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JUSTIFICATION OF PHYTOREMEDIATION TECHNOLOGY OF DEGRADED LANDSCAPES ON THE BASIS OF ECOSYSTEM APPROACH

Об'єктом дослідження є розвиток природних та приживлюваність штучних рослинних угруповань на поверхні породного відвалу ліквідованої шахти «Селидівська» Державного підприємства «Селидіввугілля» (ДП «Селидіввугілля», Селидове, Україна).

Фіторемедіація деградованих гірничопромислових земель, зокрема породних відвалів, спрямована на створення стійкого рослинного покрову на поверхні техногенних масивів порід. Найбільшою проблемою біологічного етапу рекультивації відвалів є правильний підбір асортименту деревинно-чагарникової рослинності та створення рослинних угруповань, стійких до тривалого впливу токсичних речовин породних масивів. Самозаростання породних відвалів триває впродовж їх експлуатації, а домінуючими видами є типові для степової та лісостепової зони рослини. Виявлення домінантних видів рослинності на поверхні породних відвалів є джерелом важливої інформації для обґрунтування цільової фіторемедіації гірничопромислових ландшафтів.

Протягом 1996–2016 рр. досліджувалось рослинне різноманіття породного відвалу. Встановлено, що рослинні угруповання представлені переважно сімействами Злаків, Бобових, Складноцвітих і Хрестоцвітних, а найбільша кількість видів спостерігається вздовж нижньої основи відвалу та на вершині. Обґрунтовано доцільність застосування методики фіторемедіації техногенних укосів породних відвалів дерновими матами в якості альтернативної екотехнології відновлення гірничопромислового ландшафту до стану природної екосистеми. Згідно з результатами польових досліджень, приживлюваність дернових матів на верхньому і нижньому ярусах поверхні відвалу найбільша і становить 53 % та 34 % від загальної кількості висаджених зразків рослинних угруповань.

Запропонована методика фіторемедіації укосів породних відвалів дерновими матами з типовою для обраної місцевості рослинністю є перспективним напрямком прискореної фіторемедіації гірничопромислових земель

Ключові слова: *фіторемедіація деградованих земель, породний відвал, рослинне різноманіття, гірничопромисловий ландшафт, дерновий мат.*

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1. Introduction

The final stage of the development of minerals in the mining regions is the initial stage of the process of mining and restoration of disturbed lands, in particular waste dumps. Usually, external overburden dumps are subject to phytoremediation with full restoration to the state of the primary ecosystem. Forestry reclamation in mountainous regions includes a set of agrotechnical and phytomeliorative measures aimed at creating sustainable vegetation cover on the surface of technogenic rock masses.

World experience in the field of phytoremediation of industrial lands shows that there are problems associated with the creation of sustainable plant communities. As well as the selection of the assortment of woody and shrubby vegetation, the availability of elements of the mineral nutrition of plants and the long-term exposure of the toxic substances of the massifs to the flora and fauna. Therefore, identifying priority environmental factors for the restoration of disturbed mining landscapes and determining effective measures for directed phytoremediation is an urgent problem.

2. The object of research and its technological audit

The object of research is the development of natural and survival of artificial plant communities on the surface of the waste dump of the liquidated «Selydivska» coal mine of the State Enterprise «Selydivvugillya» (SE «Selydivvugillya», Selydove, Ukraine).

The «Selydivska» coal mine of the «Selydivvugillya» State Enterprise has been in operation since 1963 and was liquidated in 1996. On the territory of the mine there is a waste dump of 18 hectares. Dumps height is 40 m. The volume of stockpiled rocks is 5.4 million m^3. The rock heap is flat, without chopped terraces. A road is laid from the mine's industrial site for transporting rock mass. Two sites for storage and rock planning is preserved on the dump.

For the study of plant diversity, sections of the dump, differing in the exposure of the slope and the vertical arrangement, are selected:

– foot of the dumps (including drainage ditches around the perimeter of the lower dumps base);

– technological road to the dump (roadsides, drainage ditches);
– lower (wetter) slopes;
– upper (arid) slopes;
– unplanned hills at storage sites;
– depressions, funnels and excavations at the site of storage of rocks;
– top of the dumps.

