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Taking into account the relief variability when creating an industrial eco testing site and reclamation and remediation technologies

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Abstract

One of the first conditions for the success of restoring the former biodiversity is the restoration of the leading basic characteristic of natural landscapes – topsoil. The purpose of this work was to study the consideration of terrain variability in the creation of an industrial eco testing site and technologies of reclamation and remediation. The analysis of data on observations of experimental sectors showed that the average slope of sector 1 was 10.8°, the elevation difference on the ground lies in the range from 248 to 278 m. The average slope of sector 2 was 6.1°, the elevation difference on the ground lies in the range from 254 to 267 m. The average slope of sector 3 was 12.6°, the elevation difference in the area ranges from 236 to 277 m. The presence of a large height difference in experimental sectors 1 and 3 can lead to significant flushing of biomass during the spring flood. The relatively flat surface after the planning work on sector 2 allows predicting a lower percentage of plant loss because of next season's flood. The area of erosive processes in sector 1 exceeds 30%, in sector 2 – 12%, and in sector 3 – 30%. Comparison of orthophotoplan data with NDVI index maps allowed us to confirm the hypothesis about the loss of the area of the projective cover during erosion. Based on the data on the dynamics of the NDVI index values, the largest increase in biomass was observed at the end of the growing season. After photofixation, it can be seen that the green phytomass of herbaceous plants is well formed, which indicates good viability of the vegetation cover. The difference in the projective plant coverage of sector 2 compared to sectors 1 and 3 increased from 25 to 58%. The timely passage of phenological phases was facilitated by the addition of stimulating components of TOR-organic, which had a positive effect, saturating the soil with useful macro and microelements. The results obtained indicate the correct choice of bioremediation technology and rational options for choosing phytoremediants, taking into account the difference in relief. Subsequently, the data obtained is planned to be used in the biorecultivation of disturbed territories in other areas of the Kuzbass region

Keywords: Technogenically Disturbed Landscapes, Erosion, Biological Product, Normalized Difference Vegetation Index (NDVI), Phytomass

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1. Introduction

Currently, intensive development of natural resources is acquiring a qualitatively new character. Technogenesis manifests itself at the global and regional levels, affecting elements of the atmosphere, hydrosphere, lithosphere and biological communities [1]. The anthropogenic pressure on nature is increasing every year. The number of disturbed lands in the world is gradually increasing [2-4]. Disturbed lands are considered to have lost their original natural and economic value and, as a rule, are a source of negative environmental impact. Kemerovo region – Kuzbass is a powerful industrial center of Russia. Today, due to the active extraction of coal, metallurgy, coal chemistry, petrochemistry and the development of new industries, the lands of the Kemerovo region are experiencing a fairly high anthropogenic load. The consequences of the loss of land in recreational and protected areas are steadily deteriorating the state of the environment and the quality of life of citizens, and therefore the management of the green fund should be considered as part of the concept of sustainable urban development within the framework of a new paradigm of environmental responsibility [5-7].

It is important to restore the lands allocated to municipalities for mining, to make responsible environmental decisions, realizing the possibilities of recreational areas, for example, for the development of ecological tourism [8-10]. Achieving the initial state of natural landscapes disturbed by coal mining is an indefinitely long process, therefore, promising reclamation technologies strive to achieve a certain level of similarity between man–made ecosystems and natural ones. The choice of the direction of reclamation and the optimal way of using the territory of the used dump should be carried out when solving the issue of land allocation, based on comprehensive economic, environmental, biological and technical justification. Taking into account the necessary compensatory measures if it is impossible to restore the initial state of the territory allocated for the dump [11]. One of the first conditions for the success of restoring the former biodiversity is the restoration of the leading basic characteristic of natural landscapes – topsoil [12].

Therefore, the purpose of biological reclamation is to create vegetation cover on reclaimed lands, taking into account the variability of the landfill relief, restore the fertility of landfill soils, create favorable environmental conditions, and return disturbed lands to the land user [13]. The green cover performs protective functions, as well as decorative ones in settlements. The task of optimizing the environment requires the creation of phytocenoses on man-made landscapes with high productivity and actively performing a phytomeliorative role in the early years of development of disturbed lands. When selecting various plant species for reclamation, it is necessary to take into account their bioecological features, ecological plasticity, growth and development rates, reproductive ability, adaptability to unfavorable terrain [14]. The purpose of this work was to study the consideration of terrain variability in the creation of an industrial eco testing site and technologies of reclamation and remediation.

2. Materials and Methods

Experimental studies on the implementation of zoning to ensure the optimization of the disturbed land recultivation were carried out at the site of the coalmine dump (Figure 1) of the Kemerovo region (Russia). The coalmine affects the territories of Novokuznetsky and Prokopyevsky districts of Kuzbass [11]. There are no settlements in the section area, but a village and a village settlement are located near it, 8-10 km away, while large cities of the Kemerovo Region are 25-30 km away (Figure 1). In general, the natural and climatic conditions of the area are favorable and allow reclamation work to create forest and grassy plantations for sanitary, forestry and agricultural purposes on the surface of man-made landscapes. However, without the formation of a favorable root layer, climatic resources will not be spent rationally. This is because unfavorable physical conditions on the surface of the dump will not allow the formation of sufficient moisture reserves in the root layer, and the increased temperature of the surface of the dump will contribute to increased evaporation in the root layer. Therefore, reclamation measures will be characterized by low soil and environmental efficiency, which may significantly limit the possibility of creating and using reclaimed land for agriculture.

