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Pollution of Soils by Heavy Metals from Irrigation near Mining Region of Georgia

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Abstract

The main goal of our research was to study the composition, migration and accumulation of heavy metals in irrigated soils, plants and partially natural waters in Bolnisi district, Georgia (southwards of Tbilisi capital city), and to establish the possible sources of pollution and their impact on the environmental situation of the region. The contents of toxic elements in the irrigated soils adjacent to ore mining and processing enterprise were studied. All samples from soils and water were inspected with Perkin Elmer device with the use of atomic-adsorptive method.

There were identified different concentrations of heavy metals. Our research has shown that more than half of the territory is seriously polluted by copper and zinc. Some part of the area can be considered catastrophically polluted. Due to the technological process and practices, irrigations play a major role in polluting the soil, since the area is irrigated using the water from rivers where wastewaters from the enterprise are discharged.

Our study shows that pollutant heavy metals, first of all copper, zinc and manganese have active negative effect on the properties of soil, its composition and soil-forming processes. It is especially well represented in the deterioration of hydro-physical potential of the soil. Balanced correlation among solid, liquid and gas phases is disrupted. In the highly polluted soils, cementing processes take place and sharply increase bulk density of the soil. Thus, the porosity of the soil deteriorates and water permeability is critically low.

Keywords: *Soil Ecology, Heavy Metals, Water Pollution, Soil Pollution, Mashavera River, Madneuli Multimetallic Mine.*

Rezumat. Poluarea solurilor cu metale grele în urma irigațiilor în regiunea minieră din Georgia

Scopul principal al acestei cercetări l-a reprezentat studierea compoziției, migrării și acumulării metalelor grele în solurile irigate, plante și parțial ape naturale în districtul Bolnisi, Georgia (în sudul capitalei Tbilisi), precum și stabilirea posibilelor surse de poluare și impactul acestora asupra mediului regiunii. Lucrarea analizează conținutul elementelor toxice din solurile irigate adiacente exploatării miniere și fabricii de prelucrare.

Toate mostrele de sol și apă au fost analizate cu ajutorul aparatului Perkin Elmer, folosind metoda atomo-adsorbtivă. Astfel au fost identificate concentrări difereite ale metalelor grele. Studiul nostru a arătat că peste jumătate din teritoriul analizat este serios poluat cu cupru și zinc. Unele areale din regiune pot fi considerate chiar poluate catastrofal. Irigațiile au un rol major în acest sens, întrucât aceste teritorii sunt irigate intens folosind apa râurilor în care se deversează apa folosită la întreprinderea minieră. Prin urmare, aceste ape ajung în sol prin intermediul irigațiilor.

Studiul prezent demonstrează că metalele grele, în primul rând cupru, zinc și mangan, au efecte negative majore asupra tuturor proprietăților solului, compoziției acestuia și proceselor pedogenetice, fapt evidențiat foarte bine de deteriorarea potențialului hidro-fizic al solului. O corelație echilibrată între fazele solidă, lichidă și gazoază este întreruptă. În solurile puternic poluate, au loc procese de compactare care duc la o creștere rapidă a densității solului, cu o deteriorare critică a porozității și permeabilității stratului de sol.

Cuvinte-cheie: *ecologia solului, metale grele, poluarea apei, poluarea solului, râul Mashavera, Mina Madneuli*

Introduction

Soil is a very specific and complicated component of nature. In case of water and air pollution, if the toxic substances are removed, they will easily return to their original conditions. In case of soils, this process is much more complicated. If the soil is polluted the centuries old balance is upset and restoring that balance takes a very long time.

As a result of human economic activities, the environment is polluted with industrial waste, wastewater, various radioactive substances, chemicals/ pesticides used in agriculture etc. One of the most considerable problems is the pollution of environment with heavy metals. Some metals are characterized by high toxicity and if a considerable amount of such metals penetrate a live organism it can have a strong impact on human health And even more, if we take into account the fact that the period needed for semi-disintegration of heavy metals can last from several decades to hundreds and thousands of years. Besides having adverse impact on human health, heavy metals also decrease the productivity of soil. Therefore, the research of the accumulation and migration of heavy metals in soils is currently a very important and relevant issue. The research results will strongly benefit environment protection and future generations' health.

