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Study of ecosystem edaphic components in the tailings storage of a decommissioned sulfur mining enterprise

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ABSTRACT

The study examined the abiotic components of the ecosystem within the tailings storage facility of a decommissioned sulfur mining enterprise located in the territory of the "Roztochia" Biosphere Reserve. An assessment of the physicochemical properties of the surface soil layer was conducted, including density, solid phase density, porosity, actual acidity, humus content, and elemental composition. It was found that the studied soils are characterized by low porosity (41.56%), an almost complete absence of humus, and high concentrations of sulfur (28.55%) and calcium (68.83%). These characteristics create unfavorable conditions for the formation of vegetation cover. The results underscore the necessity of remediation measures to restore natural ecosystems and biodiversity.

Keywords: tailings storage, abiotic components, remediation, physicochemical properties, humus, porosity.

INTRODUCTION

Abiotic components of ecosystems determine the potential for the existence of all groups of organisms within a given environment, influencing the geographical distribution of plants, animals, and microorganisms. They interconnect different organism groups, ensuring the structural and functional integrity of ecosystems. The abiotic components of terrestrial ecosystems include physical and chemical factors of non-living origin that affect the living conditions of organisms in a given environment. These factors encompass geological characteristics (e.g., soils, minerals, relief), climatic conditions (temperature, precipitation, humidity, wind conditions), the availability of water resources (rivers, lakes, streams, groundwater), topography (relief, altitude), and the chemical composition of the environment (nutrients, pH, mineral concentrations).

These abiotic factors form the fundamental structure and functionality of terrestrial ecosystems. They influence organisms' distribution, diversity, and adaptability to the environment. For instance, different soil types and textures affect the availability of moisture and nutrients for plants, influencing their distribution and growth potential. Climatic conditions determine the distribution of plant and animal species and affect their physiological processes. Water resources are crucial for living organisms, while topography influences microclimate formation and living conditions for organisms. Abiotic factors create unique conditions for the distribution and interaction of various species in terrestrial ecosystems. Their combined action impacts energy flows, nutrient cycles, water balance, as well as stability and functioning of ecosystems [Furtak et al., 2019; Baraban et al., 2024].

Roztochia, a key European watershed dividing the Black and Baltic Sea basins, is currently designated as a biosphere reserve. However, this region was previously home to one of the world's largest sulfur mining enterprises, the Yavoriv Sulfur Plant, which faced closure and the subsequent need for ecosystem restoration on disturbed lands.

During the extraction and processing of sulfur, rock materials were brought to the surface, leading to mechanical and chemical disruption of natural ecosystems. According to previous studies, sulfur ore primarily consists of limestone with high concentrations of chemical elements (Cu, Zn, Cd, Pb, Fe, Mn, Sr, S) and inclusions of pure sulfur. Mining technologies, the physicochemical properties of the overburden, and the soil-climatic conditions have largely determined the formation of tailings. During mining, overburdened rocks were often deposited as dumps without systematic planning, resulting in the mixing of Tertiary and Quaternary deposits. Consequently, the current soil cover of the deposits is heterogeneous in terms of mechanical composition and physicochemical properties. The knowledge of the physicochemical properties and elemental composition of these rock materials is also essential for determining the potential use of reclaimed areas.

The construction of the tailings storage facility for the sulfur mining enterprise within the Roztochia Reserve caused the complete destruction of the natural ecosystem in this area. After the cessation of sulfur mining in 2006, natural recovery processes have been taking place in the tailings storage area. However, this territory remains unsuitable for the Roztochia Reserve typical ecosystem functioning. Reclamation of the damaged soils is essential for the full restoration of life-sustaining functions in the tailings storage area [Tarnawczyk et al., 2021; Oliferchuk et al., 2023; Stepanova et al., 2021]. Therefore, studying abiotic components in this area to effectively restore the destroyed ecosystem is relevant.

MATERIALS AND METHODS

The study utilized rock samples formed due to the solidification of sulfur mining waste through underground melting processes. The waste deposited in the tailings storage facility consists of paste-like slurries with high moisture content, reaching 50–70%, which imparts a liquid consistency. These slurries exhibit an acidic nature due to sulfuric acid formation resulting from the oxidation of sulfide minerals. Their chemical composition includes a significant amount of sulfates and metals, such as iron, calcium, magnesium, manganese, and aluminum. The ionic composition reveals a high concentration of dissolved salts, including sulfates, chlorides, calcium, magnesium, and sodium ions. These physicochemical properties determine the chemical activity of the slurries and their potential impact on the surrounding environment.

