Monitoring the process of bioremediation and revegetation of a phosphogypsum waste stack by remote sensing

N R Ermolaev¹, V P Belobrov¹, S A Yudin¹ and E L Torochkov²

¹V.V. Dokuchaev Soil Science Institute, 7, Pyzhyovskiy lane, Moscow, 119017, Russia
²“PhosAgro” group, 75, Severnoe highway, Cheremovets, 162622, Russia

E-mail: hukitoc94@gmail.com

Abstract. Production of phosphorus-containing fertilizers is related with the problem of reclamation of phosphogypsum dumps formed during the processing of Apatite-nepheline ore. In this regard, some attention should be paid to biological remediation as the most effective ecological method. Biological reclamation is one of the ways to protect the environment in the formation of phosphogypsum dumps. In this article, we propose a method for assessing the effectiveness of remediation using phyto monitoring using satellite data, which are used as the results of remote sensing. The proposed method allows estimating the volume and state of biomass of plants forming vegetation cover on the surface of man-made massif.

1. Introduction
Production of phosphorus-containing fertilizers at Balakovo branch of "Apatit" is a complex, multifunctional process, as a result of which phosphogypsum is formed and accumulated. Form of phosphogypsum dump is in compliance with the established rules and regulations for the protection of the environment. Biological remediation can be considered as an additional way to protect the environment. Many experts in biological restoration of lands pay much attention to processes of natural overgrowth of the disturbed territories in many respects defining the choice of plants for carrying out a biological stage of the planned reclamation. The study of the potential of natural vegetation restoration involves considering the sequence of successions as stages of development and restoration of disturbed habitats by vegetation [1]. Vegetation and field experiments on biorecultivation on the phosphogypsum dump during 2013-2015 showed that the use of the proposed technology makes it possible in a shorter time (2-3 years) to obtain a stable vegetation cover from the most adapted plants, to which, first of all, the crested wheatgrass (Agropyron cristatum). Remote sensing technologies can be used to determine the effectiveness of the biorecultivation process, diagnostics and monitoring of the earth's surface, which are an effective means of collecting spatial and temporal information about vegetation [2, 3]. One of the methods of processing and interpretation of remote sensing data is the calculation of indices of vegetation, soil, hydrological, etc. The most common and convenient for determining the dynamics of phyto productivity of the territory is the vegetation index NDVI (Normalized Difference Vegetation Index) [4].

2. Materials and methods
The research area is located in Balakovo district of Saratov region and is a landfill phosphogypsum storage area of about 150 hectares (Figure 1). The object of study is the surface of the landfill phosphogypsum “Apatite”. The assessment of the effectiveness of biological reclamation for the
reporting period is based on both the previous basic studies at the experimental sites, and conducted by the staff of the Balakovo branch of “Apatit” in 2016-2018 considering the formation of terraced slopes and the distribution of sludge on them, as the main substrate. To analyze the state of vegetation, a site was selected in the southern part of the phosphogypsum dump, where the formation of terraces for reclamation began from the beginning of 2015 [5].

For a detailed analysis of the restoration of vegetation cover in this area, the boundaries of the two most characteristic and undisturbed areas with vegetation were determined, as well as those of the control area with no vegetation (Table 1).

Table 1. Properties experimental plots on the phosphogypsum waste stack in Balakovo

| Plot   | Properties            | Coordinate                  | Elevation |
|--------|-----------------------|-----------------------------|-----------|
| Headland | Native vegetation | 51°54'49.94"/47°54'48.53" | 52        |
| Terrace | Native vegetation    | 51°54'42.98"/47°54'56.40"   | 54        |
| Control | freshly poured        | 51°54'34.13"/47°55'17.07"   | 68        |
|         | phosphogypsum         |                             |           |

\[\textbf{Figure 1.} \text{Experimental plots on the phosphogypsum waste stack in Balakovo 1. “Headland”, 2. “Terrace”, 3. “Control”}\]
NDVI index is the best parameter used to characterize fitoproducton in environmental studies. It is a standardized index showing the presence and condition of vegetation (relative biomass). Its value is used as a contrast between the characteristics of two channels from a set of multispectral raster data – chlorophyll pigment absorption in the red channel in the range of photosynthesis 0.55-0.68 µm (RED) and high reflectivity of vegetation in the infrared channel corresponding to the spectrum range 0.73-1.10 µm (NIR). The NDVI process creates a single-band dataset that mainly reflects the density and intensity of vegetation. Different reflection in red and infrared channels allows controlling density and relative intensity of vegetation using spectral reflection of solar radiation. Healthy and dense vegetation usually shows better near-infrared reflection than in the red region of the visible spectrum. If the leaves have a moisture deficit, are withering or dead, they become more yellow and reflect much less in the near infrared. The infrared range is absorbed by clouds, water and snow, and is reflected by rocks and bare soil almost as much as the range of the red region of the visible spectrum [6, 7]. The most suitable for large-scale data mapping and analysis, from our point of view, is the Sentinel-2 system. Sentinel-2 includes multispectral images in 13 channels with visible, infrared and short-wave parts of the spectrum. The images are of high resolution in the necessary NDVI channels to determine the index [8]. Decoding of remote sensing data, mapping and support operations were carried out in Q-gis.