The composition of (micro and macro) chemical elements in soils is conditioned by soil-formation processes, chemical make-up of rocks and concrete landscape conditions – relief, climate, water, vegetation and fauna – the factors that define the processes of opening, accumulation and migration of various substances.

The first "blow" is taken by the upper (humus) layer of the soil, where the main part of root system is developed. That is where the micro and macro elements and other toxic substances intensively accumulate. Toxic substances that penetrate the soil through water, air, pesticides, mineral and organic fertilizers have a very negative impact on live organisms.

The following economic activities can become the source of pollution: mining, energy generation, industry, transport, community facilities, animal husbandry, farming etc.

The use of wastewater rich with heavy metals for irrigation purposes is especially alarming. It has a significant impact on the chemical composition of the soil and brings about disastrous results. However, according to some researchers (Alekseev, 1987; Saet et al., 1982), the use of such water for irrigation is dangerous only when zinc, copper and nickel levels in such waters are high, as those elements are highly phyto-toxic. The ability of soils to resist the polluting elements is also diverse.

The presence and distribution of some heavy metals in soils, plants and natural waters has been researched in order to determine the impact of the existing mines in the study area (Bolnisi district, Georgia) on the environment.

With the enhancement of ore-dressing industry, the issues connected with pollution of environment with heavy metals are becoming more and more relevant. Almost identical geo-chemical processes are taking place in practically all copper-sulfide mining sites situated in the region.

The accumulation of large quantities of heavy metals in waters and soils has an adverse impact on the region's biosphere. We must view several aspects of that matter. First of all, we should note the direct impact of hazardous substances on vegetation. Besides, increasing levels of heavy metals in hydro-system and soils can have a serious impact on the microflora of the soil; it can change their composition and have a negative influence on the self-recovering processes (A.Kabata-Pendias & H.Pendias, 1989).

Soil is the most informative part of the landscape because it is formed as a result of the interaction of all the other elements of the landscape. Therefore, all those anthropogenic and natural processes that are taking place within the concrete ecosystem are reflected there (Blume, 2004; Felix-Henningsen et al., 2007; Hanauer et al., 2010; Matchavariani, 2011).

The regions, which are rich in chemical substances or poor for various reasons, are called geochemical provinces. Anthropogenic accumulation of heavy metals in the soils in biogeochemical provinces with increased presence of chemical elements as well as near the ore mines is conditioned by exogenous mines and emission of industrial wastes into the environment. The intensity of accumulation depends on the ability to absorb the metals by the soil. Heavy clay loam absorbs heavy metals more intensively than other types of soil.

Rocks are the main source of microelements in the soil, the concentration of various microelements in rocks defining microelement composition of the soil. During the soil formation, process elements are distributed in layers, some of them are lost and some of them are accumulated; however, the main characteristics received from rocks are always preserved.

The soils covered by our research, developed on the weathered crust of volcanogenic and sedimentary rocks. Their chemical composition is defined by the chemical composition of rocks, soil-formation processes and various anthropogenic factors connected with human economic activities.

The main goal of our researches was to study the composition, migration and accumulation of heavy metals in soils, plants and partially natural waters in Bolnisi district; besides, we also aimed at establishing the possible sources of pollution and their impact on environmental situation.

Similar works were not conducted in the study area before, but only survey researches of prospecting type. Basically, they focused on geochemical studies and revealing of ore deposits. Therefore, scientific publications in this sphere are very few. A wider and thorough research concerning the pollution of soils and water in the region was done for the first time by us. So, all the data from our research will be used as background materials for the further researches on this territory.

At present, on the basis of our researches and with our participation, within the international projects, new studies are taking place for the same territory, using new international approaches. In particular, quality estimation of soil pollution is based on the European standards, according to the German Federal Soil Protection Ordinance (Sites exceeding the Precaution value – BBSchV, 1998; DIN EN ISO 14688 – 1:2003-01, 2003; DIN ISO 10390 2005-12, 2005; DIN ISO 16072:2005-06, 2005). The thresholds of the EU food regulations (2006) are also considered.