Before the stage of biological reclamation, a mining and technical stage of reclamation was carried out on the territory of the testing site in accordance with the approved project for the biological reclamation of land allotments destroyed by mining and adjacent territories of the coalmine. The scientific and methodological basis of these studies was the zoning method [15]. In accordance with the zoning of the site, in order to form the scientific base of the experiment, the surface was finished and a layer of potentially fertile soil layers (PFSL) with a capacity of at least 1 m and a fertile soil layer (FSL) with a capacity of at least 0.5 m was applied. The entire testing site was divided into 3 sectors (1, 2, 3). The following grasses were sown in sector 1: white clover, Hungarian sainfoin (with and without the use of b/p). The following grasses were sown in Sector 2: tall fescue, couch grass (with and without the use of b/p). The following crops were planted in Sector 3: common ninebark, bird cherry, Chinese elm, Sorbus sibirica, Rosa glauca, blue honeysuckle (with and without the use of b/p). The observation period for the vegetation of each sector was 36 days.

At the experimental site, the treatment of seeds of perennial grasses and the root system of woody and shrubby plant species with a complex of rhizospheric bacteria (b/p) obtained on the basis of animal husbandry waste TOR-organic was introduced into the experimental scheme. The characteristics of TOR-organic are presented in Table 1. The technological process of conducting hydraulic sowing was as follows. The container was filled with water through a specially designated filling hole. The accompanying engineer of the hydroseeder disconnected the plug from the water meter and attached the suction sleeve, the other end of the sleeve with the filter was lowered into the water. The filter was used to ensure that the working nozzle was not clogged when spraying the working mixture. After preparing the working mixture, the hydroseeder was brought to the site for loading materials. After loading all the materials, the hatch of the neck was closed, the working mixture was thoroughly mixed, the agitator was turned off and the process began.

The site after the hydraulic seeding works is shown in Figure 2. When planting seedlings, b/p were introduced by the method of root irrigation. When processing sectors with hydraulic seeding, b/p were added to half the volume of the substrate used. Observations of the vegetation of the planted material were carried out by the visual method and by evaluating the NDVI index with a frequency of once every two weeks. Aerial photography with a Red, Green, Blue camera (RGB camera) was performed using unmanned aerial vehicles (UAVs) of the DJI Phantom 4 Pro+ model with an onboard Global Navigation Satellite System (GNSS) receiver installed. The appearance of the device is shown in Figure 3. The KemSU Institute of Digitalization has used the DJI Phantom 4 Pro+ UAV (upgraded with the Teokit kit) since 2017. The UAV is a multi-rotor aircraft with 4 electric brushless motors.

Technical characteristics of the UAV:

- Flight speed (air): up to 72 km/h;
- Maximum horizontal flight altitude: 6,000 m;
- Radio communication range: up to 7 km;
- Maximum flight duration: 30 minutes;
- Permissible wind speed: no more than 10 m/s;
- Maximum take-off weight: 1.375 kg;
- operating temperature range: from 0°C to +40°C;

DJI Phantom 4 Pro+ is equipped with a built-in visible spectrum camera. The design of the flight task was carried out in the FLY Teofly software (software from the manufacturer of Teokit upgrade kits). The flight was carried out with the circumference of the terrain, the data of which were obtained as a result of surveys previously performed at the site. The design altitude relative to the terrain was determined to be 100 m. Overlap of photographs: 79% (longitudinal) × 60% (transverse). Design spatial resolution of photographs: 2.6 cm/pixel. The designed flight task was imported into the Litchi flight software [16]. During aerial photography, 2,630 photos from an RGB camera and 4,600 multispectral images were obtained over the entire period. The in-house processing consisted of: processing geodetic measurement data performed during the creation of a planned altitude justification; calculating the coordinates and heights of the projection centers of aerial photographs; photogrammetric processing of aerial survey materials, as well as creating maps of intrafield slopes based on the resulting digital terrain model (relief) and calculating the average slope of sites.

The processing of geodetic measurement data performed in order to create a planned high-altitude justification of the work was carried out in the Trimble Business Center software [17]. The result of the processing were accurate projection centers of aerial photographs, ensuring high accuracy of the results during photogrammetric processing and eliminating the need to use reference markings for georeferencing the results. Based on aerial photographs from an RGB camera, digital orthophotoplanes, elevation maps, and digital terrain models (relief) in the form of dense point clouds were built. Based on multispectral images, maps of the normalized difference vegetation index (NDVI) were made. NDVI is a numerical indicator of the actual quality and quantity of vegetation in a given area, which is determined by comparing the intensity of absorption of red light and reflection of near infrared light by plants. Healthy plants tend to absorb red light and reflect near infrared light [18].

Possible index values range from -1 to +1:

- -1 to 0 are objects of inanimate nature;
- 0 to 0.2 are typical for open soil;
- 0.2 to 0.5 – sparse vegetation;
- Above 0.5 – dense vegetation.

Work on the creation of geospatial materials (with the exception of the map of intrafield slopes) was carried out in the Agisoft Metashape Professional software package. The initial materials for processing were photographs, as well as the coordinates and heights of the projection centers of the aerial photographs. During the construction of geospatial materials, the following stages of work were performed:

- orthotransformation of aerial photographs using external orientation parameters
- automatic identification of images and the construction of a thin point digital model of the terrain (relief);
- control of the position and construction of a thin point digital model of the terrain (relief) according to control markings;
- construction of a terrain model (relief) in the form of a dense point cloud;
- construction of a digital terrain model (relief) (2D elevation maps);
- construction of an orthophotoplane/NDVI map;
- ropping of an orthophotoplane and a digital relief model/NDVI map along the boundaries of the work object.