Usually the process of self-dumping of dumps continues for several decades after its dumping. However, even at the mine closure, in some places of the dump, vegetation was observed, which was represented by individual trees (white acacia, black poplar, green ash), small shrubs (common wild rose, black elderberry) and grassy vegetation along the lower contour of the base of the dump. Within a few years after the cessation of the mine, the surface of the dump was relatively quickly populated by primary vegetation typical of the steppe and forest-steppe zones. The dominant species of plant communities are weed-ruderal garbage species, as well as wild cereals with a powerful root system.

At the initial stage of self-breeding, the rock mass contains few essential elements of mineral nutrition, and caused poor species diversity in the first years after the cessation of bedding. In 1996, vegetation was not yet observed at the rock storage sites, on the top and on the slopes. The eastern and south-eastern slopes were the most soddy, due to their exposure and the prevailing direction of the winds. The technological road to the dump was subjected to the most intensive self-growth, on both sides of which weed-ruderal (garbage) vegetation was formed, which is a constant companion of man. Abundant vegetation is found along the drainage ditches along the perimeter of the lower base of the dump, where they began to actively conquer the territory of sody and rhizome wild grasses, as well as shrubs (wild rose, black elderberry) and tree (white acacia, black poplar). During the research period (1996–2016), the tendency of the self-harvesting of the dump persisted and the green cover increased both quantitatively and qualitatively due to the settlement of new species.

3. The aim and objectives of research

The aim of research is determination of the dominant types of vegetation on the surface of the rock dump of a coal mine to justify the target phytoremediation of mining territories. To achieve the aim, the following scientific objectives are set:

1. To investigate the plant diversity of the rock dumps and identify the dominant species for potential phytoremediation of mining landscapes.
2. To justify the appropriateness of applying the phytoremediation methodology of technogenic slopes of waste dumps with sod mats.

4. Research of existing solutions of the problem

Integrated technical and biological reclamation is the main area of optimization of mining territories. The land restoration technologies existing today do not sufficiently take into account the environmental component in the practice of general restoration of degraded landscapes [1].

So, in [2] it is shown that forestry phytoremediation can be an effective tool to reduce the content of Zn, Cd, Mn, Pb and Cu metals on mining lands in the UK. It is found that fourteen years after the first tree planting, the metal concentration in the soils decreased: Cd – by 52 %, Cu – by 48 %, Zn – by 47 %, Pb – by 44 %, Mn – by 35 %. Nevertheless, it is unclear which particular tree species have hyperaccumulative properties that produce the greatest increase in biomass.

One of the promising areas is the cultivation of energy crops, in particular, the species Miscanthus, Ricinus, Jatropha, Populus [3]. But despite the informativeness and comprehensiveness of the presented concept of phytoremediation, the effectiveness of the predicted results is called into question.

At the Gumuskoi silver mining plants in Turkey [4], the effects of the accumulation of As, Ag, and Pb from the soil by tree-shrub plants were studied, which makes it possible to use them as bioaccumulators and phytoremediation. But the given concentrations of heavy metals in the roots and leaves of plants do not allow to say with certainty about the effectiveness of the bio-mowing process in time.

The technical and biological reclamation of degraded lands in the coal region of Ostrava-Karvina in the Czech Republic, where approximately 281 landfills and waste dumps are located, can be quite large-scale [5]. However, the options and the most appropriate land restoration technologies are not detailed.

The work [6] refers to the removal of heavy metals from contaminated soils in the coal mining areas of Cobre Las and Aznalcollar containing high concentrations of Cr, Fe, Ni, Cu, Zn, Cd, Hg, Pb and As using phytoremediation using Jatropha curcas L. It is found that the plant absorbs Fe about 3000 mg/kg of plant biomass, significantly reduces the content of Pb, Zn, Cu, Cr and Ni, As, and Cd, Hg and Sn completely removes from the soil. However, the appropriateness of using an extremely poisonous plant as a phytoremedian is not clear.

In [7], a pilot study is conducted to identify the potential of the vetiver grass of Chrysopogon zizaniodes (L.) to restore iron ore dumps. It is established that the vetiver grass can be effectively used to restore and stabilize the soil in areas contaminated with a high content of heavy metals, in particular Fe, Mn, Zn and Cr. But in this work, the grassy groups of vetiver on the surface of dumps in time may be somewhat less stable.

Also, bioremediation of coal mine dumps is possible by introducing microorganisms into the rock mass, which leads to a significant improvement in the state of fertility and biological productivity of technogenic soil [8]. However, the publication does not provide extended information on the species composition of the microbocenosis and its potential impact on the environment.