Interesting researches in this sphere have been carried out in Serbia. Various techniques have been used by authors for studying water quality degradation (Dragicevic et al., 2010). Some researchers (Grabicet et al., 2011) were testing a combined approach based upon leading European and United States concepts for the assessment and better management within the hydrosystem. Statistical analysis of water quality parameters has been made by some authors (Pantelici et al., 2012).

Study area

Our research covered Bolnisi district (Fig. 1) – part of the Lesser Caucasus mountains' metallogenic province. It is one of the most important mining areas of Georgia. The main part of the territory is occupied by orchards and vineyards, partly by crops (arable land). The presence and distribution of some heavy metals in soils, plants and natural waters has been researched in order to determine the impact of the existing mines in that area on the environment.

Madneuli multimetallic mining combine situated 80 kilometers south of Tbilisi capital city (Fig.1), is divided into several sectors. The area is mountainous (middle and high mountains), altitudes ranging between 500 and 1,300 meters. Its genesis is hydrothermal (group of hydrothermal deposits).

Highly acid waters containing sulphuric acid, the pH of which may be less than 1, moving 40 meters deep under-ground, contain large amounts of copper, iron and zinc sulphates. Usually they have no exits to the surface. As a result of their impact on sulphides, secondary sulphides are formed. Hydrogen sulphide is emitted. These processes bear great significance as the formation of secondary beneficiated ores is connected with the above-mentioned processes. Pit-run waters contain high amounts of copper, iron and zinc, that process is conditioned by sulphuric acid formed as a result of the oxidation of sulphide minerals; the minerals bring out sulphuric acid through water in the form of soluble sulphates.

Currently the mine is open and the ore is mined in the quarry. Waters rich in sulphuric acid are flowing straight into the river from the quarry. Wastewater from ore-dressing and processing enterprise is added to them and it first goes to the Kazretula River and then to the Mashavera River; subsequently, these waters get into the ground and soil through Mashavera irrigation system (Fig. 2).

In addition, the waste products of the enterprise – broods - are stored in the special storage facilities (tanks) wastewaters are flowing through treatment devices into the Kazretula River. The water coming from those tanks and the wastewater from the enterprise are potentially dangerous for the environment, because those waters are strong sulphuric acid solutions rich in heavy metals. As a result, both hydro-systems and soils are polluted. At the same time the river system becomes the main source of pollution for the district. Besides rivers, the pollution is spread by winds: dust created as a result of explosions in the quarry is carried for many kilometers by winds. Eventually the hazardous substances are accumulated in the soils and river sediments.

The researched area is situated within 17-23 kilometers of the main site of pollution (Madneuli enterprise's quarry). Itlies 18-41 kilometers along the irrigation system (Fig. 2). Bolnisi district's agricultural lands are distributed within the Mashavera and the Poladauri Rivers valleys. Brown soils under fields and forests are situated there. According to the WRB (World Reference Base, 2006) and Soil Map of Georgia (1999), there are Cinnamonic-Eutric Cambisols, Calcic Kastanozems, and Cinnamonic Kalcareous-Calcaric Cambisols. They have a deep genetic profile, differentiated morphogenetic structure, heavy clay loam and light clay granulometric composition, medium and high amounts of humus. Nitrogen and phosphorus are not represented in large quantities, but soil is rich in absorbed bases. The soil reaction is alkaline (pH = 8-9).

