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RESOLVING OF ENVIRONMENTAL PROBLEMS CAUSED BY THE PROCESSING OF COPPER ORE

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Abstract

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The constantly increasing need of raw materials for industry and energetic requires to grow the extraction of ores. Various mining resources are employed in different sectors of manufacturing, construction, transport, and human life. However, intensive mining and processing of minerals have negative impact on pedosphere. The present paper deals with effectiveness of technical and biological reclamation of "Elshitsa" tailing pond which was build to store the industrial waste products from copper ore mine, located in the village of Elshitsa, Panagyurishte municipality, Bulgaria. The negative impact of tailing pond on the environmental components is result of toxic characteristics of the tailings. The waste toxicity flows from the high content of sulphur, copper and lead which exceed the amounts assumed as typical of soils. The copper amount is 27 times higher than in natural soils, the lead – 16 and sulphur's – about 10 times. Besides their direct toxicity in terrestrial and aquatic environment, Cu and Pb are slightly biodegradable and cause long-lasting lethal effect. Restoration of damaged and contaminated sites was carried out in two stages – engineering-technical reclamation and biological reclamation. Combined usage of sludge from Plovdiv Treatment Plant for waste water, encapsulation of tailing surface with a polymer - Soil Cement and appropriate selection of grass species formed a tightly sealed cover. The assessment of reclaimed site showed that the strong anthropogenic pollution of the environment components is quickly prevented by applied effective technological solution for reclamation. There is no surface runoff and there are no pollutants to be controlled after three years of tailing pond's reclamation. The analysis of plants grown on reclaimed terrain shows that levels of heavy metals in their tissues are within the safe concentrations.

Key words: Copper ore; Tailing pond; Sewage sludge; Reclamation

Abbreviations: IWP – Industrial Waste Products; WRBSR – World Reference Base for Soil Resources; RSG – Reference Soil Group; PTPWW – Plovdiv Treatment Plant for Waste Water; CT1 – Collection Tank 1; CT2 – Collection Tank 2; PC – Precautionary Concentrations; MPC – Maximum Permissible Concentrations; LPC – Limit of Permissible Concentrations; CF – Correction Factor; IC – Intervention Concentrations

Introduction

Mining is one of the factors, which determines achievements of modern civilization (Ivanov, 2010; Sheoran et al., 2010). However, intensive mining and processing of minerals lead to more noticeable alteration of pedosphere (Cooke and Johnson, 2002; Donggan et al., 2011; Saviour, 2012; Sheoran et al., 2010). During mine operations, soil cover has destroyed, hydrological conditions have changed and new relief forms have created. This exterminates ecological balance and alters natural landscape. Massive disturbances are caused by processing of ferrous and nonferrous metals and inert materials, building of linear construction and engineering facilities, urban agglomerations, etc. (Banov et al., 2010).

Anthropogenic impacts on the landscape caused by copper ore mining are also connected with relief changes resulting from the construction of industrial buildings, mine equipment, dumps and tailings. Constructions, serving mine activities, affect the vegetation in the area, which is strongly reduced. The vegetation is dominantly represented by for-

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est communities: *Quercus cerris* L., *Q. frainetto* Ten. and *Q. dalechampii* Ten. According to the factors that determine the value of terrestrial communities (level of anthropogenic interference in the formation of biocenoses; tolerance to anthropogenic impacts, species diversity and uniqueness of communities and their species composition) the area, where the mining technogenic structures are located, refers to biocenoses under strong anthropogenic influence in some extent man-made (artificial plantations, agricultural vegetation), with a high degree of tolerance and lack of rare floristic elements.

The ore mining plays a prominent part in mine industry of Bulgaria. Mining and processing of copper in Bulgaria amounted to 27 222 819 kg according to the published data in 2008 (BCMG, 2008). The coal mining, as well as the ore mining and processing of extracted minerals (ores) are related to the enormous alterations of local geobiosystems. Neutralization of their negative impact on the environmental components is sometimes an extremely difficult process, requiring search and implementation of specific reclamation activities.