The accuracy of the obtained geospatial materials was monitored using control markings in the Agisoft Metashape Professional program [18]. The control of the planned altitude positions of the control markings obtained as a result of photogrammetric processing was performed according to the difference in coordinates and heights of the markings on the orthotransformed photographs and their values obtained as a result of processing satellite geodetic measurements. The standard error in determining coordinates and heights, determined for each control identification, for geospatial materials obtained from photographs from an RGB camera did not exceed 5.76 cm in plan and 5.23 cm in height, and for geospatial materials obtained from multispectral images it did not exceed 7.1 cm in plan and 23.78 cm in height.

The above values of spatial resolution and standard deviation allowed concluding that the geospatial materials obtained as a result of surveys are at a high level of convergence in the planned position, which made it possible for their further comparison and analysis. For further analysis of the relief and slopes, the expediency of using a digital relief model was determined on the date when all test areas for planting were prepared and handed over for planting. Accordingly, on this date, using the software Free and Open Source Desktop GIS (QGIS), a map of intrafield slopes was prepared and the average slope of the site was calculated. Based on the digital geospatial materials obtained because of in-house processing, cards of experimental sites were formed [19]. The cards aggregated all available key site parameters (crop name, planting date, growing season), as well as parameters calculated on the basis of geospatial materials (NDVI values, slopes) in dynamics for the entire period from the planting date

3. Results and Discussions

Work on the laying of the site was carried out on 30.08.2023. The site was divided into three experimental sectors. The sectors were prepared before the start of experimental work on biological reclamation, and the surface was laid out with a natural slope (adjacent territory). Figure 4 shows an overview of Sector 1. Figure 5 shows a digital terrain model of Sector 1. Figure 6 shows a map of the intrafield slopes of Sector 1. Figure 7 shows a diagram of the distribution of intrafield slopes of Sector 1. The diagram of Sector 2 is shown in Figure 8. Figure 9 shows a digital terrain model with horizontal lines and an average slope of Sector 2. In Sector 2, there are areas of erosive process (Figure 10).Figure 11 shows a diagram of the distribution of intrafield slopes of Sector 2. Figure 12 shows a general overview of Sector 3. Figure 13 shows a digital terrain model of Sector 3, and Figure 14 shows a map of the intrafield slopes of the studied sector. Figures 16-18 show the dynamics of the distribution of NDVI index values in Sectors 1, 2 and 3. An example of the formation of a testing site with bioremediation is shown in Figure 19.The analysis of data on observations of Sector 1 led to the following results. The average slope of Sector 1 was 10.8°.

As can be seen from Figure 6, the elevation difference in the area lies in the range from 248 to 278 m. The presence of a large elevation difference in the experimental Sector 1 and its territorial location near the floodplain of the river, presumably, can lead to significant flushing of biomass during the spring flood. The presence of erosive areas in the distribution diagram of the intrafield slopes of Sector 1 is due to the appearance of groundwater on the surface of the experimental sector, followed by erosion of the upper soil layers. As can be seen from Figure 7, the area of erosive processes increases towards the middle of the site and in total exceeds 30%. Thus, considering that the area of the sites of the deepest soil erosion in Sector 1 is more than 30%, it is possible to predict significant losses of the projective cover. When observing Sector 2, it was found that the average slope of Sector 2 was 6.1°. As can be seen from Figure 9, the elevation difference in the area lies in the range from 254 to 267 m. The presence of a relatively flat surface after planning works allows us to predict a lower percentage of plant loss as a result of flood events of the next season.

The erosive areas in the distribution diagram of the intrafield slopes of Sector 2 are caused by the appearance of groundwater on the surface of the experimental sector, followed by erosion of the upper soil layers. It should be noted that the total area of the areas subjected to erosive processes increases towards the boundaries of Sector 2. The area of the soil erosion sites in Sector 2 is about 12%, which makes it possible to predict not significant losses of the projective cover. The average slope of Sector 3 was 12.6°. As can be seen from Figure 13, the elevation difference in the area lies in the range from 236 to 277 m. The presence of a large height difference after the planning work allows us to predict a high probability of plant loss as a result of flood events of the next season. The erosive areas in Figure 16 are caused by the appearance of groundwater on the surface of the experimental sector, followed by the erosion of the upper soil layers. The area of the soil erosion sites in Sector 3 is about 30%, which makes it possible to predict significant losses of the projective cover. When comparing the orthophotoplan data in dynamics, it is possible to trace the development of areas subject to the erosive process due to the occurrence of groundwater.

By comparing the coordinates of such areas with maps of the NDVI index, the hypothesis of the projective cover area loss was confirmed. Nevertheless, there is a positive trend in the distribution of the NDVI index in the sectors of the site. Based on the data on the dynamics of the NDVI index values, the largest increase in biomass was observed at the end of the growing season, from the moment of planting. At the same time, the peak of vegetation in all sectors falls in October, the increase in biomass of the grass mixture occurs until the end of the growing season due to subzero air temperatures and soil freezing. The timely passage of phenological phases was facilitated by the addition of stimulating components of TOR-organic, which had a positive effect, saturating the soil with useful macro and microelements. As a result of the experiment, it was found that the greatest plant survival was observed in experimental Sector 2, since this sector is least susceptible to erosive processes, is located on a relatively flat surface, which makes it possible to predict a lower percentage of plant loss as a result of flood events in future seasons. When studying the germination and survival rate of plants on the projective cover of experimental sectors of technogenically disturbed landscapes, it showed a high result.

The difference in the projective cover of Sector 2 compared to Sectors 1 and 3 ranged from 25 to 58%. It should be noted that the formation of vegetation cover is also influenced by the introduction of plant survival and growth stimulants (b/n).