Fig. 1 Physical map of Georgia with location of study area

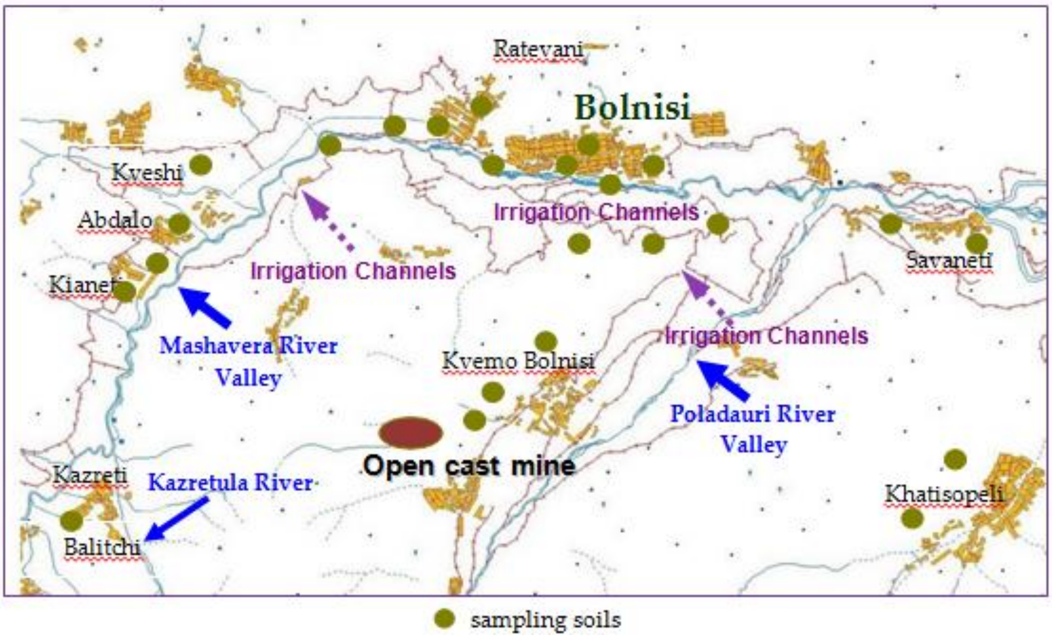

Fig. 2 Location of sampling soils

Method

There are various methods of land reclamation of the polluted soils: mechanical, physical-mechanical, chemical etc. The use and effectiveness of each land reclamation method depends on the climatic, bio-climatic, geo-ecological and soil-edaphon (granulometric composition and structure of the soil,

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humus concentration, absorption volumes, oxidation-restoration potential, pH etc.) factors.

The field study is based on three parameters: the first is the agricultural land plot from which soil samples must be taken in order to define the level of heavy metal pollution; second, the amount of soil samples, which is necessary for having a representative, mixed soil sample; third, the selection of the essential agricultural land plot. Essential agricultural land plot is the smallest geomorphological unit, which accurately reflects the soil's genesis, characteristics, soil-formation rocks, relief, vegetation, hydrologic conditions of the site.

Soil samples were taken from ploughed fields, vineyards, orchards, as well as crofts of some villagers. We used the average sampling method: we took 10 samples from an approximately 10 hectare land plot with the use of a field drill, after mixing those samples together we received one mixed sample. We also took samples from the vertical profile of the soil. All samples from soils and water were inspected with Perkin Elmer device with the use of atomic-adsorptive method (Zeien, 1995). For the definition of mobile forms of heavy metals in soils, the known method of the buffer acetate ammonium (САН ПИН 42-128-4433-87) has been used. In addition, in order to define the total forms, all samples from soils and water were inspected with the use of ISO 11047, ISO 11466 standard.

The concentration of acceptable maximum levels of heavy metals in agricultural lands is defined taking into consideration the following factors: initial levels of microelements in soils; dynamics of increasing levels of concentration of heavy metals as a result of anthropogenic factors; general accumulation of heavy metals in soils; adequate evaluation of toxic impact of heavy metals on plants; maximum levels of concentration of microelements in soil; mutual antagonism and synergy of heavy metals and quantitative and qualitative evaluation of those factors; physical, chemical, physical-chemical and agro-physical characteristics of the soil (carbon levels, humus levels, granulometric composition, moisture, moisture balance, aeration, filtration capacity etc.); balance of penetration and extraction of heavy metals in the soil; plants' tolerance towards heavy metals.

The criteria of soil pollution are made basically according to Saet et al., 1982. Various criteria and norms have been adopted for evaluating soil pollution levels Clarke Concentration Coefficient is one of the notable examples of such norms/criteria, the coefficient is calculated with the use of the following formula: Kk=Cf/K; where Kk is Clarke Concentration Coefficient; Cf – is actual concentration of chemical elements in the soil; K – is the clarke of a chemical element. That criterion shows how high or low is the concentration of a concrete chemical element in comparison with that of Clarke's.

The geo-ecologic condition of the soil is also evaluated using the Pollution Concentration Coefficient, which is calculated with the use of the following formula: Hc = Cf/level; where Hc – is pollution concentration coefficient; Cf – is actual concentration of a chemical element, f – is local or general established levels of a concrete chemical element, which indicates how the concentration increased in comparison with the general levels (Saet et al., 1982).

