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THE STATE OF LAND COVER IN THE FLOODPLAIN OF THE SAMARA RIVER CAUSED WITH LONG–TERM COAL MINING

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Abstract: Long–term coal mining in the Western Donbas region leads to the Samara River surface of the floodplain lowering (up to 3–7 m). The most pronounced changes were noted after 2017, especially, in 2022. It was established that covering the mine rocks with additional layers of soil, loess–like loam, and red–brown clay leads to significant inhibition of the migration of toxic salts in the contact zone with the dump due to the action of several geochemical barriers. The territory of the studied reclamation areas characterizes by insignificant species diversity. The herbal mixture should include wild plants with minimal transpiration.
Keywords: floodplain, land cover degradation, remote sensing, plant biodiversity

1. INTRODUCTION

The problems associated with environmental restoration after coal mining are considerable in different parts of the world (*Chugh and Behum 2014; Bellenfant et al. 2013; Wiessner et al. 2013; Lottermoser 2010; Bian Zhengfu et al. 2010*). Meanwhile, the ratio of precipitation and evaporation is the main reason to take strategy for land reclamation. The chemical weathering processes of pyrite, calcite, dolomite, gypsum, and halite, as well as ion exchange, appear to be the dominant hydrogeochemical processes in the Ruhr Area, Germany (*Tran et al., 2020*). Taking into account that in the Ruhr Basin precipitation at the level of 750 mm annually leads to the leaching of mine rocks, the problem of solving this problem arose by applying 5 cm of various calcium–containing compounds (loam, lime, etc.) and increased amounts of organic matter (sewage sludge, compost) and mineral fertilizers in dose 400 kg/ha P_2O_5 (*Kostenko, 2003*). Meanwhile, the main environmental protection problem regarding the identification of the optimal land reclamation scheme in Western Donbas is the prevention of vertical salinization and man–made pollution of artificial reclamation profiles (*Yevgrashkina et al., 2021*).

The problem of environmental protection in Western Donbas is particularly important since 35% of coal reserves lie under the floodplain of the Samara River and its tributaries (*Yevgrashkina et al, 2009*). The development of coal seams by mines leads to the formation of deep cracks and intensive subsidence (up to 40–60 cm, sometimes up to 3–7 m) on the surface of the floodplain, which is filled with ground and surface water, turning into swampy reservoirs (*Klimkina et al, 2018*). The subsidence of the earth's occurred at 75–90% of the developed thickness of the seams. Depressive funnels with an area of tens and hundreds of square kilometers were formed. Large–scale flooding and swamping of the undermined territory arose. Coal mining was accompanied by pumping out mineralized mine waters with the issuance of waste rocks to the earth's surface.

All these processes have affected the increase in the area of degraded soils in the floodplain of the Samara River. Lowering the surface floodplain leads to massive drying of the forest. Weak – and medium–saline meadows are gradually formed under these conditions (*Fedonenko et al., 2018*). Reclamation of disturbed lands is carried out with the use of waste from coal processing plants and rocks from mine workings. They are represented by such lithological varieties as argillites, siltstones, pyrites, sandstones, etc. Usually, the average amount of argillites in the mine rock does not exceed 50%, siltstones – 30%, sandstones – 20%, and the rest – pyrite and other rocks (*Yevgrashkina, 2003*). The processes of weathering of coal mine rocks are mainly associated with the leaching of alkaline and alkaline earth metals from them by atmospheric precipitation, the extrusion of cations that are in an exchange state in clay minerals, and the oxidation of sulfides (*Hayes et al. 2014; Huff, 2014*). Several land reclamation approaches connected with the application of various calcium–containing substances fly coal ash, and sludge from alumina processing have been proposed (*Zhenqi Hu et al. 2004; Kyncl 2008; Malik and Thapliyal 2009; Nkongolo et al. 2016*). Field experiments laid out on lands disturbed by mining operations are connected with the rationale for choosing one or another technology for “mitigation” or placing rock deposits in such a way that the slightest negative consequences for the environment are minimized. The need to introduce an environmental impact

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assessment procedure for the recommended technologies for the reclamation of disturbed lands is obvious.

The main objective of our study was a long–term geospatial assessment of changes in the state of land cover in the floodplain of the Samara River in conjunction with ground–based observations.