In areas using basal irrigation of used seedlings, the formation of a plant community occurred 25-30% faster, which indicated the correct choice of bioremediation technology and rational options for choosing phytoremediants, taking into account the difference in relief. Prolonged intensive mining activity leads to irreversible changes in the landscape. A mountain landscape is a special type of landscape that has specific features in terms of geology, geomorphology and the environment. Dumps, ponds, underground areas and collapse zones are among the negative consequences of mining activities on the mining terrain. The correction of each form must be considered separately, since it can be time-consuming from a technical and financial point of view [11]. The results obtained by us on taking into account the variability of the relief when creating an industrial eco testing site and technologies of reclamation and remediation are consistent with the research of leading scientists [20-25].

The study [20] shows that the relevance of the issue of biological reclamation is dictated by changes in terrain, land use violations and the formation of a man-made landscape as a result of coal mining, both open and underground methods. The study presents an analysis of the use of green technologies to improve the efficiency of land use. Reclamation was carried out in areas with different terrain with a high concentration of mining enterprises. These studies allow us to compare and evaluate the possibilities of using different types of plantings in the restoration of anthropogenic territories with a relief prone to erosive processes [20]. The same researchers found that the mechanical structure of the soil is also important for biorecultivation. It determines the efforts that need to be made to cultivate the soil, comply with the required amount of irrigation. The particle size distribution affects not only the remediation stability, but also the nature of the wind erosion process development.

Unstructured soil is characterized by the worst water, air and other regimes that ensure the formation and accumulation of humic substances that promote plant growth.In the case described in this study [20], the variability of the eco testing site relief indicates uneven heating of the base as a result of ongoing exogenous processes in some rocks. When exposed to elevated temperatures, the process of denitrification occurs – the loss of nitrogen in gaseous form, which also contributes to the survival and growth of plants used for biological reclamation. The study [21] examines the restoration of coal mine dumps by reforestation in the forest-steppe zone of Kuzbass. 3 main forest-forming species (*Betula pendula*, *Pinus sylvestris* and *Populus tremula*) and 11 related tree species were used for the formation of plantations. The main forest-forming species was Betula pendula. It was found that the volume of seedlings survival is 10.7, 3.1 and 1.0 thousand units/ha in areas with favorable, moderately favorable and unfavorable terrain conditions.

The level of natural reforestation on the dumps of the southern forest-steppe zone was characterized as weak, which was determined by the constant drift of seeds on dumps with a large number of soil erosions, seedlings and young seedlings did not reach generative age [21]. Kowalska and Sobczyk [22] considered issues related to the influence of the eco testing site relief on remediation issues in order to choose a rational technology for biological remediation. The study characterized the causes of land degradation leading to the formation of technogenically disturbed landscapes When choosing the direction of reclamation, the development plan took into account local relief features and climatic conditions for the most effective protection of the environment and plant survival. The soil profile is the basis of reclamation. The study shows that due to rational reclamation and subsequent development, a reduced part of the eco testing site was restored for agricultural use [22].

Figure 1: Map of the Kemerovo Region coalmine

Figure 2: The site after the hydraulic seeding works

Figure 3: Appearance of DJI Phantom 4 Pro+

Figure 4: Overview of Sector 1

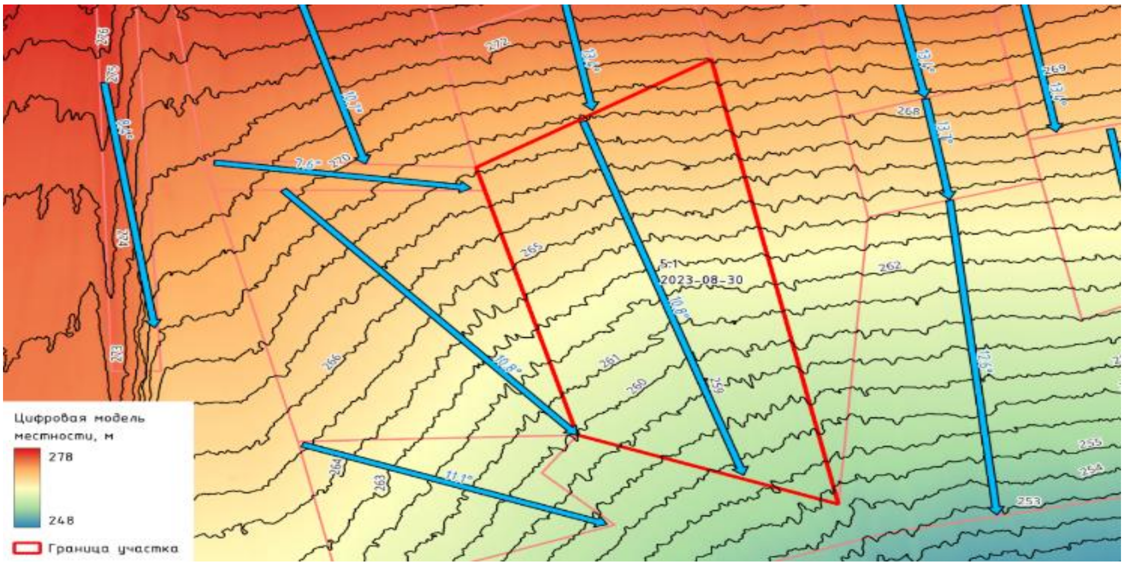

Figure 5: Digital terrain model with horizontal lines and average slope of Sector 1