The pollution probability concentration coefficient is also used for evaluating the levels of soil pollution. The formula used in that case is C = Cf/maximum permissible level, where C – is the coefficient of pollution probability concentration; Cf – is the actual concentration of a chemical element.

These indicators show how high is the actual concentration of a chemical element in comparison with the maximum permissible levels of concentration of that element; the higher that coefficient is in comparison with 1, the higher is the probability of soil pollution and negative impact of chemical elements on live organisms.

We took into consideration the correlation between the various elements of the soil and their joint impact on the soil in order to establish/evaluate the maximum levels of concentration of microelements in the soil.

Soils are grouped according to the total actual concentrations of toxic chemical elements-pollutants, this grouping is based on the methodology elaborated by A. Vinogradov (1957); according to that methodology, the first group is general level + 1 Clarke; the second group is general level + 2 Clarke etc. When soils are grouped this way, the level of pollution of soils is classified according to the following classification: slightly polluted; moderately polluted; medium pollution (or averagely polluted); higher than medium pollution, strong pollution (or high pollution), very strong pollution (or extreme pollution/extremely polluted).

Territories adjacent to strong pollution sites such as non-ferrous metal processing plants, ore-dressing and processing enterprises etc. are extremely polluted and sometimes their level of pollution exceeds 10 Clarkes.

The pollution levels can be used as approximate indicators of adverse impact of the chemical elements on environment. For example: at the first and second (group) level pollution, the soil biota is strongly deteriorated, biochemical processes are suppressed. At the third and fourth (group) level of pollution, agrochemical characteristics of the soils are worsened, vital functions of plants are disrupted and their chemical composition is violated. At the fifth and sixth (group) level of pollution, plants become sick and they die; plant and animal products are not fit for use due to sanitary-hygienic considerations. The chemical composition of the upper layer of the soil changes and all agrochemical characteristics quickly deteriorate.

Discussion

According to our data, total amounts of copper, zinc, cadmium and sulphate-ion in the Kazretula River, which is flowing under the above-mentioned tanks, exceed several times the maximum permissible levels established for surface waters. The Kazretula River is rife with ore elements. Due to the very low pH of the water, these metals are mainly present in the soluble form and they can travel long distances. After the Kazretula River flows into the Mashavera River, its water is diluted 10 times. The pH of irrigational water fluctuates from 3 (at the spring of the Kazretula River) to 5 (in the Mashavera River, depending on distance of inflow Kazretula). At the same time, pH and turbidity of the water increase. Consequenlty, the metals start to float in the water and continue to migrate in that form. Despite this, the levels of sulphate-ion in the water remain quite high.

The copper levels in the soils inspected by us are very high. Minimal levels are found in 17.9 per cent of the total number of samples, 200 mg/kg and more is found in 18.3 per cent of the samples (Table 1, 2).

Figure 3 shows the levels of concrete elements according to each land plot. The number of taken samples (n) is also indicated. For n-quantities, there are given the average values.

The soils in Bolnisi district are diverse both in their genesis and soil-formation patterns. The character and intensity of agricultural activities result in dramatic differences in the amounts of various elements. High quantities of heavy metals (more than 200 mg/kg) are found in the soils of several villages.

Table 1 Levels of heavy metals found in soils of arable land, mg/kg

Place of sampling and quantity of samples, n	Cu	Zn	Mn	Pb
Ratevani, n=12	60-3625	75-2250	625-1000	19-36
Abdalo, n=5	40-88	100-625	1125-1375	20-35
Kazreti, n=10	35-200	85-100	750-1000	15-25
Khatisopeli, n=4	60-100	110-212	1000-1250	14-19
Balitchi, n=8	55-85	90-120	750-1125	25-25
Savaneti, n=4	40-115	105-135	875-1000	14-17
Kveshi, n=7	42-125	100-120	1000-1250	15-20