2. MATERIALS AND METHODS

The main focus on determining the best version of the reclaimed profile was related to biological conservation, since the mine rocks of Western Donbas turned out to be unsuitable for growing agricultural crops. Three options of artificial soil profiles differed on black soil bulk layer thicknesses were made. The next three trials were created with the inclusion of 50 cm of the carbonated loess–like loam layer as a buffer screen for toxic salts and heavy metals. It was assumed that the presence of a loose layer of soil and a layer of loess–like loam with a total thickness of 100–120 cm should retain the soil moisture and allow the root system of plants to settle. The choice of the reclaimed artificial profile option was due to the availability of sufficient soil or rock mass. That is why additional attention was paid to the study of meadow soils (MS), which are the main component of the surface of the floodplain of the Samara river. The second selected substrate was red–brown clay (RBC) from a nearby open pit mine. So, the two additional options for reclaimed profiles were as follows: MR+100 MS and MR+50 RBC. The use of red–brown clay for covering mine dumps allows counting on its waterproof properties, which, despite the lack of moisture, is a low–cost water–saving technology.

So, the reclamation scheme of disturbed mine lands at the Pavlograd Research Station consisted of options without and with a screening layer of loess–like loam:

A. The mix of mine rocks (MR) was not covered.
B. MR + 30 cm of bulk layer of black soil (30BS).
C. MR + 50BS.
D. MR + 70BS.
E. MR + 50cm of loess like loam (50LLL) + 30 cm bulk layer of black soil (30BS).
F. MR + 50LLL + 50BS.
G. MR + 50LLL + 70BS.
H .MR+100cm of meadow soil (MS)
I. MR+50 cm of red brown clay (RBC)

Stationary field observation allows the collection of representative samples for the determination of biomes and ecomorphs of vascular plants. The ecomorph system, developed by prof. Alexandr Belgard (1988), was applied to evaluate the species' ectomorphic indexes in the tabular form. Abbreviated Latin names of ecomorphs were used. The xenomorphs notations are as follows: *Aq (Aquant)* – aquantes (water plants), *Pal (Paludosus)* – paludantes (marsh plants), *Pr (Pratensis)* – pratanted (meadow plants), *Sil (Silvaticus)* – silvantes (forest plants)*; Ps (Psammophyton)* – psammophytes (sandy plants), *Ru (Ruderatus)* – ruderanted (weed plants). Hygromorphes notations are the following: *Hy (Hidatophyton)* – hidatophyte (submerged water plants); *Pl (Pleistophyton)* – pleystophyte (floating plants); *He (Helophyton)* – helophyte (aero–aquatic plants); *UHg* (Ultrahygrophyton) – ultrahygrophyte (wet habitat species), Hg (Hygrophyton) – hygrophite (moist habitat species); Ms (Mesophyton) – mesophyte (medium–moisture habitat species), Ks (Xerophyton) – xerophyte (dry habitat species) – in modern Latin transcription – X. Special valuable it becomes when establishing of ecomorph range (hygromorphes, trophomorphes, cenomorphes) in eurytopic species, rather than the average ecomorph (as is customary).

The pH index was determined using an ion meter, and the degree of soil salinization was estimated by the gravimetric method. The content of heavy metals in plant samples was determined by atomic absorption spectrophotometry.

3. RESULTS

The extent of soil, surface and underground water contamination by rocks extracted after coal mining in Western Donbas depend on the relief, the depth of the first aquifer from the surface, and the filtration properties of the rocks at the base of the dump. It becomes possible to assess the state and dynamics of the development of the vegetation cover by assessing the spectral reflective features of the land cover (Kong et al., 2016). Multispectral images of the Landsat satellite system were used for remote sensing of the floodplain of the Samara River in 2004, 2007, 2010, 2013, 2017, and 2022 (Figure 1 and 2).

A comparison of the levels of projective cover the Samara River floodplain with vegetation indicates the degradation of the land cover over the past 18 years. The most pronounced changes were noted after