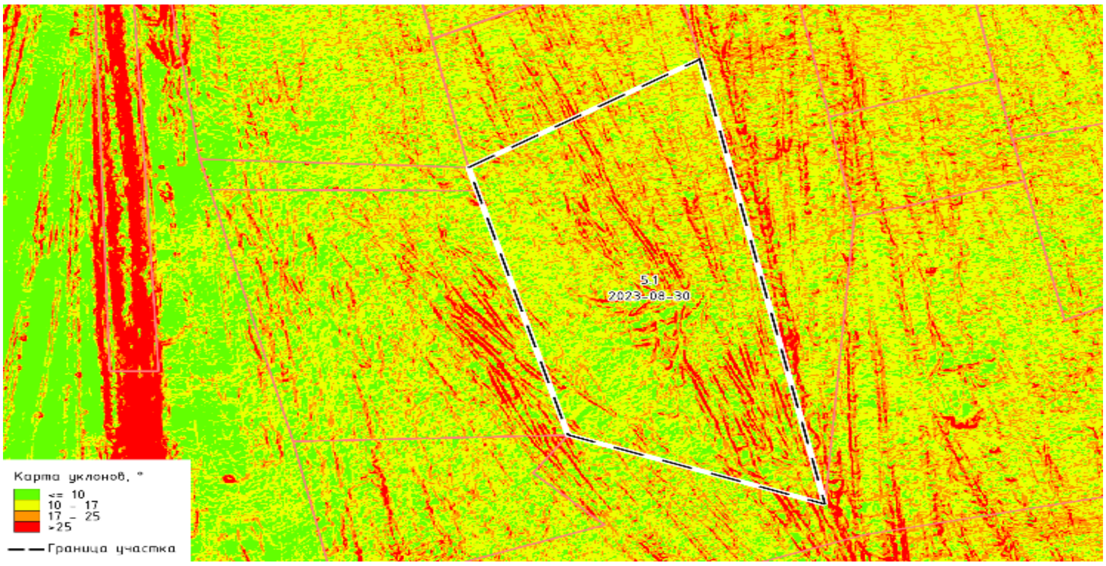

Figure 6: Map of the intrafield slopes of sector 1

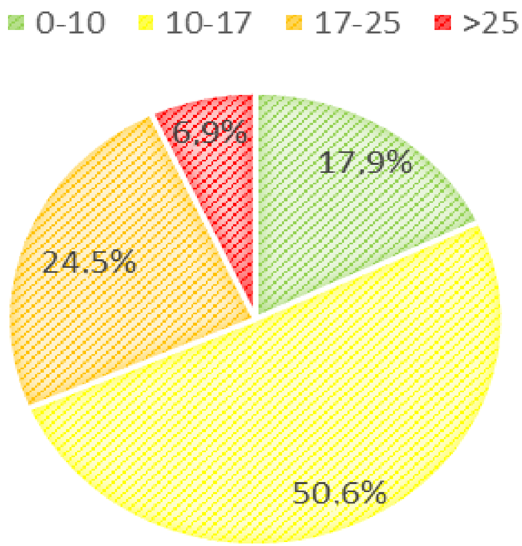

Figure 7: Distribution diagram of the intrafield slopes of Sector 1

Figure 8: Overview diagram of Sector 2

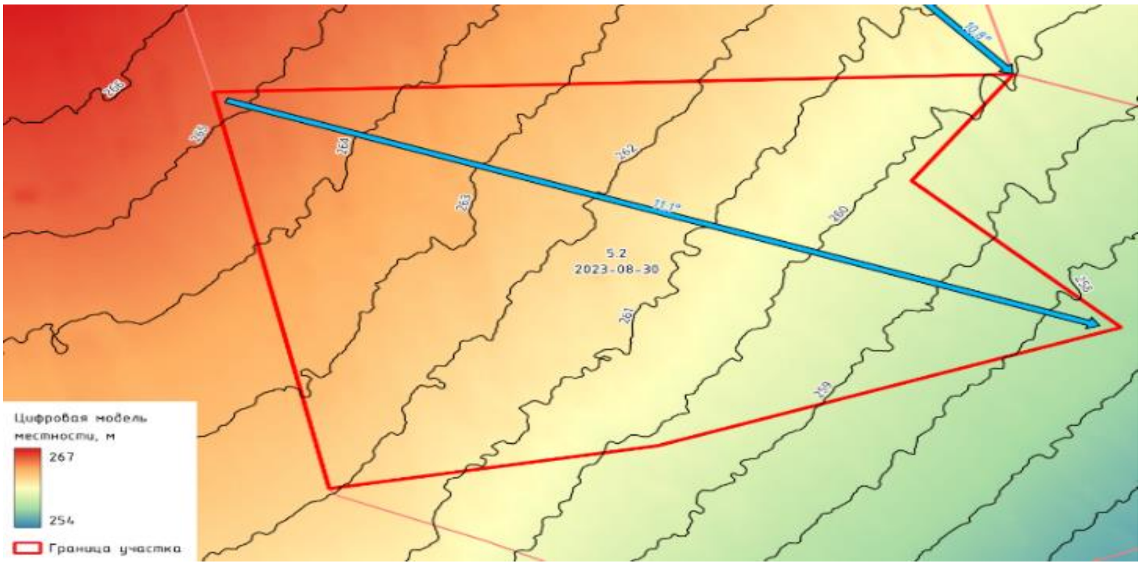

Figure 9: Digital terrain model with horizontal lines and average slope of Sector 2