Processing of remote sensing data was carried out in several stages:

1) Selection and loading of necessary images

The first stage of obtaining data of NDVI of the surface is to download remote sensing data. One of the main sources of remote sensing data is the files of the U.S. Geological survey (USGS). The site presents multispectral images of Sentinel, Landsat, MODIS, digital elevation models of different platforms, etc.

2) Correction of images

After receiving multispectral images, the data is processed and analyzed in GIS programs. For the correction and processing of satellite images in q-gis there is a specialized plugin called Semi automatic classification.

3) The calculation of the NDVI

The next step in data processing is the calculation of the NDVI vegetation index. For its calculation are used images of RED and NIR channels. Calculations are made by the formula (NIR-RED)/(NIR+RED). When applying the formula to calculate the vegetation index, the raster calculator calculates and builds a raster image reflecting NDVI values on the surface of research area [9].

4) Spatial analysis and statistical analysis of data and presentation of results

The end of data processing is spatial analysis and statistical analysis. This stage consists in obtaining digital data on the state of vegetation at the studied sites.

3. Results and Discussion

The statistical analysis of the data allows us to talk about a significant difference between the control area and the areas of “headland” and “control” (Figure 2, table 2). This difference suggests that the terracing of the slopes of the phosphogypsum waste stack and the overlap of their substrate allows us to successfully carry out bioremediation.

| Table 2. Results of T-test experimental plots data |
| :----------------- | :----- | :------ |
|                  | T-test | df   | p value |
| headland-terrace | 0.784  | 24   | 0.441   |
| headland-control | 9.788  | 24   | 0.001   |
| terrace- control  | 4.175  | 24   | 0.001   |
In addition, the obtained NDVI raster images were classified into groups according to the values of NDVI: group 1 – below 0.2 (conditionally without vegetation); group 2 – above 0.2-0.3 (occupied by vegetation in the early stage of development or oppressed vegetation); group 3 – 0.3-0.6 (well-developed vegetation); group 4 – more than 0.6 (highly developed vegetation). Due to the lack of vegetation, the first group was not taken into account. Thus, polygons were built, reflecting the area occupied by vegetation for each selected month. Areas covered by vegetation were calculated using standard vector data processing tools. The analysis of NDVI values made it possible to confidently identify the presence of vegetation on the surface of the phosphogypsum dump. High NDVI values were observed at the sites where the most "lush" vegetation was observed. Based on statistical analysis of the data obtained, graphs were constructed, reflecting the dynamics of vegetation with different values of the vegetation index from 2016 to 2018.

Analysis of changes in the NDVI value in space and time indicates that the plants on the phosphogypsum dumps are under conditions of continuous growth and recovery. The area occupied by the vegetation on the dump increased almost 3.5 times (figure 4), and the NDVI value increased from 0.01 - 0.02 to 0.49-0.56 (figure 3). In addition, the qualitative composition of vegetation has changed significantly.

![Figure 2. Box-plots of NDVI data](image)

![Figure 3. Qualitative change of vegetation on the surface of dumps](image)
Figure 4. Quantitative change of vegetation on the surface of dumps

4. Conclusion
Remote sensing is an important tool in addressing environmental monitoring issues. This study has shown that satellite data provide information on spatial and temporal trends in the growth and restoration of vegetation on phosphogypsum dumps. This information can be used to assess the parameters of phytomass growth in the process of changing the phenological phases of plant development and climatic conditions of growth. The results of phytomonitoring are necessary for the design, monitoring and evaluation of the effectiveness of technologies for the reclamation of phosphogypsum dumps.

References
[1] Beck P S A, Wang T J, Skidmore A K and Liu X H 2008 Int. J. of Remote Sensing 4277–83
[2] Weber D, Schaepman-Strub G and Ecker K 2018 Ecological Indicators 447–60
[3] Chang J and Shoshany M 2016 IGARASS pp 5300–3
[4] Iftikhar A and Cawkwell F 2016 J. of plant ecology 649–71
[5] Belobrov V, Lebedeva M, Abrosimov K, Grebennikov A, Torochkov E and Ryashko 2018 Spanish J. of Soil Sci. 183–92
[6] Taleai M and Yameqani A 2018 Ksce J. of civil engineering 279–91
[7] Sitokonstantinou V 2018 Remote sensing 1–21
[8] Lessio A and Fissore V 2017 Imaging 1–16
[9] Silveira O and Martiniano E de Mello 2018 Int. J. of remote sensing 2597–619