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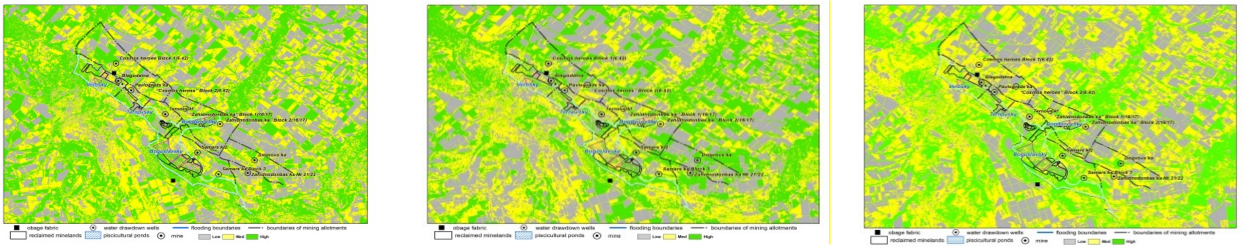
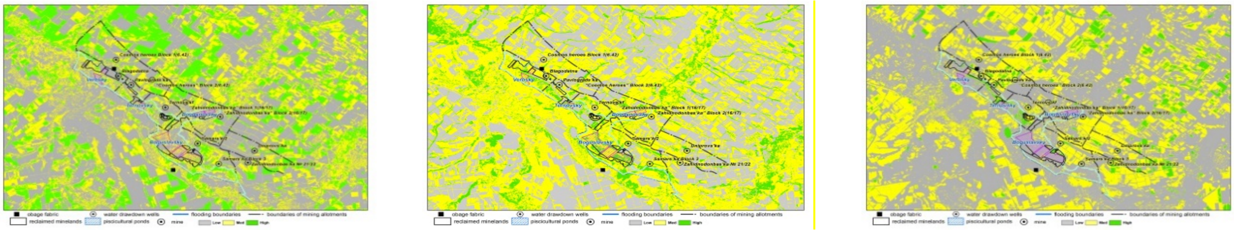
2017, especially, in 2022. It should be noted that in recent years, the priority direction in the reclamation of mine dumps is the creation of favorable conditions for their natural overgrowth with grasses and forest crops. The study of the dynamics of herbaceous biogeocenoses in such an industrially developed region as the Western Donbas coal mining region was made in order to assess the vegetative projective cover on landscape elements depending on the technogenic impact.



2004 2007 2010

Figure 1 – Samara river floodplain projective cover for 2004, 2007 and 2010



2013 2017 2022

Figure 2 – Samara river floodplain projective cover for 2013, 2017 and 2022

In the process of observation in the floodplain of the Samara River, the typical sample plots were identified. Trial area No. 1 was near the Pavlogradska coal mine in the immediate vicinity of the mine water ponds. The choice of this area was motivated by the reason that this is one of the typical plots of the saline floodplain of the Samara River. The herbage is represented mainly by halophytic species, the total projective cover is 65–80%. Trial area No. 2 is located on the second terrace of the Samara River opposite the Pavlogradska mine. The studied biocenosis is surrounded on one side by a black maple oak forest, and on the other side by a pine forest, but now it is used as a pasture. The grass cover keeps traces of the formation of a typical steppe flora growing on saline soil. The total projective grass cover does not exceed 30–40%. Trial area No.3 is located on the third terrace of the Samara River near the Ternovska coal mine.

On the one hand, it adjoins the halophytic–meadow–marsh complex formed around the flooded depression. But on the other hand, it is a pine forest, in the marginal zone of which there are birches and poplars. At this stage, the vegetation has characteristic signs of the meadows process associated with the of this area flooding over the past decades. The total projective cover is 60–70%, with halophytes accounting for 15%, which make up 9% of the total number of species.

The vegetation cover of plot No.4 located on the territory of the Taranov ravine near the Ternovska mine is represented by meadow, meadow–steppe, halophilic, wetland, and aquatic communities. Test plot No. 5 is located on a reclaimed mine dump with backfilling of meadow soil with a thickness of 1 m not far from the Ternovskaya mine. The couch grass stage of succession dominates in the study area. The projective cover of couch grass creeping reached 50%. Test plot No. 6 is located on a reclaimed mine dump with a 50 cm thick layer of red–brown loam. Weeds predominated in the first stage of self–overgrowth. The total projective was 5%. The fate of chemicals in soil is complex and dynamic and depends on factors such as texture, pH, salinity, and many others. Our research was also related to the provision of a comprehensive geochemical assessment of artificial soil profiles. Changes in pH along the reclaimed profile in trials with different thicknesses of the black soil bulk layer were investigated layer by layer (Figure 3).

The obtained data confirm that the absence of a protective screen of loess–like loam leads to rapid acidification of the soil profile due to the rapid flow of the process of rocks' chemical weathering in contact with pyritized mine rocks. It was confirmed by the data on the salt's vertical distribution according to the mine dump reclamation options (Figure 4).