In a full-scale study of abandoned mining territories in the south-center of Morocco, presented in [9], an assessment is made of the level of soil pollution with heavy metals and the potential for their accumulation by plants. It is established that tolerant local plant species can be used as tools for effective phytoremediation of metal-contaminated lands. However, there is no clear pattern for the use of plants in relation to specific objects, in particular waste dumps, sludge collectors and the like.

Thus, the introduction of mining and biological reclamation technologies is a prerequisite for the effective further use of land for the needs of the agricultural sector or the creation of recreational territories [10].

In this context, a set of measures for phytoremediation and phytomelioration of degraded lands is crucial for the sustainable functioning of the landscape and restoration of biodiversity [11].

5. Methods of research

The following methods are used to complete the research objectives:

1. The method of full-scale study of the plant variety of the waste dump to identify dominant species and their use in the phytoremediation technology of degraded mining landscapes.

2. Methods of phytoremediation and stabilization of technogenic slopes of waste dumps with sod mats. The method consists in applying plant communities selected from a ravine-girder network of the selected area, with a sod of 40×40×10 cm in size to the surface areas of the dump with different exposures.

6. Research results

6.1. Research of plant diversity of the waste dump. Stable zonal vegetation is formed on the dump, especially at the top of the dump, characteristic of the steppe zone (Fig 1).

The development of such a biogeocenosis is associated with the activity of the wind. The dump is located on a plain and surrounded by farmland. The average wind speed is 3–6 m/s. East winds prevail. Wind erosion is a determining factor in the application of black soil particles to the surface of the dump from adjacent farmland. The accumulation of chernozem is also promoted by primary vegetation, with the help of which particles of fertile soil are retained.

The natural vegetation cover of this steppe zone is formed mainly by perennial grasses well adapted to a dry climate. The phytocenosis of the waste dump is heterogeneous both in appearance and in the composition of plants. The basis of the vegetation cover is made up of representatives of the family Cereals, Legumes, Compositae, and Cruciferous (Table 1).

Table 1

Species vegetation diversity in the waste dump of the liquidated «Selydivska» coal mine

Family	Plant species
Asteraceae (Compositae)	Ambrosia artemisiifolia, Cirsium arvense, Tragopogon dubius, Lactuca tatarica, Taraxacum officinale, Sonchus arvensis, Tanacetum vulgare, Artemisia absinthium, Artemisia vulgaris, Matricaria inodora, Crepis paludosa, Onopordum acanthium, Achillea millefolium, Cichorium intybus, Carduus crispus
Poaceae (Gramineae)	Calamagrostis epigeios, Calamagrostis arundinacea, Bromus inermis, Poa pratensis, Avena fatua, Festuca sulcata, Festuca pratensis, Aeluropus litoralis, Agropyron repens, Phragmites communis
Fabaceae (Leguminosae)	Robinia pseudoacacia, Vicia crassa, Melilotus officinalis, Medicago falcata, Lotus corniculatus, Ornithopus perpusillus, Lathyrus pratensis
Brassicaceae (Cruciferae)	Descurainia sophia, Erysimum cheiranthoides, Capsella bursa-pastoris, Thlaspi arvence

At the foot of the dump there is a rather high indicator of species saturation (the number of plant species per unit area), 5...11 species per 1 m^2. The dominant species is perennial grasses of the family of Cereals and Legumes (creeping wheatgrass, shoreweed saline, ordinary reed, sickle alfalfa, mouse nut, white acacia). Rhizome wild cereals are unpretentious plants, have a powerful root system and are able to grow rapidly in all directions, capturing new territory. An important role is also played by sodgrains, which form dense sods that contain dead remains of old stems and tend to vigorously absorb atmospheric moisture and hold it for a long time. Soddy cereals are able to keep the rock mass on the slopes of the dump, strengthening them and thereby prevent the slope from slipping, erosion processes, and also contributes to the rooting of tree-shrub species. Around the perimeter of the lower base of the dump, especially along the drainage ditches, there are a large number of species from the family Asteraceae. Many of them are medicinal plants (common wormwood, common chicory, common yarrow, common dandelion, curly thistle, prickly thistle, common tansy).

a

b

c

Fig. 1. Plant groups on the surface of the waste dump:
a – foot of the dump; *b* – the second tier of the dump; *c* – the top of the dump

Along the technological road to the dump, there are mainly garbage plant species (ragweed, creeping wheatgrass, white gauze, field sow thistle, bitter wormwood, common wormwood, herbal wormwood, medicinal dandelion, bird highlander, field sow thistle, common colza, etc.). The species saturation here is 1–5 species per 1 m^2.