The study area was located at Tailings Storage 1 of the underground sulfur melting site near the village of Volia Starytska (Fig. 1). The tailings storage is surrounded by an earthen embankment. A water body has formed in one section of the tailings site (2), while the remaining area is a barren landscape (3) comprised of solidified waste with soil cover fragments up to 5 cm thick (Fig. 2).

Soil sampling was conducted according to the regulations stipulated in relevant normative documents [Stepanova 2021; DSTU ISO 10381-5:2009; DSTU ISO 10381-2:2004]. Elemental composition analysis was performed using the "EXPERT-3L" X-ray fluorescence analyzer and its associated software. Soil density was determined using the thermogravimetric method. Soil solid phase density was calculated as the ratio of soil mass to the total volume of solid particles. The solid phase volume was measured using the pycnometric method, which involves determining the displaced water volume corresponding to the solid phase mass in the pycnometer. Porosity was calculated based on soil density and solid phase density. Soil solution pH was determined using the potentiometric method.

Experimental studies were conducted on a typical 0.6-hectare section of the tailings storage area. The site has a rectangular shape, measuring 120×50 m. To analyze soil physical properties and structure five point samples were collected along the site diagonals at 50 m intervals (Fig. 3). Before sampling, the sod layer was removed. For chemical composition analysis, a composite sample weighing 1 kg was formed.

To determine soil density, the samples were placed in pre-weighed containers and weighed in their wet and dry state. The drying process lasted

Figure 1. Location of the underground sulfur melting tailings storage facility near Volia Starytska: 1 – general area of the underground sulfur melting tailings storage, 2 – water body, 3 – solidified production waste

6–8 hours, at 150°C to constant weight. The hot containers were sealed with lids and transferred to a desiccator filled with calcium chloride. Weighing was performed after complete cooling. Soil density was calculated as the ratio of soil mass to its volume. The average soil density was found to be 1.42 kg/m³. Notably, when soil density reaches 1.6–1.7 kg/m³, the roots of tree species are almost entirely unable to penetrate the ground [Stepanova et al., 2021; Taras et al., 2013], which explains the absence of trees in the studied tailings area.

Simultaneously, the soil solid phase density was determined as the ratio of soil mass to the total volume of solid particles. The average solid phase density was 2.43 kg/m³. Solid phase densities within the range of 2.5–2.7 kg/m³ classify soils as low-humus [Stepanova et al., 2021; Taras et al., 2013]. Soil porosity significantly affects its fertility by influencing its capacity to retain and supply water to plants, which is essential for healthy development. Porosity also determines the availability of air for plant root systems as well as the ability of the soil to drain excess moisture, preventing waterlogging and rot. Optimal porosity facilitates the retention and delivery of nutrients to plants.

Figure 2. View of the underground sulfur melting tailings storage facility

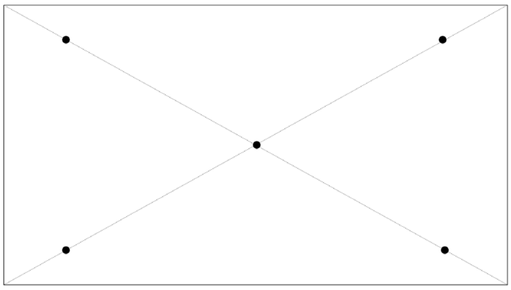

Figure 3. Scheme of soil sampling point locations on the study site

RESULTS AND DISCUSSION

The determination of soil porosity (Vpor.) is expressed as a percentage of the total volume of soil in its undisturbed state. Soil porosity (void ratio) is characterized by the shape and size of the pores within structural differences between them. It was determined that the average porosity of the soil at the study site is 41.56%. For zonal soil types, total porosity at a level of 50–55% during the growing season is considered satisfactory, while values below 40% are classified as excessively low [Taras et al , 2013].

Soil acidity is not a morphological (external) property, but rather a physicochemical characteristic acquired during the soil formation process under the influence of various pedogenic factors. Simultaneously, soil solution pH is an extremely important property that determines genetic and productive (including fertility) soil characteristics and is also one of the diagnostic indicators of soil. To determine the soil solution pH, a water extract was prepared. Ten grams of soil were placed in a 250 ml flask, followed by the addition of 50 ml of distilled water. The flask was shaken for 5 minutes. The content of the flask was then filtered through filter paper until a clear filtrate was obtained. The filtrate pH was measured using a HI98103 digital pH meter with a glass electrode. The average pH value was found to be 6.5, indicating that these soils can be classified as neutral to slightly acidic.