The introduction of a 50 cm layer of loess–like loam in the MR+50BS led to significant inhibition of the process of chemical weathering of the rocks of the mine dump. Therefore, pH stabilization in the MR+50LLL+50BS option is possible within 7.7–7.9.Chemical analysis data on the distribution of salts along two model reclamation profiles are shown in Figure 5.

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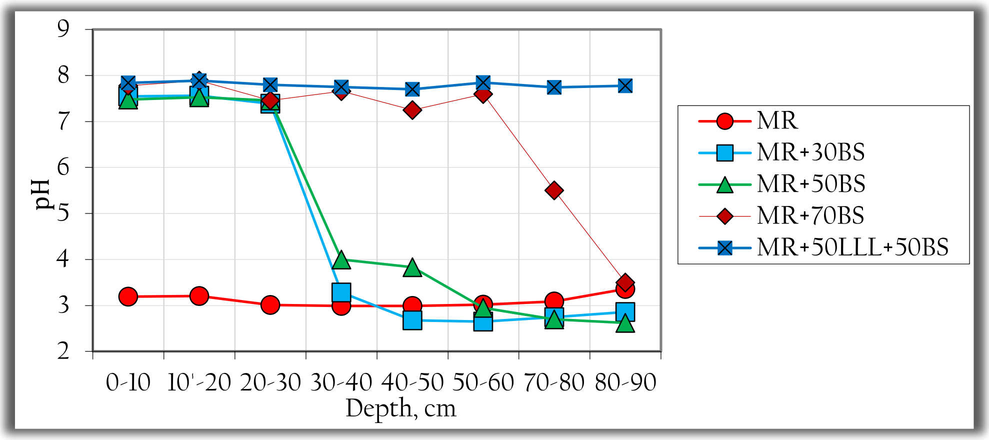

Figure 3 – pH profile distribution according to land reclamation options

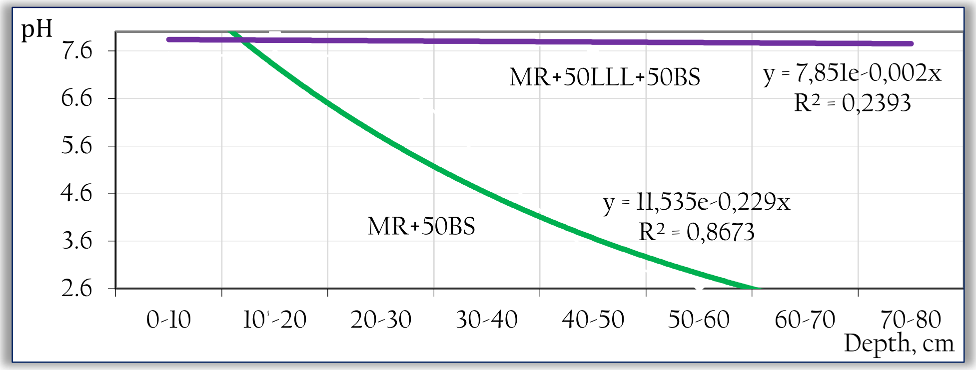

Figure 4 – Stabilization of the pH profile distribution in contrast options

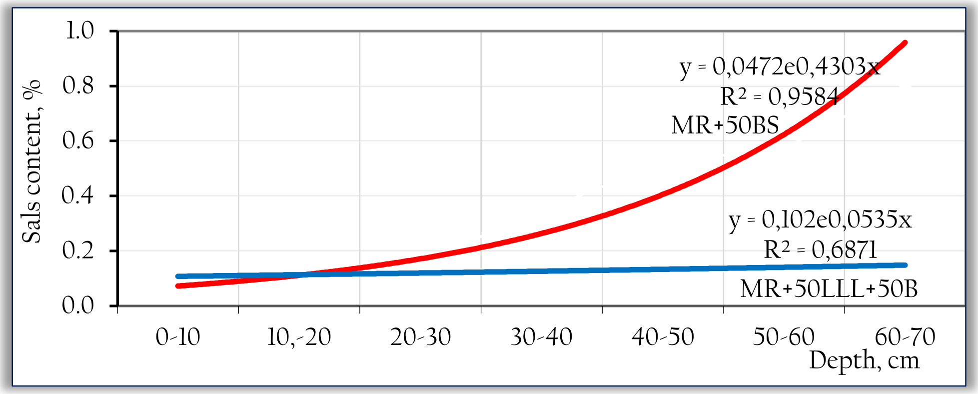

Figure 5 – The impact of the geochemical screen on the distribution of salts along two artificial soil profiles in trials MR+50BS and MR+50LLL+50BS

The study of the distribution of salts along two model profiles (without and with 50cm loess–like loam) indicates a significant restraint of the rate of salinization in the MR+50LLL+50BS option. Heavy metals are the main factor causing soil–plant chain pollution depending on the selected trial of the reclaimed profile (Figure 6).