Our study focuses on the results of a new technology for technical and biological reclamation implemented to the "Elshitsa" tailing pond which was built to store the Industrial Waste Products (IWP) produced in processing of copper ore and its impact on the environment. The tailing consists of refuses, obtained in processing of copper ore and occupies an area of 108.5 ha. In order to assess the environmental impact of "Elshitsa" tailing the quality of surrounding soils is also studied. The present research involves the climatic and geological concerns, formation of soil cover and vegetation grown on reclaimed territory. Climatic data (Climatic Reference Book of Bulgaria, 1982, 1983) is used to suggest the most suitable crop for cultivation in studied region as well as to trace the pollution distribution.

Material and Methods

Site description

"Elshitsa" tailing pond is located on the land of Elshitsa village, Panagyurishte municipality, Pazardzhik district, Bulgaria. It is lying in the transition areas between Sredna Gora Mountain and Thracian Valley. The tailing pond is situated at about 1.5 - 2 km south – southeast of Elshitsa village and occupies an area of 108.5 ha. Geographical coordinates of several points of the site are presented below:

East: 42º 20` 56.18`` N; 24º 14` 38.65`` E; 405 m.
West: 42º 20` 52.20`` N; 24º 14` 04.79`` E; 413 m.
North: 42º 21` 09.50`` N; 24º 14` 19.58`` E; 413 m.
South: 42º 20` 34.62`` N; 24º 14` 22.21`` E; 405 m.
Center: 42º 20` 52.01`` N; 24º 14` 21.68`` E; 410 m.

Geology

In geological and structural terms, the area where the tailing pond is located is composed by materials of Cambrian and Upper Cretaceous (intrusive and sub volcanic rocks – granites, dacites, and andesites). The site and adjacent areas are characterized by porphyry copper ore manifestations, pyrite and copper-pyrite mineralization with volcano-hydrothermal origin (Kolchakov, 1975).

The geological setting determines formation of fissure groundwater in the area. Main accumulators of these waters are cracked rock formations of metamorphic (gneiss) volcano-sedimentary (andesites, dacites, rhyodacites) and intrusive (granites) rocks. Groundwater is distributed to a depth of about 100 – 150 meters and underground flow module is less than 0.1 l/s/km^2 in most cases. Types of water mineralization are sodium-calcium sulfate and calcium-magnesium-sulfate (Kolchakov, 1975).

Climate

The area is located in the southern part of temperate zone, adjacent to the subtropical Mediterranean climatic region. This defines climate as temperately continental to transitional to the average sea. The average January temperature is around 0–1.5ºC below zero. Permanent retention of temperatures above 10ºC occurred in mid-April. Warmest month is July with an average temperature of about 23.5 to 25ºC. In extremely warming days, maximum temperature can reach 40–42ºC. The average temperature in October is around 11–13ºC, and the first autumn frosts occur at the end of the month (Climatic Reference Book of Bulgaria, 1982, 1983).

The wind is the essential factor for the diffusion of harmful substances and air pollution, especially in the closest vicinity of the source of contamination. The region is characterized by poor circulation of air masses with average monthly rate 1.2 – 1.8 m/s. Rose of the winds (Figures 1 and 2) shows, that mainly transfer of air masses is from the northeast and northwest (79.9 percent of the time with wind).

Soils

Soil cover in the region is represented by several soil types (Koynov et al., 1968). In present paper soils are classified according to the Bulgarian Soil Classification (Penkov et al., 1992; Soil Atlas of Europe, scale 1: 2 200 000). Bulgarian soil taxons are correlated with the World Reference Base for Soil Resources – WRBSR (IUSS Working Group WRB. 2006) and the corresponding Reference Soil Groups (RSGs) are also represented in the study. The main soils types located in the region are:

- Leached Cinnamon Forest Soils – Leptic Luvisols. These soils have illuvial horizon with low thickness which is pass-

