last step incudes the analysis and interpretation of the data acquired.

RESULTS AND DISCUSSION

In order to analyse changing the vegetation index, MOD13Q1 16-day Vegetation Indices (250 m) were used over the period from 2010 to 2018, for 193 a year, in other words, 16-day averaged values from June 27 to July 13 for each year.

Figure 2 reports the dynamics of changing average NDVI values. The dynamics was calculated using the Zonal Statistics device of the ArcGis 10.2.2 geoinformation system. MOD13Q1 satellite data for territories of five investigated hydrocarbon deposits were used over the period from 2010 to 2018.

As can be seen, the maximum NDVI value corresponds to vegetation cover condition of the background section (Oglatskiy) in 2016. As determined, the trend of the index for five areas of hydrocarbon deposits is similar: high and minimum values in 2016 and 2012, respectively. The maximum values were acquired for the vegetation in the territories of Olenie and Luginetskoe fields in 2012. The data received is in agreement with that given in Table 1.

For example, the number of failures in the territory of the Luginetskoe deposit was increased from 106 to 144 in 2012 compared to 2011. According to the Tomskneft VNK OJSC, oil and highly mineralized liquid in the amount of 8.7 t and 7.8 t, respectively, leaked away from pipelines in 2012. The total area of polluted lands was 2.0 ha. Luginetskoe deposit lands were exposed to the maximum pollution (0.53 ha) [8]. That is what explains such a low value of NDVI (see Fig. 2).

According to the data provided by the Tomskneft VNK OJSC, the costs of environmental

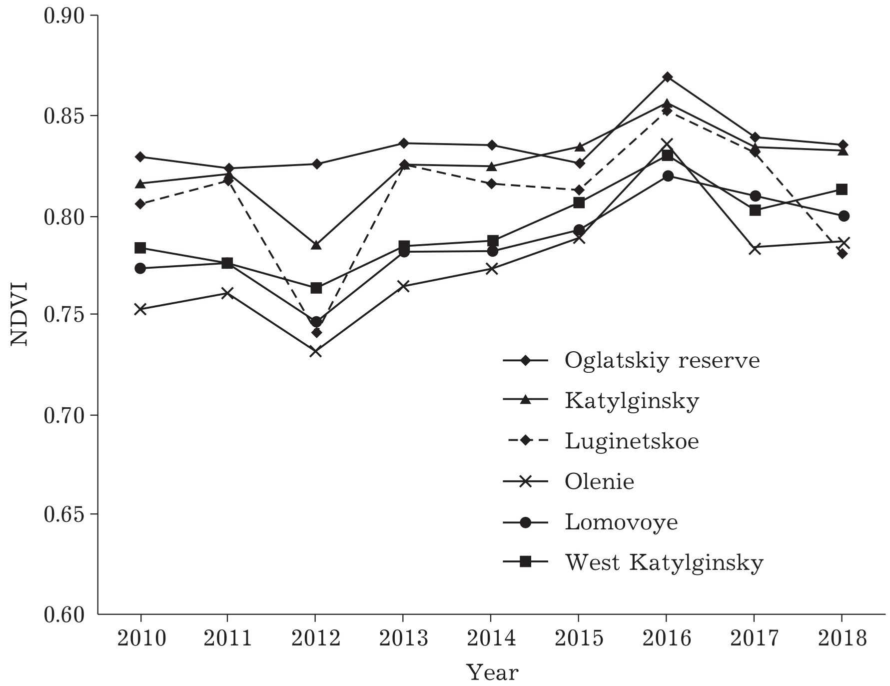

Fig. 2. Dynamics of changing average values of the normalized difference vegetation index (NDVI).

protection measures were increased by 16 % in 2012 compared to 2011. Moreover, a major increase in costs took place resulting from performing measures for the protection of atmospheric air [9]. In order to reduce atmospheric air pollution with pollutant emissions, the Government of the Russian Federation adopted Resolution No. 1148 "Regarding peculiarities of calculating the fee for negative environmental impact from emissions of pollutants formed upon combustion in flare installations and/or dispersion of associated petroleum gas into atmospheric air" in 2012 [10]. This resolution formed the basis of a more meaningful attitude to the environmental condition. According to the graphs of the dynamics of average values of the normalized vegetation index (NDVI) (see Fig. 2), it is possible to identify the improvement of vegetation in the investigated areas since 2012. The NDVI values calculated using satellite images are in agreement with the data regarding the failure rate at oil and gas producing areas of the Tomsk region.

CONCLUSION

As determined, in the north-west and southeast of the Kargasok district of the Tomsk region, where the investigated areas are located, the trend of changing the vegetation index is preserved for the period of 2010 – 2018: the values were minimum and high in 2012 and 2016, respectively, whereas the latter were reduced again hereafter. The calculated values of the normalized vegetation index (NDVI) according to satellite images are in agreement with the data regarding the failure rate in oil and gas producing areas of the Tomsk region.

Thus, the use of satellite data and geographical information system (GIS) technologies allows the analysis of vegetation cover condition in hard-to-reach oil and gas producing areas of the Tomsk region, and also the carrying out of mapping and the dimensional analysis of the swampland. Owing to this, one may assess the environmental situation in due time and make a decision on the elimination and the preventive measure of environmental pollution.

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