The slopes of the dump, having a slope of 40–60°, are weakly sod. The richest diversity of vegetation is observed on lower, more humid slopes, where the floristic composition is similar to that at the foot of the dump. In addition to cereals and weeds, such herb species are often found, such as common tar, Descurainia Sophia, field bindweed, Tatar lettuce, odorless chamomile, Field yarut, ordinary colza, etc. On the upper slopes of the dump, growth conditions are more complicated due to a decrease in the amount of moisture and wind activity. If on the lower slopes the species richness reaches 9 species per 1 m^2, then on the upper slopes this indicator is 0–3 species per 1 m^2. The most adapted and very unpretentious species settled here, for example, common bruise, bird highlander, medicinal sweet clover, yellow reseda, field bindweed.

On the dump there are 2 sites for storing the rock with absolute elevations of +28 m (lower platform) and 40 m (top of the dump). On the lower site after the liquidation of the mine, unplanned rock heaps remained, as well as piles of construction waste, and caused the development of specific vegetation. The dominant species on unplanned rock piles is empty oats (wild oats), which grows in symbiosis with flax moss. In the lowlands and ravines between the hills of the rock, the same plants are found on the lower platform as on the lower slopes of the dump. Species saturation in the unplanned hills reaches 0–4 species per 1 m^2, in lowlands and depressions – 2–6 species per 1 m^2.

During the study period, a thick grass cover was formed on the top of the dump for the vegetation typical of floodplain floodplain meadows, which in itself is an interesting fact, considering that the dump height is 40 m. The main species are dominant: common chicory, cypress spurge, common sap, creeping wheatgrass, yellowness left-handed, small seredella, common tansy, wormwood, common wormwood, medicinal dandelion, yarrow, shepherd's bag, odorless chamomile, horse sorrel. It should be noted that meadow vegetation has certain requirements for soil moisture. These plants are mainly mesophytes, that is, they do not tolerate both strong drying of the soil and prolonged waterlogging. They are also very demanding on soil nutrition and usually prefer soil rich in nutrients. At this facility, a large amount of nutrients is provided by the accumulation on the surface of particles of fertile soil from adjacent farmland as a result of aeolian activity.

Along with steppe grasses on the upper plateau there are many common meadow grasses characteristic of the forest-steppe zone, meadow steppes subzone. Here a type of vegetation is formed, characteristic of flood meadows with moderately moist fertile soils. One of the dominant species is common reed, which forms dense thickets. At the top of the dump, a stable biogeocenosis with a high species richness is formed – 7–12 species per 1 m^2.

A wide variety of leguminous plants, such as sickle alfalfa, mouse peas, meadow ranch, horned lamb, etc. They play an important role in improving primary ecotopes. These plants have the ability to fix atmospheric nitrogen with the help of nodule bacteria and turn it into compounds available for assimilation by plants. Thus, they contribute to the enrichment of the soil and the creation of favorable conditions for the growth of other plant species. Legumes also have high vital and productive indicators on substrates of mine dumps.

Of the woody vegetation on the surface of the waste dump, acacia white, a typical plant of forest belts, predominates. Black poplar, green ash, and apricot are also found. Trees grow separately, mainly at the foot of the dump and storage areas. The height of the trees is 0.7–3.2 m. Several specimens grow on steep slopes, almost not covered by vegetation. Of the shrubs, wild rose and elderberry are presented along the lower base of the dump.

The floral composition of the rock dump is rich and diverse, as evidenced by the high species richness of the vegetation cover. If for the steppes of the southern and southeastern zone of Ukraine, the species saturation averages 12–15 species per 1 m^2, then, for example, for the top of the dump, this indicator is 7–12 species per 1 m^2. This fact indicates that after the termination of exploitation of waste dumps under certain climatic conditions, arbitrary self-growth of their surface by plant communities typical of the area may occur.

The process of populating the surface of a waste dump with vegetation under certain meteorological conditions can occur spontaneously, without human intervention for a long time. However, this natural process can be accelerated by the targeted introduction of the above plants, which can improve the quality of the breed substrate, thereby creating favorable conditions for the growth of trees and shrubs [12].

6.2. Substantiation of the phytoremediation technique for technogenic slopes of waste dumps with sod mats. One of the most difficult tasks of phytoremediation of waste dumps is the greening of their surface. The greatest problem is represented by slopes, on the surface of which processes of surface erosion, filtering of combustion products or leaching of heavy metals from the rock and the like.