Table 2 Levels of heavy metals found in soils of vineyard, mg/kg

Place of sampling and quantity of samples, n	Cu	Zn	Mn	Pb
Ratevani ,n=20	255-3125	165-2125	750-1625	22-41
Pakhralo, n=3	130-625	150-255	1000-1375	22-31
Kianreti, n=2	290-305	100-110	875-1125	32-35
Bolnisi, n=5	100-170	115-175	750-1375	17-22

These areas are mainly situated on the banks of the Mashavera River. It should be noted that sections that have especially high levels of metals are often situated between the river basin and the railway. Naturally, copper levels in vineyard soils are much higher than metal levels in the ploughed fields. Copper levels are also high in the orchard soils. The main part of the inspected land plots (150 hectares) is situated on the right coast of the Mashavera River. Most of the territory is occupied by vineyards and orchards; more than half of the territory is occupied by wheat crops andis quite seriously polluted by copper and zinc; most of the area has 200-700 mg/kg copper and zinc concentration and about 8-9 per cent of the area can be considered catastrophically polluted. This area is intensively irrigated with the Mashavera River water. We can actually say that we are dealing with a clear case of anthropogenic impact, which means the impact of the irrigation system using water polluted by the ore-dressing and processing enterprise. In other areas of the district where copper and zinc concentrations (500 mg/kg) have been detected, the pollution is fragmented.

Lead levels in wastewater and pit-run waters are minimal due to the low dissolubility of its sulphates. Anthropogenic lead gets in the environment mainly

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from vehicles. The maximum levels of lead in the soil were found in the Kianeti village's fields: average amount of lead in vineyards is 33.75 mg/kg, in ploughed fields – 24.33 mg/kg. If we take into consideration the fact that levels of copper and zinc in those land plots are minimal, we should assume that lead is coming from vehicles only. The maximum concentration of copper was 875.0 mg/kg. High levels of zinc in the same area have also been detected (500-1,600 mg/kg).

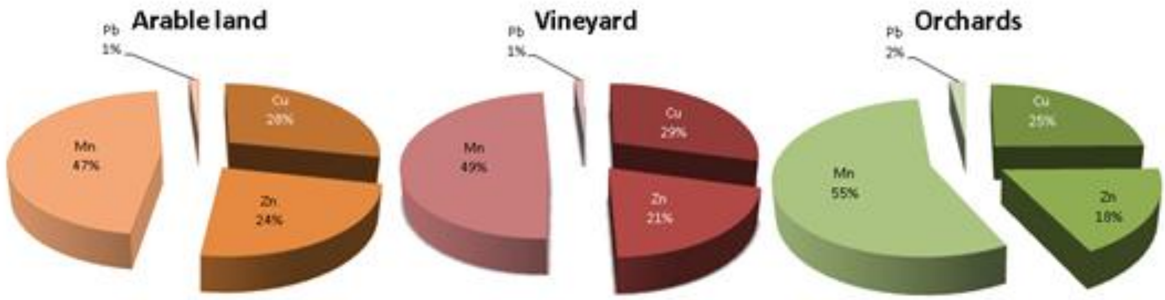

Fig. 3 Average levels of heavy metals in the surface layer of the soil, 0-20 cm (n – number of samples)

Arable land (n=12): Cu – 597 mg/kg; Zn – 501 mg/kg; Mn – 979 mg/kg; Pb – 25 mg/kg;
Vineyeard (n=20): Cu – 682 mg/kg; Zn – 480 mg/kg; Mn – 1150 mg/kg; Pb – 30 mg/kg;
Orchards (n=12): Cu – 349 mg/kg; Zn – 250 mg/kg; Mn – 781 mg/kg; Pb – 29 mg/kg

Thus, we can conclude that these territories are under clear anthropogenic influence, which is intensified even more by several other factors.

We should especially point out manganese. It is a well-known fact that manganese plays a special physiological role and that it is also very important as far as geochemical processes are concerned in the soil, plants and waters. Maximum levels of manganese are 1,125-1,375 mg/kg. Pollution Concentration Coefficients are 5.6-6.8. The minimal concentration of manganese is 875 mg/kg. Manganese is an element of foundation rocks and is accumulated in those rocks. It is especially prevalent in clay and smallest quantities of manganese are present in sandy soils. Within the inspected areas the maximum levels of manganese were found in basalt rocks' crusts, its minimal levels were found in alluvial soils where sand prevails (Fig. 3).