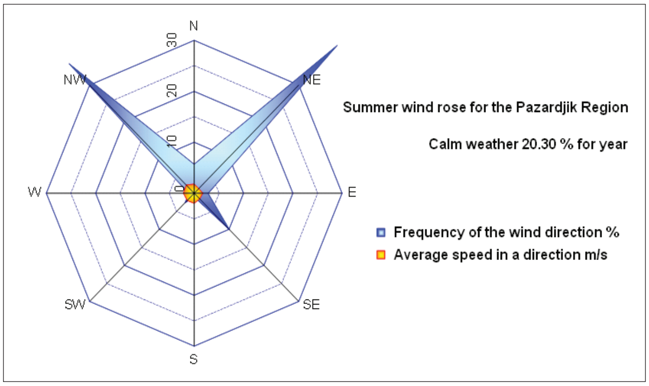

Fig. 1. Summer wind rose

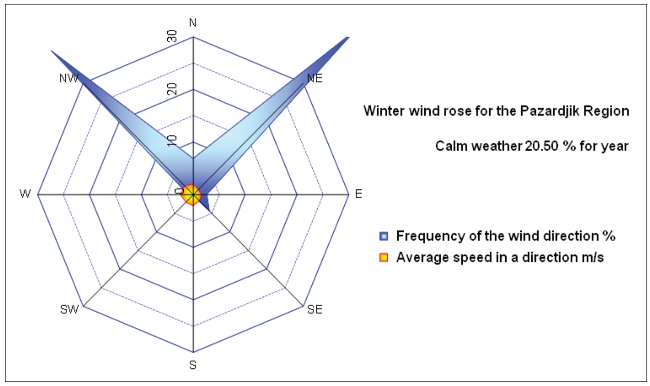

Fig. 2. Winter wind rose

ing to hard regolith and bedrock. The humus horizon has thickness between 25 – 30 cm and the total soil profile – 55 – 65 cm. The soil texture is sandy clay loam. pH activity in topsoil is strongly to moderately acid (4.6 – 5.0).

- Cinnamon Forest Soils – Leptic Cambisols (Chromic), formed on weathering products of acid rocks. These soils are characterized by a dense profile nearby solid rock (bedrock). Texture is sandy loam with a high content of regolith materials. The total thickness of soil profile is 50 – 60 cm. pH activity ranges from very strongly acid to slightly acid (3.7 – 4.6).
- Cinnamon-podzol (pseudopodzol) Forest Soils – Planosols (Chromic). These soils are formed on Quaternary sediments under the influence of forest vegetation. The RSG is characterized by clearly differentiated profile – pronounced podzol and illuvial horizon and a clear texture differentiation. The pedon texture is sandy clay loam. This determines the low water permeability. The illuvial horizon is reddish by hydroxides of iron and aluminum.

Vegetation

The vegetation is represented by forest communities of *Quercus cerris* L., *Quercus frainetto* Ten. and *Quercus dalechampii* Ten. In some places there are small remnants of *Fraxinus oxycarpa* Bieb. Ex Willd, *Ulmus minor* Mill., *Quercus pedunculiflora* C. Koch.. There are also artificial plantations of *Pinus nigra* Arn. and *Pinus sylvestris* L. From bush formations, most common are those of *Rosa canina* L., *Rubus caesius* L., *Crataegus monogyna* Jacq. The grass species are represented mainly by *Poaceae*.

Methods

Laboratory tests

Laboratory tests include determination of chemical composition of "Elshitsa" tailing pond, and chemical characterization of soils surrounding spoil, Sewage sludge from Plovdiv Treatment Plant for Waste Water (PTPWW) and crop harvested from reclaimed tailing pond were also analysed. Sampling procedure is described in ISO 10381-4:2003. Soil samples were prepared for analyses according to the ISO 11464:2006 (BSS[1] ISO 11464:2012). Individual tests were carried out by following methods:

- Chemical composition of "Elshitsa" tailing pond – Arinushkina (1970). Method is recently published as ISO 14869-1:2001.
- Heavy metals content in soils, sewage sludge and tailing pond – ISO 11047:1998.
- pH (H_2O) – method of FAO (Dewis and Freitas, **1970**).
- Total N – method of Kjeldahl modified by Urumova (1974). The decomposition of test sample is carried on a sand bath in the presence of both H_2SO_4 and 500 g.kg^{-1} $HClO_4$ (3 – 4 drops). After moderate heat treatment the totally decomposed sample left for 1 night.
- Available N – following the method of Stanchev and Boboshevska (1970) - ammonia and nitrates are extracted by 1 n KCl at soil: extract ratio 1:5. Through distillation in the apparatus of Parnas-Wagner is first determined the amount of ammonium chloride, then nitrates reducing and detached ammonia is distilled.
- Available P and K – colourimetrically, by the acetic-lactate extraction (method of Ivanov, 1984) and flame emission spectrophotometry detection by Flaphokol-C. Zeiss.
- The mixed crop production is analyzed through the ISO 6498:1998 and ISO 6869:2000 (BSS EN ISO 6869:2001).

Technical and biological reclamation of Elshitsa tailing pond and adjacent contaminated areas

Plan for reclamation of tailings has been developed in accordance with Regulation 26 (State Journal 89, 1996) for reclamation of disturbed areas, improvement of low productive lands, removal and utilization of the humus layer and Regulation 8

[1] BSS – Bulgarian State Standard

(State Journal 83, 2004) for the conditions and requirements for construction and operation of landfills and other facilities and installations for the utilization and recovery of refuse.

In essence, the reclamation is environmental action aimed at restoring and protecting the environment and human health. In most cases, the reclamation has no rapid economic effects that lead to immediate and rapid recovery (redemption) of money, but there is strong social and future effect. Restoration of damaged and contaminated sites is carried out in two stages – engineering-technical reclamation and biological reclamation. During technical stage, the terrain is refining and preparing for cultivation which represents the biological recovery of damaged areas. In the next stage (biological reclamation), certain crops are growing on the technically prepared areas in accordance with specific technological schemes. The design of biological reclamation includes actions which provide highest degree of restoration of damaged areas and improvement of the landscape.

Reclamation of the studied tailing pond had passed through following stages:

Temporary roads constriction. First of all it should be noted that the tailing surface is not sufficiently compacted. This imposed the construction of roads to be realized with spreading of geo grid on tailing surface and covering with soil materials. This protects heavy machinery from sinking during foreseeing.

The second stage is connected with encapsulation of tailing surface with polymer – Soil Cement, to form a shielding layer on the surface IWP and to prevent surface water from penetrating to the tailing.

Soil Sement is a polymer, composed of molecules, forming chain and network structures. A single chain holds more than 1 000 000 molecules. The molecules have the ability to bond with the materials constituting the treated area. Soil Sement is versatile and easy to use. It is an environmentally friendly product and is completely harmless when used. It prevents the water absorption in the treated surfaces.

The utilization of polymer Soil Sement® at rate of 95 g/m^2 leads to a number of beneficiary effects: the dust pollution of the surrounding areas and the soil erosion are prevented and soil moisture is retained during the initial period of plant vegetation.

It is diluted with water at a ratio 1:4.5. The mixture is sprayed by a tanker vehicle. As water evaporates Soil Sement hardens and seals the surface and thus even in the case of strong wind it prevents the formation of dust clouds.

After encapsulation, stabilized sewage sludge from PT-PWW is outspreaded. They form a layer 10 cm thick.

The last reclamation stage was grassing of the tailing surface with grass mixtures.

To reduce the harmful effects of drainage water leaking from tailing pond and control of quantitative and qualitative indicators, several hydro technical solutions were made (system of concrete gutter, concrete tanks and pumping unit).

– Point 1: Collection tank 1 (CT1), built in the heel of the main wall of the tailing pond.

– Point 2: Collection tank 2 (CT2), built in the heel of the partition dike.

Through the two concrete reservoirs and Pumping Plant accumulated polluted water is passed for purification in tank called “trench”. It is intended to bring the content of harmful components to the emission standards.

Measures that are performed for contaminated soils are the following:

1. Cleaning of soil surface from blew tailing. Excavation took place at a depth of about 15 cm.
2. Amelioration of contaminated soils with lime materials at the rate of 2000 kg.ha^{-1} to reduce the harmful effects of acid pH.
3. Introduction of organic matter (manure) at the rate of 100 t.ha^{-1} to provide nutrients for plants. After spreading of manure, deep plowing to a depth of 20 – 25 cm was made.
4. Sowing of grass mixtures.

