Assessment of soil contamination using remote sensing data in the Tamsag-Bulag oil field, Mongolia

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Abstract. Although field surveys represent an essential method for determining oil contamination of soils and soil cover, the use of remote sensing techniques has become one of the main trends over recent years due to their economic and temporary advantages. The fundamental basis of this approach is the assessment of changes in vegetation cover by vegetation indices as an indicator. In this study, the problems of assessment of the soil cover contamination during oil production are considered. It is aimed to select and evaluate objective criteria for soil cover contamination with oil in the Tamsag–Bulag field (Eastern Gobi, Mongolia). For this purpose, during the period of maximum vegetation growth, various vegetation indices were investigated at test sites (4 km²) from 2015 to 2019. The Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) were used with Sentinel-2 and MODIS of the Terra satellite images at 30 and 250 m resolution, respectively. The monitoring of the land quality with satellite images via NDVI and SAVI allows us to assess the area of oil contamination of the soils and soil cover. The significant increase in the values of the NDVI and SAVI at a distance of more than 4 km from the center of the Tamsag-Bulag oil field is shown. The obtained results indicate the possibility of assessment and monitoring the state of the oil-ed territories of the Eastern Gobi by NDVI и SAVI using satellite images.
1. Introduction
The decline in reserves and production volumes of "light" oils in Mongolia, as in most oil-producing regions of the world, has recently caused increased interest in the resources of hard-to-recover oils and the production of heavy and high-viscosity oils [1]. Such oils have a high content of paraffins and resins, which leads not only to technological complications during oil production, transportation and processing, but also to serious environmental problems. Contamination of soils in oil production areas with "heavy" oils, the destruction of which in situ proceeds extremely slowly, causes serious violations of their functioning and self-purification. The first stage of solving environmental problems in case of soil contamination with heavy oils is the choice of reliable and objective criteria for contamination of soil cover.

Using methods of remote sensing of the Earth has become one of the main trends in assessing the state of soils and soil cover at oil contamination due to the economic and time advantages over field methods [2–5]. The fundamental basis of this approach is the assessment of changes in vegetation cover by vegetation indices, since vegetation degradation is a direct distinguishing feature of soil degradation at oil contamination [3, 4]. The Normalized Difference Vegetation Index (NDVI) [6, 7] and the Soil Adjusted Vegetation Index (SAVI) [8, 9] are commonly used as a proxy of vegetation activity. The latter index is preferable for arid regions.

The aim of the study is to select and evaluate the reliability of criteria for soil cover contamination with oil in the Tamsag–Bulag field (Eastern Gobi, Mongolia). The tasks of the work are to calculate the NDVI and SAVI and to assess the reliability of the influence of oil contamination on them.

2. Materials and methods
The Tamsag–Bulag field is located in the east of Mongolia, in the Dornod Aimag (47°40’ N, 117°02’ E). The studied territories are salt marsh deserts with areas of sparse vegetation (Figure 1a). To assess the influence of the contamination on the vegetation cover in the vicinity of the Tamsag–Bulag oil field, test sites oriented to the cardinal points with areas of 4 km² were considered. The centers of the studied A and B sites were located at a distance of 4 and 8 km from the center of C site, the territory of the oil field (Figure 1b).

The state of the vegetation cover in the period 2015–2019 on the test plots near Tamsag–Bulag was assessed using NDVI and SAVI. The NDVI were determined as follow:

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

where \(\text{NIR}\) – near-infrared reflectance; \(\text{RED}\) – red band reflectance. SAVI calculates as follow:

$$\text{SAVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED} + L} (1 + L),$$

where \(L\) – soil adjusted coefficient.
Figure 1. Predominant landscape of the Tamsag-Bulag oil field (a), and location of the test sites (b).

Data obtained from the Sentinel-2 satellite were used to calculate the reflectance values in 2019. The spatial resolution of the images was 30 meters, the temporal resolution was 8 days, excepted cloud images, in the period from July 15 to August 15 (corresponds to the maximum vegetation growth). Also, we used weekly composite values from the VEGA-Science web service (http://sci-vega.ru/) to calculate the average maximum NDVI in 2015–2019. These composite values were obtained using the MODIS of the Terra satellite.