According to I. Vazhenin's classification (Definition Methods..., 1987), 70 hectares of land (61.3% of all inspected lands) is slightly and moderately polluted with copper; pollution of 17.3% of soils (30 hectares) is more than average; and 21.2% (24 hectares) of land is either highly or extremely polluted.

As far as zinc concentration is concerned, the soils are mainly slightly or moderately polluted (about 70 hectares), which is about 61.3% of the inspected lands. Pollution of 20 hectares of land (18.4% of the inspected lands) is more than average; 24 hectares of land (21.2% of all inspected lands) is either highly or extremely polluted. 81.5% (93.0 hectares) of inspected soils have a medium or higher than medium manganese pollution levels, 18.4% (21.0 hectares) of inspected soils have a strong manganese pollution level.

As far as total indicators of concentration coefficient are concerned, only 19 hectares of soils' upper layers (0-20 cm) have small pollution levels; 91.0 hectares of the lands are strongly polluted.

Chemical elements are represented in the following diminishing order: Mn > Zn > Cu in slightly polluted soils (pollution concentration coefficient (Hc). In averagely polluted soils' upper layers (0-20 cm) under minimal values of total quantities of pollution concentration (according to values of concentration coefficients) chemical elements are represented in the following diminishing order: Mn > Zn > Cu, the same diminishing order for Zn (n-1) is completely changed when applying maximum values: Cu>Zn>Mn.

In highly polluted soils under minimal and maximum values of Zn (n-1) (according to concentration coefficients), chemical elements show different orders. In the first case (minimal values) they show the following order: Cu > Mn > Zn, but under maximum total values of pollution concentration coefficients that order is changed: Cu > Zn > Mn.

During the last few years the soil characteristics have sharply deteriorated. In some places the ground is covered with whitish/greenish waterproof coats. Porosity of the soil as well as its productivity is diminished. In our opinion, in this case we are dealing with gypsumming. As we found out, limestone is added to the wastewater of the

Madneuli enterprise in order to neutralize acid, after that this wastewater is flowing through the sewer. In that case gypsum is formed, which is flowing into the river and then this water is used for irrigation of agricultural land plots. With the course of time, gypsum is collected on the ground surface and it coats the soil, which worsens aeration and filtration capabilities of the soil, which subsequently causes sharp decrease in its productivity.

Characteristics of averagely polluted soils in the inspected areas according to total values of pollution concentration coefficient: Soil is heavy clay loam, the solid-phase density of the soil (specific weight d) in the cross-section is unnaturally differentiated, it is higher in the ploughed layer (3.53 g/cm), and lower as we go deeper (2.49-2.33 g/cm). Optimal bulk density (dv) of soils, which is 0.90 cm in the ploughed layers, is naturally increased up to 1.18 g/cm. According to the analyzed data, the soil is not consolidated in the lower layers of the ploughed field, which is a very positive factor as it conditions positive indicators of the rest of the parameters. General porosity of the soils in ploughed field and below is very good and the whole cross-section of the soil shows that the conditions for plants are satisfactory (45.3%-64.4%). In that case favorable aeration conditions for plants are created in the soil, favorable hydrologic characteristics are formed and thick and capillary pores are able to keep lots of moisture. This is evidenced by large quantities of productive moisture and high levels of maximum moisture volumes in the fields. The amounts of productive moisture and levels of maximum moisture volumes in the soils are 30.50-51.00% and 19.3-32.7%, which is considered to be the best values for irrigated soils. Fig. 4 shows the average content of heavy metals in soils vertical profile.

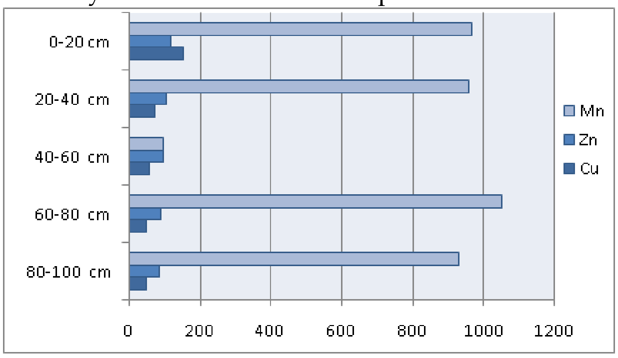

Fig. 4 Average levels of heavy metals in soil profile, mg/kg

Due to low bulk density (dv) and high general porosity (P) the soils have a good filtration capability, water travels 1.5 meter during the twenty-four hour period.