The study of the previous stage shows that the development of sustainable phytocenosis on the surface of waste dumps is a long-term process. Even at the stages of their operation, pioneer plant species are formed on their surface, the role of which is the primary accumulation of organic matter and the creation of prerequisites for the development of phytocenosis [13]. Therefore, the use of plant species typical of the territory of mining landscapes and resistant to pollution is a promising area of phytoremediation.

On the slopes of the waste dump of the liquidated «Selydivska» coal mine of the Selydiv coal state enterprise, the technique of phytoremediation of the slopes of sod mats with vegetation typical of the area is applied.

The objective of the research is assessing the survival rate of plant communities in the form of sod mats on the surface of the slopes of waste dumps and the feasibility of using this method as a phytoremediation measure. Covering disturbed areas with a layer of sod plants, represented mainly by wild cereals with powerful root systems, allows the development of artificial phytocenosis in areas lacking vegetation. Sod cover promotes loosening of soil and drainage, it is important to eliminate sloping water erosion.

The methodology for the introduction of sod mats consists in applying rectangular pieces of sod with natural vegetation selected on a ravine-girder network 40×40×10 cm in size to the slopes of the waste dump. Sod planting on a selected site of the slope surface is performed with excavation of the rock under the size of the sod mat to the depth of immersion about 10–12 cm to prevent unwanted slipping of samples on the slope surface. After placing specimens with herbaceous vegetation, they are irrigated with water to increase contact with the rock substrate.

The slope surface of the dump is conventionally divided into 8 sections in accordance with the sides of the horizon (Fig. 2). In each of the sections along the slope, 3 points are selected located at the level of the upper and lower bases, and the midline of the dump. Thus, on 24 selected sites, sod deposits with grassy vegetation are applied, which are selected from the slopes of nearby ravines and arroyos. 4 samples of sod mats are applied to each plot.

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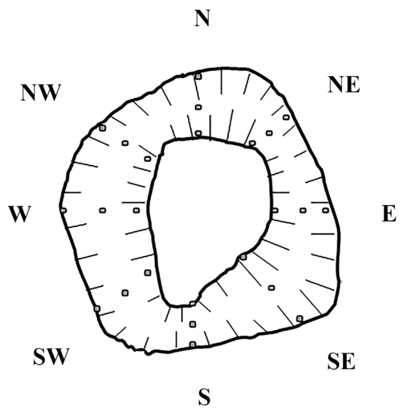

Fig. 2. The scheme for applying sod mats with vegetation on the dump surface: ▢ – areas of introduction of vegetation samples. Exposure of the dump slopes; N – north; NE – northeast; E – east; SE – southeast; S – south; SW – southwest; W – west; NW – northwest

The analysis of the results of the experiment on the survival of samples of sod mats on the surface of the slopes of the waste dump is presented in Table 2.

Table 2

The results of the experiment on the introduction of sod mats on the surface of the slopes of the waste dump

Tier	Exposition of the dump slopes							
	N	SW	W	SW	S	SE	E	NE
Upper	░	░	≡	■	■	■	▦	▦
Middle	□	□	░	▦	▦	≡	≡	░
Lower	▦	▦	▦	■	■	■	■	▦

Legend:

■	Excellent survival of sod mats with expansion of the range and spontaneous settlement of new types of vegetation. Around the plant layer, deposits of fertile soil from adjacent farmland as a result of wind erosion are observed
▦	Good survival rate of introduced vegetation samples without expansion of habitat. The sod has to be firmly fixed to the slope; insignificant deposits of fertile substrate (soil) from adjacent farmland as a result of wind erosion are observed along the contour of the sample. There are single plants introduced naturally
≡	Survival of sod mats is satisfactory. The samples were not sufficiently firmly fixed on the slope; expansion of the range and the presence of sediments of the fertile substrate are not observed. Plant forms naturally populated are absent
░	The samples are poorly fixed on the slope and significantly clogged with rock fractions. The vegetation of sod mats is suppressed; dead plants are observed along the contour. Sludge fertile substrate is not detected. Plant forms naturally populated are absent
□	Samples practically do not take root in the rock substrate; they are largely dried or covered with rock particles as a result of water erosion processes. Fertile substrate sediments and naturally occurring plant forms are absent

Note: N – north; NE – northeast; E – east; SE – southeast; S – south; SW – southwest; W – west; NW – northwest