The assessment of the reliability of differences средних значений NDVI on sites A, B, C was carried out by two-way ANOVA, and an а posteriori comparison was carried out using Tukey’s test.

3. Results and discussion

Figure 2a shows the Sentinel-2 image of the Tamsag-Bulag oil field the with ranking by NDVI values, where NDVI less than 0.4 matches to black color, from 0.4 to 0.6 – gray color and over 0.6 – green color (NDVI is calculated in the range from -1 to 1). The characteristic black color corresponds to the areas directly adjacent to wells, locations of oil contamination, roads for oil transportation, etc. Figure 2b shows the Sentinel-2 image of the oil field with ranking by SAVI values. In this case, pixels with SAVI less than 0.3 are highlighted in black, in the range 0.3–0.4 in gray, and over 0.4 in green. The area directly near the oil field is highlighted in gray, more distant surroundings are colored green. As well as in the NDVI using, the characteristic black color corresponds to the areas directly adjacent to the wells and locations of oil contamination.

Table 1 shows the average NDVI and SAVI values of A, B and C sites for images processed in August 2019. The values of the vegetation indices in both cases increase significantly with the distance of the test sites from the center of the oil field (on average from 0.53 to 0.61 for NDVI and from 0.36 to 0.41 for SAVI).
Figure 2. NDVI- and SAVI-ranking (Sentinel-2, August 2019) of the Tamsag-Bulag area (a and b, respectively).

Table 1. Average NDVI and SAVI for test sites (August 2019)

| Site | NDVI     | SAVI     | p-value |
|------|----------|----------|---------|
| C    | 0.53±0.01| 0.36±0.01|         |
| A    | 0.59±0.03| 0.39±0.02| P<0.05  |
| B    | 0.61±0.02| 0.41±0.03|         |

As the spatial dynamic of the NDVI and SAVI has the same thread for 2019, and NDVI is characterized by a large resolution, the temporal dynamic of the vegetation activity maximum for 2015–2019 was estimated precisely by NDVI. The analysis of the NDVI maximums dynamic of 5-year revealed a similar trend – the increase in the values of the NDVI max at a distance of more than 4 km from the center of the Tamsag-Bulag oil field. Table 2 shows the average NDVI max, calculated for the test sites.

Table 2. NDVI max for test sites in 2015–2019

| Site | 2015 | 2016 | 2017 | 2018 | 2019 | p-value |
|------|------|------|------|------|------|---------|
| C    | 0.50 | 0.30 | 0.34 | 0.46 | 0.53 |         |
| A    | 0.52 | 0.33 | 0.35 | 0.48 | 0.59 | P<0.01  |
| B    | 0.55 | 0.34 | 0.40 | 0.48 | 0.61 |         |
| p-value |      |      |      |      |      | P<0.01  |

According to the two-way ANOVA, the NDVI max values depend on the year and the distance of the test sites from the oil field. Supplementary *a posteriori* analysis of the data with Tukey-test showed that the values of the maximum vegetation index significantly increase at a distance of 4 km from the source of oil contamination, while difference in the NDVI max for A and B sites were not detected (Table 3).
Table 3. Pairwise comparison of NDVI\textsubscript{max} using Tukey test for sections A, B and C sites

| Site | C  | A      | B      |
|------|----|--------|--------|
| C    | 0.043 | (P<0.05) | 0.002 | (P<0.01) |
| A    | 0.043 | (P<0.05) | 0.09   |
| B    | 0.002 | (P<0.01) | 0.09   | (P>0.05) |

4. Conclusion
The use of remote sensing techniques at study soil contamination with oil has shown a certain negative impact on the vegetation cover within a radius of 4 km at the development of the Tamsag-Bulag oil field – the vegetation activity of the area reduce. Some spatiotemporal decreases in the values of the Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) was revealed. There was no significant effect of oil contamination on vegetation cover and soils further away. The validation and statistical analysis results indicated that the approach proposed in this study is useful for assessing soil contamination during oil production in the Eastern Gobi (Mongolia).

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