The determination of humus content serves as one of the most important parameters for evaluating the agrochemical properties of soils. It provides insight into the impact of forest phytocenoses on soil formation processes. Humus influences the development of beneficial soil properties that determine its fertility, by enriching it with nitrogen and other elements essential for root nutrition, improving its water-physical and thermal characteristics, increasing the capacity and buffering of the soil solution, and enhancing the microbiological activity of the soil. In the studied soil samples, no humus was detected. The practical absence of humus in the solidified waste surface layer at the tailings site allows these soils to be classified as low-humus. This characteristic is corroborated by the density values of the studied samples.

The elemental composition of the soil is a key chemical characteristic necessary to understand its fertility, potential for agriculture, and assessment of the ecological state of the given areas. The main elements in soil composition include oxygen, carbon, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and others. The elemental composition can vary depending on the soil type, climatic conditions, geological activity, and other factors. The main soil types characteristic of the sulfur mining area are podzolic loamy and sandy loamy soils. A distinctive feature of the elemental composition of these soils is a wide range of concentrations. Table 1 presents the average elemental composition (in %) of a one-meter soil layer recalculated to absolutely dry weight [Didukh et al., 2008; Dent et al., 2011]. The results of the chemical composition analysis are presented in Table 2.

Analysis of the data presented in the tables indicates a significant anthropogenic impact on the soils in the area affected by sulfur mining activities. The sharp increase in sulfur concentration is one of the primary indicators of this impact, which ranges from 0.66–0.67% in the meter-deep soil layers but reaches 28.55% in the soils of the tailings storage facility. This substantial sulfur

Table 1. Average elemental composition (in %) of a one-meter soil layer in the sulfur mining activity area

Soils	Elements							
	O	H	C (humus)	N	P	Si	Al	Fe
Podzolic								
Loamy	49.60	0.06	0.66	0.080	0.054	34.86	6.33	3.02
Sandy loamy	50.66	0.05	0.67	0.066	0.022	39.57	4.31	1. 16

Table 2. Average elemental composition (in %) of the composite soil sample from the sulfur extraction tailings site

Element	S	Ca	Ti	Fe	Rb	Sr	Cd	Ba
Mass fraction, %	28.55	68.83	0.20	0.23	0.009	0.712	0.04	0.82

accumulation reflects its deposition as a result of industrial processes, particularly underground sulfur extraction. Additionally, the tailings storage facility exhibits a high calcium content (68.83%), attributed to lime use for neutralizing acids generated during industrial processes.

Furthermore, the soils of the tailings storage facility contain heavy metals and rare elements, such as cadmium (0.04%), barium (0.82%), strontium (0.712%), and rubidium (0.009%). These elements are absent in the meter-deep soil layers of podzolic soils, suggesting their technogenic origin. They are by-products of industrial activity and may pose risks to the environment and human health. The reduction in silicon and aluminum contents, characteristic of natural soils, indicates their substitution by technogenic materials.

Another significant observation is the reduction in organic components, such as humus and nitrogen, in the industrially altered soils. In the meter-deep layers of natural soils, these components are present in small amounts (humus – 0.08–0.066%, nitrogen – 0.054–0.022%), whereas in the tailings storage facility, these values are not even reported. This highlights the degradation of the organic matter in the soil as a result of industrial activity.

The chemical composition of the substrate formed in the studied tailings storage facility significantly differs from the soils typical of the Roztochia reserve. This is a direct consequence of technological processes. The main indicators of such impact include the accumulation of sulfur, heavy metals, and rare elements, the increased calcium content, and the depletion of organic soil components.

CONCLUSIONS

The studies demonstrated that the abiotic components of the ecosystem at the tailings storage facility of the decommissioned sulfur mining enterprise exhibit significant deviations from natural norms characteristic of the Roztochya Reserve. In particular, the soil cover of the tailings site is characterized by low porosity (41.56%), which impedes the effective formation of vegetation. The surface layer density values are 1.42 kg/m³, which precludes the development of woody vegetation. The practical absence of humus indicates a low level of soil fertility. The chemical composition of the surface deposits demonstrates high concentrations of sulfur (28.55%) and calcium (68.83%), which is a consequence of sulfur mining activities.

The research results indicate the necessity of implementing remediation measures to improve the physicochemical properties of the soil and restore natural ecosystems. Effective remediation will promote the return of biodiversity and the recovery of life processes in the post-technogenic territory.

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