Composition of grass species was selected according to specific soil and weather and temperature conditions in the area, altitude, etc. Preference to low growing grasses, that create healthy and sustainable sod was given. The selection of species for grass mixtures is consistent with the aggressiveness and competitiveness of individual species:

Group I – species with high competitive ability;

Group II – species with average competitiveness;

Group III – species that inhibit the types of I and II groups.

Results and Discussion

The negative impact of tailing pond on the environmental components is a result of toxic characteristics of the IWP kept in tailing. Data of IWP laboratory analyses are presented in Table 1. The waste toxicity flows from the high content of sulphur, copper and lead which exceed the amount found in natural soils (published in Regulation 3 (State Journal 36, 1979, amended State Journal 71 from 12 August 2008), Table 2). The copper amount is 27 times higher than in natural Bulgarian soils, the leads – 16 and sulphur exceed 10 times the content in natural soils (Treykyashki and Hristov, 1982). Besides their direct toxicity in terrestrial and aquatic environment, Cu and Pb are slightly biodegradable and cause long-lasting lethal effect.

The high content of sulphides (marked as S_S in Table 1) leads to the formation of sulfuric acid in quantities sufficient to cause the well known problem of acid mine drainage – pH of drained water is 3.13. Strong acidification of the medium (pH < 4.0) may increase the mobility and toxicity of heavy metals (Table 1). It is known that the kinetics of the oxidation process is significantly influenced by sulphide minerals degree of dispersion, their simultaneous presence, the biochemical activity of thionic bacteria (*Thiobacillus ferrooxidans, Th. thiooxidans, Th. thioparus,* etc.) the physical properties and mineral composition of materials, the area hydrothermal and climatic regime (Marinkina, 1999).

The relative stability of sulphides in the tailings, where the oxidation conditions are different from those in spoils is: pirotin < sphalerite = galenite < pyrite = arsenopyrite < chalcopyrite < magnetite (most stable) (Jambor, 1994). Each of these minerals is the source of many elements-alloys which might shift from the minerals grid during the oxidation processes (eg pyrite and chalcopyrite contain As, Ni, Co, Se, Te, etc.; Sphalerite - Fe, Cd, Ga, Ge, etc.) (Benvenuti et al., 1997). Some of these elements come directly into rivers going around (with drainage and runoff), while others may be involved in secondary precipitated phases such as sulfates, Fe oxides and hydroxides, which was found to contain Ni to 7 $g.kg^{-1}$, Cu to 12 $g.kg^{-1}$, As to 47 $g.kg^{-1}$ and Pb to 67 $g.kg^{-1}$ (Benvenuti et al., 1997). These elements could again be mobilized in the environment if the physical-chemical conditions have changed.

There were several trends in the geochemical behavior of different elements that can highlight the risk for environment pollution. Usually the contents of Cd, Cu, Zn and Fe increased in soil depth, because of the solubility of their oxidation products. So they first migrate into the river and often are the most determining criterion for the degree of pollution in a region. The contents of other elements such as Ag, Au,

Table 1
Content of macro- and microelements in Elshitsa tailing pond (µg/g)

Si	Al	Ca	Mg	Na	K	Fe	Ti	Cu	Pb	Ag	Au	S_S
323724.4	65648.9	7865.0	12421.8	13356.0	23074.0	45000	2036.6	0.16	800	1.36	0.20	28000

Table 2
Levels for maximum and intervention concentrations of heavy metals and metalloids in soils (determined as a total concentrations in aqua regia, µg/g) – Regulation 3/2008

Elements	pH (H_2O)	Maximum permissible concentrations (MPC)			Intervention concentrations (IC)
		Arable lands	Permanent grasslands	Correction factor (CF)	
As	–	25	30	1.2	90
Cd	<6.0 6.0 – 7.4 >7.4	1.5 2.0 3.0	2.0 2.5 3.5	1.3	12
Cu	<6.0 6.0 – 7.4 >7.4	80 150 300	80 140 200	1.2	500
Cr	–	200	250	1.2	550
Ni	<6.0 6.0 – 7.4 >7.4	90 110 150	70 80 110	1.2	300
Pb	<6.0 6.0 – 7.4 >7.4	60 100 120	90 130 150	1.3	500
Hg	–	1.5	1.5	1.2	10
Zn	<6.0 6.0 – 7.4 >7.4	200 300 400	220 390 450	1.3	900