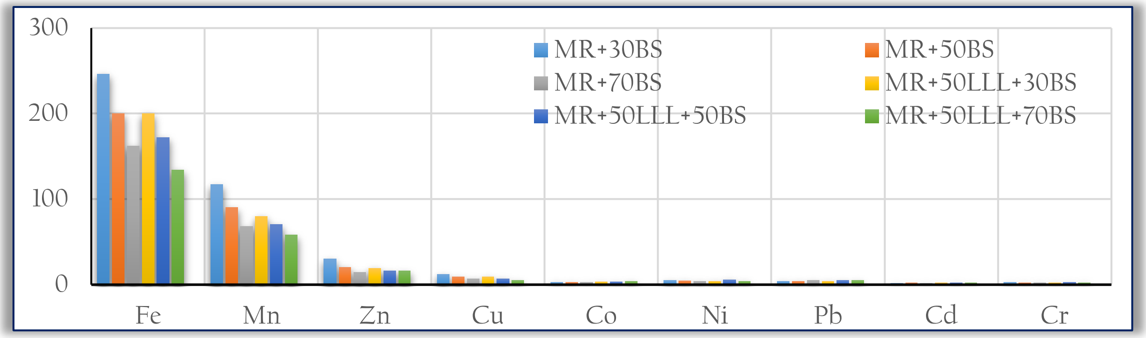

Figure 6 – The content of heavy metals in alfalfa hay according to the trials of reclaimed land, mg/kg

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The largest amount of iron, manganese, zinc, and copper was fixed in the trial MR+30BS. Taking into account the prospect of using some rocks as "geomembranes" to limit the movement of toxicants, the option of reclamation of the mine dump with the application of a layer of red–brown clay was attempted. Further plans for the reclamation of this area were related to strategy of transforming overburden into "young" soil after their long–term phyto–melioration. The risk of developing vertical salinity is significantly lower in the option of reclamation of the mine dump covered with meadow soil. This option was taken as the base (plot No. 5) for comparison with the option associated with the application of a 50 cm layer of red–brown loam (plot No. 6). The bluegrass stage of succession (*Elytrigia*) dominates within the studied site "No. 5" as the projective coverage reaches 50%. The area of self–healing is characterized by impoverished species composition. The first three places in the spectrum of leading families are occupied: *Asteraceae* – (48,2 %), *Poaceae* – (17,5 %), and *Brassicaceae* – (12,1 %). The first place in terms of the number of species belongs to the comfrey family (*Asteraceae*). Two types of life forms were distinguished in the flora of the studied area: perennial herbaceous plants (57.1%), biennials, and annuals (42.9%). The vegetation of the reclamation site "No. 5" is mainly represented by meadow and weed communities. Analysis of the xenomorphic spectrum shows the absolute predominance of weedy (ruderal) species in the vegetation cover. Their share is 44% of the total number of species. The second place in terms of number is occupied by weed–steppe species – 20%, including acquaints – 4%, pratantes–halophytes – 12%, and others – 16% (Figure 7).

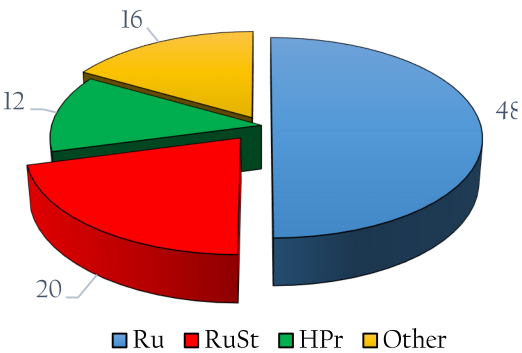

Figure 7 – Xenomorphic spectrum of the reclamation site covered with meadow soil

Moisture is one of the factors that determine both the floral composition and the structural organization of plant communities. Analysis of hygromorphs of site H revealed a predominance of mesoxerophytes in the vegetation cover (60%), mesophytes account for 24%. The smallest number of species belongs to hygrophytes and hygromesophytes (Figure 8)

