Estimation of reclamation conditions for technogenic landscapes in Khakassia

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Abstract. This article presents the results of complex assessment of the resources needed to carry out the reclamation of technogenic landscapes at coal-mining enterprises in Khakassia. An assessment based on analysis of regional natural factors (climate, soil-forming rocks, soil and vegetation cover). According to the results, regionalization of the territory by resource availability was carried out. It is shown that the region is characterized by a deficit of moisture, which is growing from south to north. The resources of potentially fertile rocks and the fertile soil layer range from acute deficiency to sufficient. In the southern part of Khakasia, where coal mining sections are located, insufficient resources of the fertile soil layer are noted. In such conditions, the implementation of the main areas of reclamation is limited.

1. Introduction
Currently operating national standard interprets remediation of land as a set of actions aimed at the reclamation of the previous qualitative condition of the lands, sufficient for their proper use [1]. From the landscape and ecology perspectives, the objective of remediation is the restoration of soil and ecological efficiency in the disturbed areas [2]. Based on the definition of the latter as the correlation between the properties and functions of the new technogenic landscape and environmental conditions, it is obvious that for successful remediation, such conditions need to be properly analysed. The urge for such research is caused by the high rate of expansion of the disturbed lands, the imperfection of the environmental law and the remediation regulations, resulting in the low efficiency of the remediation operations.

The Republic of Khakassia is one of the most promising mining regions of the Siberian Federal District. The greatest contribution to the production volume is provided by coal industry [3]. By some estimates, the area of lands disturbed in the industrial coal production process reaches 5-8 thousand hectares, with the annual increment of 260 hectares [4, 5]. With the currently estimated regional coal production dynamics [6], the disturbed area is also expected to expand. However, the remediation rates are already lagging behind; in the future, the disproportion of the disturbed and remediated lands is expected to be much more than today, with the disturbed lands prevailing over the remediated ones. The low efficiency of the remediation operations is noticed [4]. Besides the economic reasons, remediation efficiency is greatly affected by the natural conditions of the region. The available publications do not provide a thorough analysis of this effect. This paper presents a comprehensive overview of the environmental factors from the perspective of their consideration in planning and enforcing the remediation measures at the coal mining sites of Khakassia; the authors attempt to estimate the resources required for this purpose.
2. Materials and methods
The theoretic and methodological foundation of the paper is the works [2, 7, 8]. The present natural factor analysis was performed for the forest-steppe and steppe districts of Minusinsk Hollow within the borders of the Republic of Khakassia (left bank of the Yenisei River) with the comparative geographic, comparative environmental, landscape and cartographic methods and approaches. The remediation resources were assessed from the perspective of their usage in remediation operations on the spoil heaps of the coal pit mines of the Republic.

3. Results
The radiation balance, a sum of biologically active temperatures, precipitation rate and evaporation capacity are known to bear a priority meaning both for the physical and chemical transformation of the technogenic substrates and landforms, and the soil and environmental processes in the technogenic landscape [8]. The territory of Khakassia is uneven from the point of view of climate. The reason is its geomorphological segregation manifested in the alternation of the low mountain ridges and hilly plains of the Minusinsk hollow chain, framed by larger mountain ridges. In the differentiation of the radiation balance value, there is a traceable dependency on the underlying terrain: the annual balance is the greatest for the steppe and forest-steppe territories, varying within the range of 1600-1900 MJ/m² [9]. The interaction between the climatic and orographic factors manifests itself in the almost concentric isohyets distribution within the hollow, caused by the absolute height elevation directed from the centre towards the framing ridges, and the amount of precipitation increasing in the same direction. Based on the hydrothermal factor value (from 0.5 to 1), the Minusinsk Hollow territory lacks precipitation; based on the heat profile, it is classified as moderately warm. Regardless of that, in the summer period, the average monthly temperatures reach 17-19°C, and the absolute temperatures range around +36°C [10-12]. Due to the poor autumn and winter precipitation (not exceeding 40-50 mm) and the little snow cover thickness, the soil in the hollow freezes 2-3 meters deep [10].