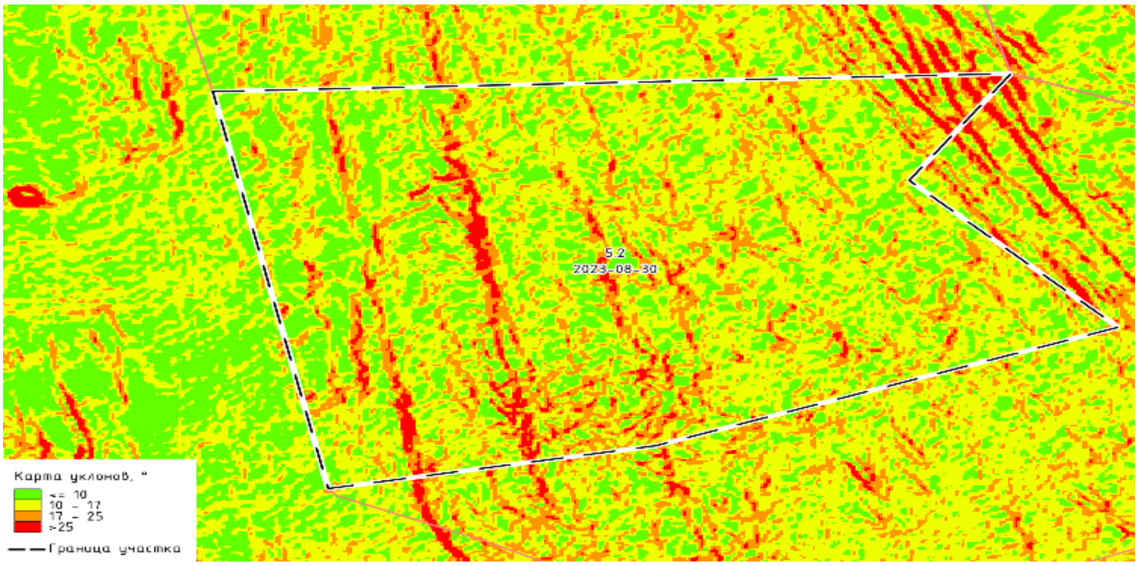

Figure 10: Map of the intrafield slopes of Sector 2

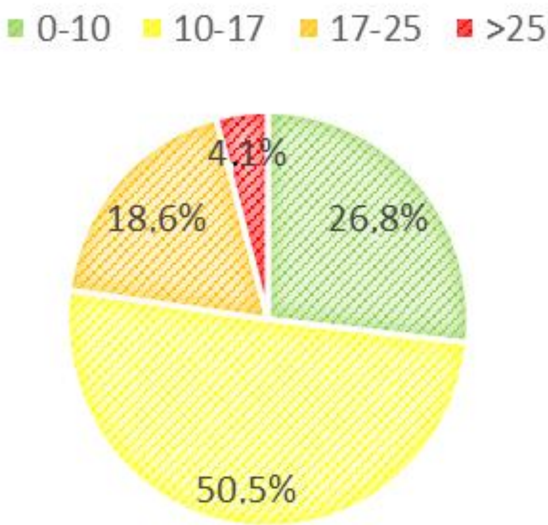

Figure 11: Distribution diagram of the intrafield slopes of Sector 2

Figure 12: Overview of Sector 3

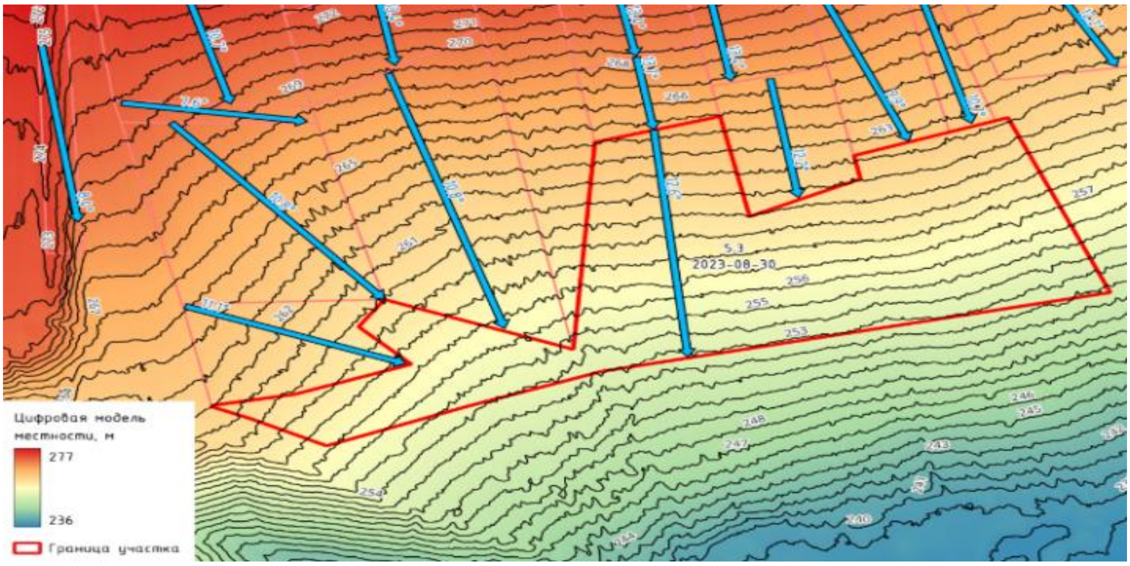

Figure 13: Digital terrain model with horizontal lines and average slope of Sector 3