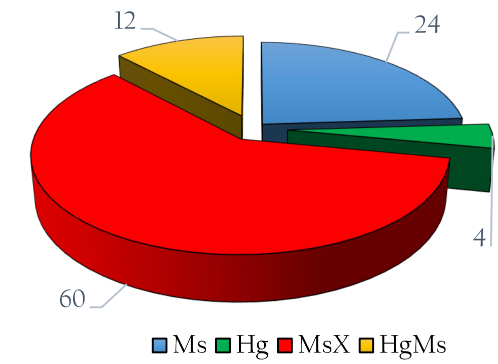

Figure 8 – Hygromorphic spectrum of the reclamation area covered with meadow soil

Reclamation site No. 6 is a leveled area of about 5 hectares. Red–brown clay, 50 cm thick, was placed on top of the mine rock. The vegetation of the first stage of self–growth is characterized as weedy. The total projective coverage is about 5%. Self–growing territory No. 6 is characterized by an impoverished species composition (Figure 9).

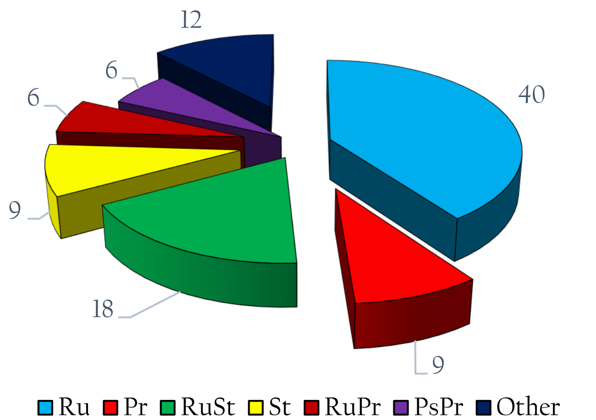

Figure 9 – Xenomorphic spectrum of the reclamation site covered with red–brown clay

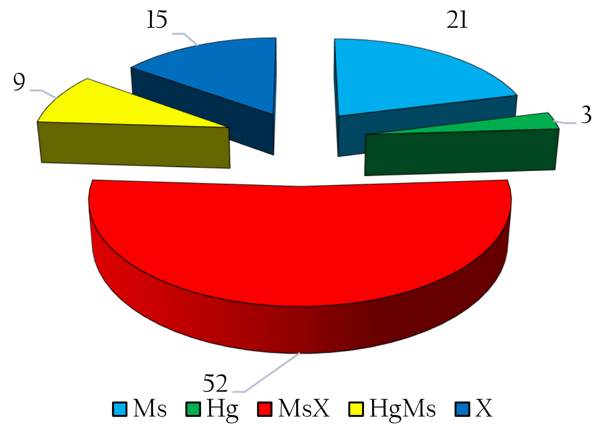

Figure 10 – Hygromorphic spectrum of the reclamation area covered with red–brown clay

Two types of life forms were distinguished in the flora of the investigated site No. 6: perennial herbaceous plants (52.9%) and biennials and annuals (47.1). The first four places in the spectrum of leading families are

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occupied by Asteraceae. Fabaceae, Ranunculaceae and Poaceae. Mesoxerophytes hold the largest share (52%) in the hygromorphic spectrum of the vegetation of reclamation site No. 6 (Figure 10).

The second place is occupied by mesophytes (21%), and the third by xerophytes (15%). According to the data of hygromorphic analysis, both investigated areas are very close in terms of moisture level. The chosen direction of reclamation – is the cultivation of meadow plantations. Even in this case, the processes of secondary salinization of the bulk soil layer develop intensively in the dump with an average salinity (up to 0.4%). Intermediate options may be connected with a low degree of salinity when an herbal mixture will be consisted of wild plants with minimal transpiration level.

4. CONCLUSIONS

Multispectral images of the Landsat satellite system from 2004 to 2022 were used for remote sensing to compare the levels of projective cover in the different parts of the Samara River floodplain over the past 18 years. The most pronounced changes were noted after 2017, especially, in 2022. Field experiments carried out on lands disturbed by mining are associated with the justification of the choice of mitigating technology with subsequent environmental impact assessment. The trend of transition to the strategy of natural meadow husbandry in the Samara river floodplain is associated with a lower risk of the development of processes of vertical soil salinization. The territory of the studied reclamation areas of Western Donbas coal mining region, where self–growth occurs, is characterized by insignificant species diversity. The xenomorphic spectrum confirms the presence of the primary stages of self–growth succession.

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