Legend: Maximum permissible concentrations – the content of harmful substances in the soil in mg / kg, which exceeded under certain conditions, leads to disturbance of the soil functions and danger to the environment and human health.
Intervention Concentrations – is the content of harmful substances in soil in mg / kg, exceeding of which leads to disruption of soil functions and danger to the environment and human health.
Correction factor – correction factor is applied to the soil with clay content (particles < 0.01 mm)> 600 $g.kg^{-1}$ in the plow horizon (depth 0-20 cm) and / or A horizon (0-10 cm) of non-arable land by multiplying of the values of MPC for arable land and permanent grasslands with CF. Data for clay content is taken from soil maps and from direct test on the field.

Sb, Pb, As, conversely, decreases in depth because of the insolubility of their weathering products.

The landing of waste products in soils, under the influence of wind, surface and ground runoffs leads to changes in their characteristics, mainly expressed in a high decrease of pH values and exceeding the Precautionary Concentrations (PC) for Cu and Cd (Regulation 3 (State Journal 36, 1979, amended State Journal 71 from 12 August 2008).

The conducted studies show that adjacent soils covering an area of 19 ha, are characterized by significant deviations from the characteristics of regional RSGs as a result of long mining and enrichment activities and under the influence of dust pollution from the tailing pond. The data in Table 1 show that the root layer (0-40 cm) of cinnamon forest soils is anthropogenic contaminated with cadmium and copper. Pollution exceeds the maximum permissible concentrations (MPC), introduced by Regulation 3 (State Journal 36, 1979, amended State Journal 71 from 12 August 2008) (Table 2) with 54 to 79 percent for copper and 67 percent for cadmium (Table 3). It also registered a decrease in the pH (Table 4) near the dam, due to the high content of sulphide minerals in tailings and the acidity generated in the course of their oxidation.

The mobility of zinc also increased in acid conditions, but it concentration does not exceed the precautionary levels in studied soils. Soil pH is also a controlling factor for manganese mobility, whose solubility decreases with decreasing of acidity. It can be expected that the reaction medium (pH) in 5.0 will create conditions for increasing the content of easily reducible manganese that determines the manifestation of toxic symptoms in plants. The accumulation of manganese found in subsurface horizons of studied soils, is most likely associated with tillage and mechanical redistribution of its compounds.

We can say that the soil near the Elshitsa tailing pond are heavily contaminated with copper and cadmium (excess over 50 percent MPC) and conceal a risk to the environment and human health. They formed an area with high content of manganese, which can also affect the quality and safety of agricultural production.

Status of site after completion of reclamation events

Combined usage of sewage sludge from PTPWW, encapsulation of tailing surface with a polymer - Soil Cement and appropriate selection of grass species are formed a tightly

Table 3
Heavy metal content in soils surrounding Elshitsa tailing pond (µg/g)

Pit location	Sample depth, cm	Cu	Pb	Zn	Mn	Cd
Arable soil bordering the tailing pond	A + B, 0–22	14.5	13.0	23.5	97.5	1.0
	BC, 22–40	143.5	24.5	61.0	993.5	1.5
	CD, 42–65	154.5	23.5	69.5	–	2.0
Arable soil distant the tailing pond	A_h, 0–21	22.0	19.5	15.5	181.0	1.0
	BC, 21–47	14.5	20.5	25.5	423.5	1.0
	C, 47–80	16.5	17.0	25.5	145.5	1.5
Leptic Cambisols (Chromic) bordering the tailing pond	A, 0–25	123.5	29.0	107.0	1000.0	2.5
	BC, 25–44	121.0	32.5	95.0	1050.0	2.5
	C, 44– ↓	98.0	21.0	77.5	750.0	2.0