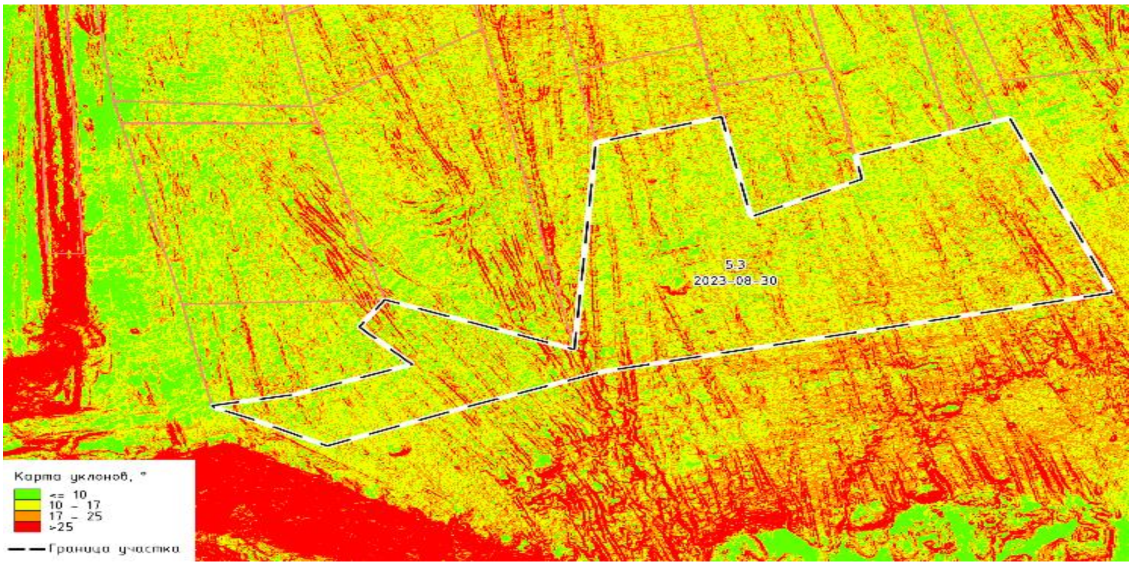

Figure 14: Map of the intrafield slopes of Sector 3

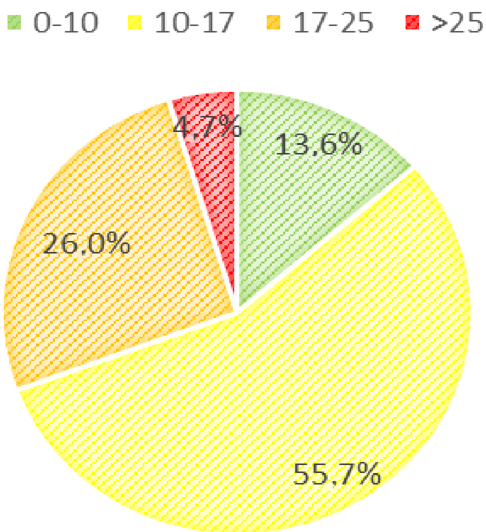

Figure 15: Distribution diagram of the intrafield slopes of Sector 3.