The most important landscape-forming and soil-forming factor is the underlying substrate. The soil-forming rock of Minusinsk Hollow is a result of alternating processes of denudation and accumulation, multiple redeposit of the ancient sediments. These include the widely spread red and yellow-brown clays and clay loams. By genesis, these are mostly represented by the eluvial and diluvial red-colour deposit of the Upper Palaeozoic era, often saline and calcareous. The material is deposited both from the mountains towards the hollow centre (ablation, drifting, accumulation of the loose material) and vice versa (eolian processes) [10]. For this reason, the low mountain slopes are rich in debris and sediments, and the thinner clay loam material is usually accumulated at the feed of the slopes as diluvial-proluvial and alluvial-proluvial deposits. The regularity of the denudation cycles causes the gritty structure and presence of the landwaste and sand-clay interlayers in these deposits. The eolian transfer of the thin particles caused the accumulation of loess loams and eolian sands in different parts of the hollow and on the slopes of the adjacent mountains [13-18]. The total thickness of the loose deposit case is uneven. The denudation (physical weathering) and subaerial transfer play a significant role both in the distribution of the loose deposits and the transformation of the landform and the soils of the hollow. The intensive land denudation is especially prominent in the western part of the hollow with a structural (cuesta) landform. In the territory of Khakassia, soil drifting is mostly typical for the steppe areas, presenting a big problem for agriculture; the southern part of the hollow (Koybalskaya steppe) tends to desertization due to the deflation of large amounts of sands, as well as land degradation. Water erosion also contributes to the process: the intensive washout of substrate and soils with storm rainfalls and melt waters forms the network of gullies and ravines. According to [19], over 70% of the total tillable land of the region is exposed to water erosion; at that, the index of degradation caused by winter and water erosion for Khakassia scores 75.4 [20]. According to [21], the amount of washout and deflation into the zonal phase of denudation in the region amounts to 0.2-0.3 and 0.3-0.9 mm per year. The sedimentation of the deposit on the piedmont shelves reaches 0.7 mm per year, with the eolian accumulation amounting to 0.2 t/ha per year. Moreover, the intensiveness of the said processes is noticed to depend on the slope direction (in the southern slopes, denudation is
more prominent, and in the northern ones accumulation prevails) and on the season (the eolian processes activate in the winter and spring-summer season, and the water erosion and washout processes begin in the summer-autumn season) [21].

This way, the studied natural conditions of Minusinsk Hollow are enough to characterize the environment where the technogenic landscapes of the coal mining facilities of Khakassia develop and function. These properties are interesting in the context of solving a number of the disturbed land remediation issues, as the natural factors bear a reclamation potential, with each of them being a remediation resource [8]. Based on the physical and geographic zoning layout of Khakassia [22], the first differentiation scheme of its territory by the availability of remediation resources is drawn up (figure 1). The resource availability rating is done in compliance with the classification developed for Kuzbass [8].

![Figure 1. Differentiation of the Khakass territory by the availability of remediation resources (see explanations in the text).](image)
3.1. South Siberian Mountain area. Verkhnechulymskaya Province. Shira District (figure 1, index 1).

Forest-steppe and steppe districts, small hill and cuesta-structured areas with vast levelled descends in the northern part of the region. The district features the lack of warm temperatures in the forest-steppe low-mountain areas (1300-1550 °C) and warmer climate in the steppe territories (1600-1700 °C). There is a lack of precipitation, especially in the steppe areas (Ivanov precipitation factor Pf = 0.6-0.9). The potentially rich rocks (PRR) available for remediation purposes are the eluvial-diluvial clay loams, diluvial-proluvial, and alluvial lake clay loams of the Caspine suite. The deposit capacity is unevenly distributed around the area, varying from 2 to 25 m; the substrate forms nests and lenses of different length and thickness. The PRR stock is estimated at 30 thousand t/ha. There is some information on the eluvial-diluvial clay loam deposits in the north of the district, estimated at 6 million tonnes [23]. With the requirements for the PRR filling layer thickness in mind, the PRR may be considered as sufficient for remediation operations. There is some stock of lake bottom ooze and turf available for use as soil conditioners.