Table 4
Chemical properties of soils surrounding Elshitsa tailing pond

Pit location	Sample depth, cm	pH (H_2O)	N, µg/g	P, µg/g	K, µg/g
Arable soil bordering the tailing pond	A + B, 0–22	4.80	550	0.174	1.660
	BC, 22–40	4.85	–	–	–
	CD, 42–65	4.80	–	–	–
Arable soil distant the tailing pond	A, 0–21	5.60	280	0.087	2.034
	BC, 21–47	5.70	–	–	–
	C, 47–80	5.65	–	–	–
Leptic Cambisols (Chromic) bordering the tailing pond	A, 0–25	5.35	1160	0.066	2.158
	BC, 25–44	5.80	800	0.044	2.283
	C, 44– ↓	6.30	260	0.044	1.141

sealed cover (surface shielding layer). It reduces the amount of rain water filtration to zero, reduces piezo metric surface and sharply decrease the amount of drainage water and increase quality of surface runoff.

Results from encapsulation and reclamation activities are suspension of dust, stabilization of slopes and creation of sustainable grass vegetation (*Onobrychis alba*, (Waldst. & Kit.) Desv., *Dactilis glomerata* L. and *Bromus inermis* Leyss).

Nevertheless the successful reclamation activities, in accordance with Regulation 8 and Regulation on the manner of utilization of sludge from wastewater treatment through its use in agriculture (State Journal 112, 2004), the recovered terrains (surface and slopes of Elshitsa tailing pond) are not intended to be used for agricultural purposes. This is because sewage sludge from PTPWW contains quantities of heavy metals exceeding the MPC for soils (Table 5, Figures 3 and 4).

Table 5
Chemical composition of sewage sludge from PTPWW

Substance/elements	Belt filterpresses	Drying fields	Storage depot	MPC, μg/g
Absolutely dry substance, $g.kg^{-1}$	358.9	313.4	841.9	-
Ash substances, $g.kg^{-1}$	405.1	489.5	680.6	-
Available N (NH_4), mg/kg	0.039	0.008	0.016	-
Total N	15000	18000	700	-
Total P	6400	2400	5700	-
Total K	1200	1400	1100	-
Total Na	800	600	500	-
Total Ca	20500	23500	29000	-
Zn	3122	3162	1673	3000
Cu	523	310	214	1600
Mn	317	319	249	-
Co	6	5	1	-
Cd	63	29	4	30
Ni	449	125	252	350
Pb	21	105	72	800
Cr	1468	1291	561	500
pH (H_2O)	6.8	6.9	6.7	-

Legend: PTPWW – Plovdiv Treatment Plant for Waste Water
MPC – Maximum Permissible Concentrations

Fig. 3.

Fig. 4.

Table 6
Content of heavy metals in crop production from Elshitsa tailing pond

Element	Value, μg/g	LPC, μg/g
Cu	20.7	280
Pb	1.68	80
Zn	76.8	370
Cd	1.31	3.0
Ni	3.0	70

Legend: LPC – Limit of Permissible Concentrations

The analysis of crop production from the site (grass mixture grown on reclaimed terrain) shows that levels of heavy metals are within safe concentrations (Table 6).

Monitoring

Reclaimed tailings, soils and crop production must be subject of periodic control and crop production to be used as forage only when it reaches the appropriate regulatory requirements. Otherwise grass mixtures should be plowed on the field i.e. to be used for "green manure".

The coming monitoring plan includes:

- Observation and measurement of the level of piezo metric surface;
- Observations and measurements of horizontal and vertical deviations of the main wall;
- Observation, measurement, sampling and testing of samples from drainage water;
- Monitoring, sampling and testing of samples from vegetation;

Conclusions

Results show that the strong anthropogenic pollution of the environment components is quickly prevented with the effective reclamation carried out. Monitoring shows that there is no negative impact on surface runoff and there are no pollutants to be controlled. The amount of drainage water reached a constant level and there is no likelihood of future dynamics of quantitative and qualitative indicators. In long term perspective, the quantity will be reduced to zero. Concentration of pollutants will be insignificant to justify the introduction of continuous monitoring measures.

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