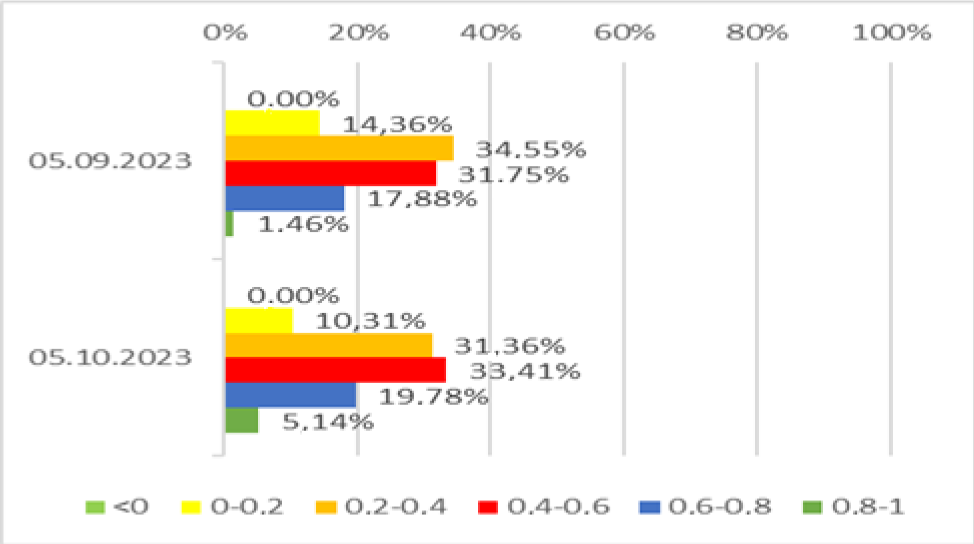

Figure 16: Dynamics of distribution of NDVI index values in Sector 1

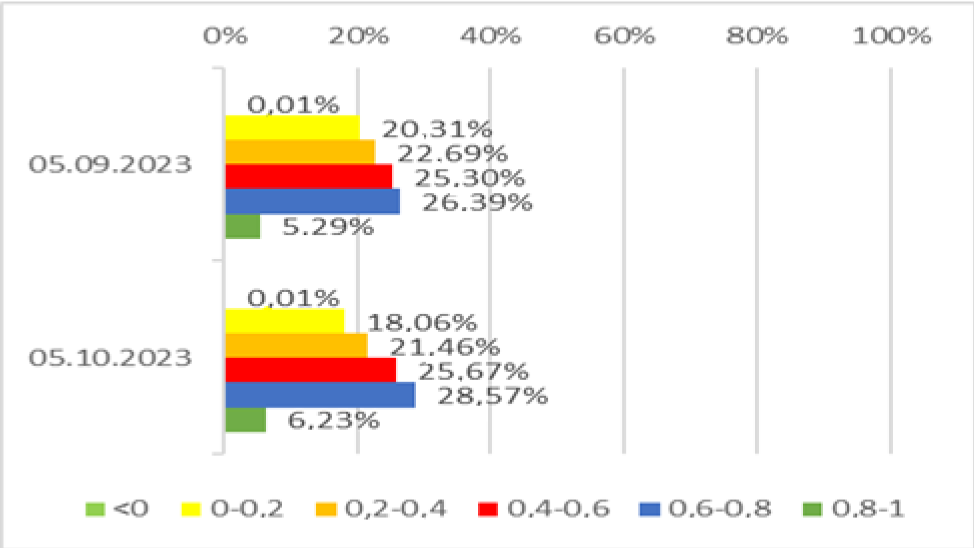

Figure 17: Dynamics of distribution of NDVI index values in Sector 2

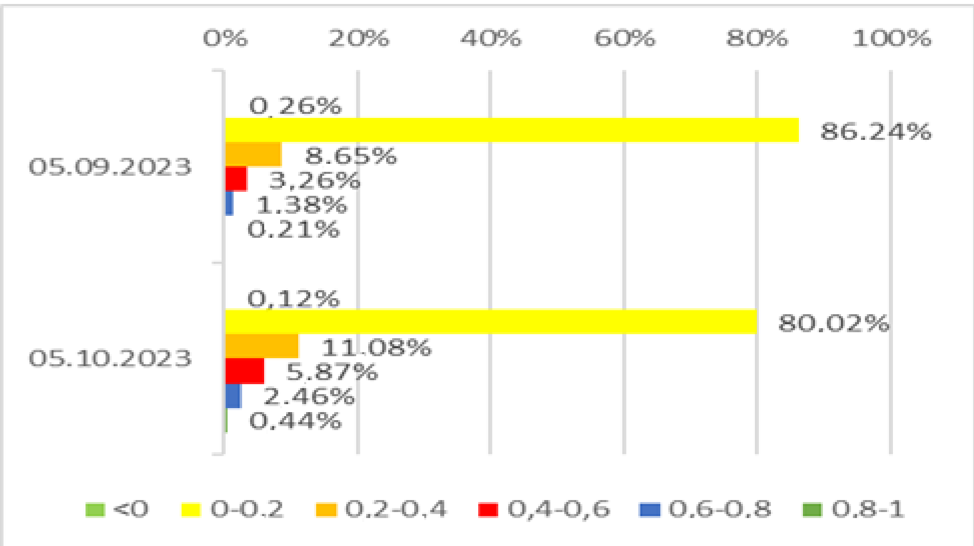

Figure 18: Dynamics of distribution of NDVI index values in Sector 3.

Figure 19: An example of the formation of a protective cover

Table 1: Composition of the TOR-organic preparation

Indicator	Units of measurement	Value
Water	%	94-96
Hydrogen index	unit pH	7.2
Macronutrients		
Total nitrogen	%	0.36
Phosphorus (P_2O_5)	%	0.3
Potassium (K_2O)	%	0.44
Micronutrients		
Copper	mg/kg	25
Copper (active form)	mg/kg	0.61
Cadmium (gross content)	mg/kg	0.06
Humic acids (humates) and fulvic acids		
Humic acids	mg/l	1,000
Fulvic acids	mg/l	1,000
Phytohormones (growth regulators)		
Auxins (by indolyl-3-acetic acid)	mg/l	3
Gibberellins (by gibberellic acid)	mg/l	17
Cytokinins (by kinetin)	mg/l	500
Macrobiological indicators		
Soil nitrogen-fixing and rhizospheric bacteria	TMC/l	1×10^{15}
Sanitary and epidemiological indicators		
Helminth larvae	pcs/kg	missing
Helminth eggs	pcs/kg	missing

A study on the reclmination of coal dumps [23] examines the emergence of a unique group of plant on reclaimed dumps of mines in Solvakia. The dumps were located on or near the mine site. The waste rock of underground mining operations was stored on the territory of the mine. The terrain was rocky, high in carbon and low in essential nutrients and water. The limiting factor was the high content of heavy metals. The appearance of so-called ecological islands on reclaimed mine sites was an interesting phenomenon. Dumps with a high content of heavy metals were populated with plants of a certain type. Some species (immigrants) who failed to adapt were excluded from vegetation for many decades. Ultimately, it was found that a small group of plants is able to grow under these phytotoxic conditions.

These plant communities have become unique habitats for species that are not found anywhere else [23]. As shown in studies [24], depending on the type of stored waste from the mining industry, environmental and economic aspects, the site may be suitable for reclamation, which can be used in the present or in the future. Some elements of the technogenically disturbed landscape, which are little susceptible to erosion and leaching of plant seedlings, have a positive effect on biodiversity due to the development of specific natural habitats on these landscapes. Under experimental conditions, the authors found that the formation of ecosystems on reclaimed dumps is facilitated by leveling and land reclamation [24-25].

4. Conclusions

Thus, as a result of the research, the principles and methods of creating artificial vegetation cover have been studied, taking into account the variability of the relief when creating an industrial ecopolygon and technologies for reclamation and remediation on disturbed industrial lands of the Kuzbass region. As a result of the experiment, it was found that the greatest plant survival was observed in experimental Sector 2, since this sector is least susceptible to erosive processes, is located on a relatively flat surface, which makes it possible to predict a lower percentage of plant loss as a result of flood events in future seasons.It was found that the seeds of herbaceous crops and tree and shrub species showed a significant increase in their vegetative mass by the time of the end of vegetation.

From the data obtained, it can be concluded that the technology of hydraulic seeding is well suited for terraced areas, this type of processing of areas of technogenically disturbed landscapes allows to protect perennial crops from wind and water erosion. A comparative analysis of all experimental parameters revealed that the most effective projective cover of the site was obtained using the biological preparation TOR-organic, which indicates the correct choice of bioremediation technology and rational options for choosing phytoremediants, taking into account the difference in relief. Subsequently, the data obtained is planned to be used in the biorecultivation of disturbed territories in other areas of the Kuzbass region.

Sources of financing

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