Based on the research results, it should be noted that the lower slopes of the rock dump are potentially fertile substrate, but only if the dump is not subject to burning and the rock is not dumped for a long time on it. For several years after the end of dump operation in the surface layer of the rock mass, especially on the slopes, leaching of acid and salt components present in the rock is intensively taking place. The presence of these chemical components is the main limiting factor limiting the survival and growth of plants. Subsequently, the concentration of aggressive substances decreases as a result of leaching and water erosion, and the rock mass becomes a potentially suitable medium for settlement and the growth of various forms of vegetation. 5 years have passed since the end of the dumping of the rock mass and a significant part of the toxic salts was washed out of the surface layer of the rock on the dump slopes. The average pH of the extract of the rock substrate at various points of the dump varies in the range of 5.0–6.2, which generally corresponds to the acidity level of potentially fertile soils.

As a result of a survey of the dump slopes, it turned out that on the upper and lower tiers the vegetation growth conditions are most favorable, as evidenced by survival at 53 % and 34 %, respectively (Table 3). On the middle tiers, the plants take root weakly. For the southern slopes, the most satisfactory values of survival of plant communities are noted.

Table 3

The results of the experiment with the survival of sod mats on the surface of the waste dump slopes

Slope exposure	Number of sod mats, units		
	Low tier	Middle tier	Upper tier
N	4*/1**	4/0	4/0
NE	4/0	4/0	4/1
E	4/0	4/0	4/0
SE	4/1	4/1	4/2
S	4/4	4/2	4/3
SW	4/4	4/1	4/2
W	4/4	4/1	4/2
SW	4/3	4/0	4/1
Total	32/17	32/5	32/11

Note: */** – the number of planted/grafted samples; N – north; NE – northeast; E – east; SE – southeast; S – south; SW – southwest; W – west; NW – northwest

The upper tier of vegetation runs along the contour of the upper base of the dump, at the top of which a phytocenosis has formed that is characteristic of bog and meadow ecosystems. The thickness of the fertile layer at the apex varies between 8–12 cm. The survival rate of vegetation in the upper tier is lower than in the lower tier due to the insufficient moisture content in the rock substrate, but significantly higher than in the middle tier. This is due to the presence of a self-regulating, stable functioning ecosystem with a high species richness of flora and fauna at the top of the dump; it has a positive effect on the good survival rate of plant communities.

7. SWOT analysis of research results

Strengths. The method described above and tested in practice for phytoremediation of slopes of waste dumps with sod mats with vegetation typical of the selected area is a promising area for phytoremediation of mining lands. The application of this technique will accelerate the process of natural restoration of the natural and technogenic landscape and minimize the emission of dust particles from the surface of waste dumps.

Weaknesses. The disadvantage of using the method of introducing sod mats is that when applied to the substrate, the sod ones are first insufficiently closely connected with the lower rocky substrate, which can lead to their slipping from the slopes of the dump and rupture. Another disadvantage is the need to apply a significant amount of sod coating to the surface of the dumps, which creates an additional problem in the search and removal of plant materials from natural phytocenoses.

Opportunities. Covering the damaged areas with a layer of sod plants, represented mainly by wild cereals with powerful root systems, allows to quickly establish an artificial phytocenosis in areas lacking vegetation.

Threats. The method may be generally unsuitable for use in conditions of excessive content of toxic compounds or heavy metals in the rock mass, extreme pH values ($5.5 \geq pH \geq 8.5$), insufficient or excessive wetting of the rock substrate, and the like.

8. Conclusions

1. The plant diversity of the waste dump of the liquidated «Selydivska» coal mine of the state enterprise «Selydivvugillya» is investigated and dominant species are identified to justify the target phytoremediation of mining territories. It is established that due to wind erosion, chernozem fractions are applied to the surface of the dump from adjacent farmland, which contributed to the development of primary vegetation. The species diversity of the vegetation is made up of the species of the family Cereals, Legumes, Asteraceae, and Cruciferous. Plant diversity varies from 0–3 species per 1 m^2 (slopes) to 7–12 species per 1 m^2 (top of the dump).

2. The feasibility of applying the method of phytoremediation of technogenic slopes of waste dumps with sod mats as an alternative environmental technology to restore the mining landscape to its natural state is substantiated. It is found that on the upper and lower tiers of the dump surface, the survival rate of sod samples is 53 % and 34 %, respectively.

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