In the soil cover of the district, the regular chernozem, the south clay and heavy loam chernozems prevail. In the forest-steppe area of the district, the grey forest soils and calcareous soils are common [24]. The humus accumulation horizon of these soils may be used as a rich soil layer in the remediation process. The richest soils of Khakassia are leached medium and heavy loam chernozems of medium thickness and medium humus content: with the humus accumulation thickness of 35-50 cm, they contain from 8% to 12% of humus (average 6%-7%) and up to 50%-60% of the physical clay fraction. The humus layer thickness (under 2%) constitutes 40-45 cm; this layer density varies from 1 to 1.2 g/cm² [10, 13]. The leached chernozem stock of the district is estimated at 4,500-5,000 t/ha. However, the majority of these soils have been tilled, and their extent area is not big. The prevailing chernozems here are regular low-humus thin clay loam chernozems. They feature the humus layer thickness (under 2% of humus) of 25-35 cm, average clay particles content of 40%-60%, humus content of 5%-6%, average humus horizon density of 1.2 g/cm² [10]. In the aridest steppe regions, the thinner southern clay and clay loam chernozems with low humus-content are common: in the accumulative layer of 25-30 cm, the humus content is 3-4%, with the physical clay particle share of 45-54%. In the southern chernozems, the rich soil content is estimated at 3,000-3,600 t/ha. With respect to the wide range of the humus layer thickness and the rank varieties present in the soil cover of the area, the rich soil layer capacity may vary from 2,000 to 5,000 t/ha, from the poor to optimal ones for the implementation of the most efficient remediation operations.

3.2. Minusinsk Province. North Minusinsk District (left bank part) (figure 1, index 2).

Forest-steppe low-mountain and steppe hilly landscapes. With the sum of biologically active temperatures of 1600-1800 °C, the climate in the region is sufficiently warm. The region has a deficit of precipitation (Pf=0.5-0.8). The potentially rich soils are represented by the eluvial-diluvial, diluvial-proluvial clay loams and clays, alluvial lake clays and clay loams with the thickness ranging from 3 to 15 m [16]. The estimated PRR stock is sufficient, amounting to 40-45 t/ha. In the territory of the districts, the chernozem (regular, southern, leached) soils, and in the forest-steppe part the calcareous soils are common [23]. The smallest areas are occupied by the thinner southern chernozems with lower humus content. The rich soil layer is sufficient (3,000-3,600 t/ha). The remediation possibility is limited by the deficit of precipitation; the remediation operations for the forest management, agricultural, and sanitary-hygienic purposes are possible.

3.3. Abakan-Yeniseysk District (figure 1, index 3).

Steppe landscape with the prevailing hill and plain landforms (river terraces, lake descends), cuesta structures, and eolian sand deposits. The heat climate of the region is warm enough with the sum of biologically active temperatures of 1800-2100 °C. There is an acute deficit of precipitation (Pf=0.5-0.6). The PRR resources are represented by the eluvial-diluvial, alluvial lake clays and clay loams of uneven thickness [14, 17]. With regard to the deposit development area and the filling layer thickness requirements, the estimated PRR stock of 45-50 thousand t/ha is enough. In the soil cover of the left
bank of the Abakan River, the southern dark chestnut and chestnut soils prevail; in the interflue area between the Yenisei and the Abakan Rivers, the regular chernozem and dark chestnut soils dominate. At the foothill of the southern part of the region, the leached chernozems are well-developed. The low-thickness clay loam and light loam soils with low humus content are the most common; on the high shingle river terraces, sabulous soil varieties prevail. The thickness of the humus accumulative horizon of the chestnut soils does not exceed 20-25 cm; the average humus content is 2%-3%, the average physical clay content is 30%-35%, and of heavy loam soils it reaches 55%-60%. The humus (up to 2% humus content) layer capacity constitutes 15-25 cm with the density of 0.9-1.27 g/cm³. Among chestnut soils, the calcareous, alkalinized, rank varieties are frequent. The humus (up to 2% humus content) layer varies to a great extent from 1,350 to 5,000 t/ha, but the average content is poor.

4. Conclusion

Therefore, the remediation resources are distributed around the Khakass territory in an uneven manner; the deposits shrink in the southern direction and are generally insufficient for the enforcement of high-efficient remediation measures. The deficit of precipitation is common for all the areas. With the quite warm climate, the aridity increases towards the south, aggravating in the technogenic landscapes. Based on the produced estimates, the PRR are sufficiently represented in the region. It is important to consider the high coefficient of uniformity of particle-size distribution, the uneven thickness of the deposits and the depth of groundwater occurrence. The rich soil layer is concentrated in the clay and clay loam soils, limited with the humus layer capacity which also decreases towards the south. This is explained both by the climate specificity and the properties of the soil-forming rocks and landscapes. The humus layer thickness is laterally uneven, with the average value not exceeding 30 cm. Among the soils, the carbonate and highly soluble salt containing rank and shingle humus horizons are frequent. As the essential condition of economically feasible remediation is the proximity of the rocks and soils involved in the process, the estimation should be adjusted for every individual mine, acting as the underlying factor for the development of remediation operations.

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