Soils grouped under medium pollution category (soils polluted with Zn(n-1) have satisfactory hydro-physical characteristics. The specific weight of the soil (d) is normal (2.51-2.60 g/cm), and is naturally distributed in the cross-section of the soil. The volume weight (dv) in the cross-section is not high (from 1.18 g/cm to 1.28 g/cm), which is quite acceptable. The levels of maximum moisture volumes in the soil are average. That important hydro-physical component in the ploughed part of the soil is about 3.5%-20%. The range of productive layer is relatively lower (16.9%-25%). As far as filtration ability is concerned, water travels 0.93 meters during the twenty-four hour period, which is not a bad result.

As far as highly polluted soils and their hydro-physical characteristics are concerned, the whole cross-section of the soil indicates that there are no favorable conditions for normal development of plants. According to granulometric analysis results, the soil is a light clay loam, which indicates the presence of heavy metals in it. The specific weight of the soil along the whole cross-section is not optimal (from 2.32 g/cm to 2.47 g/cm). Volume weight of the soil starting from the upper layer of the ploughed soil is pretty high (1.20 g/cm in the ploughed portion up to 1.35 g/cm in the lower portions). That indicates that the soil is significantly solidified, which creates unfavorable hydro-physical conditions for plants. The levels of maximum moisture volumes are not acceptable (19.0%-82.6%). And the amount of productive moisture in the soil is very low (6.0%-20.6%).

Vegetation is a defining factor of geo-chemical processes taking place in the soil. Plants have selective absorption ability. They are able to receive various chemical elements from the soil disproportionately from their composition; in other words, they are able to select the chemical elements which are necessary for their growth. In numbers that phenomenon is reflected in the biological coefficient of absorption. Fig. 5 shows the level of heavy metals in different plants (corn, pumpkin, grapes). Productive moisture is the most important component of the moisture categories existing in the soil. Productive moisture assists the plant to absorb the dissolved substances. Its deficit is acutely felt by crops, which results in deterioration of plants, decreased yields and in many cases death of the plants.

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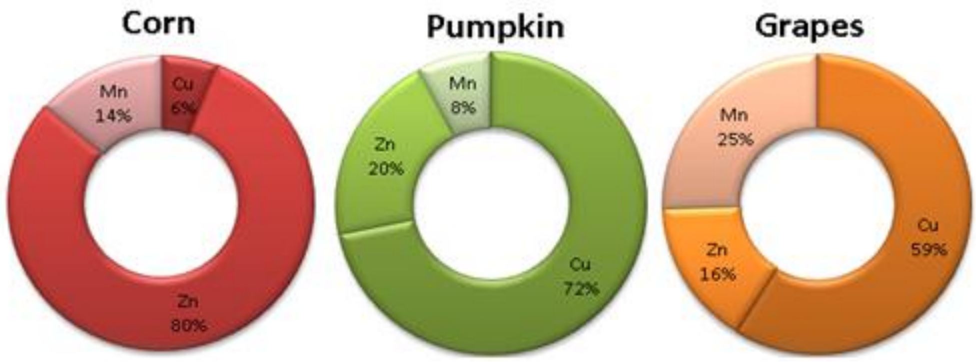

Fig. 5 Levels of heavy metals in plant

Grapes: Cu – 597 mg/kg; Zn – 501 mg/kg; Mn – 979 mg/kg; Pb – 25 mg/kg;
Pupkin: Cu – 682 mg/kg; Zn – 480 mg/kg; Mn – 1150 mg/kg; Pb – 30 mg/kg;
Orchards: Cu – 349 mg/kg; Zn – 250 mg/kg; Mn – 781 mg/kg; Pb – 29 mg/kg

Conclusion

Unfavourable parameters of important agro-physical characteristics in the soil result in sharp decrease in the filtration ability of the soil. In such soils water travels only 0.46 meters during the twenty-four hour period, which creates unfavourable conditions for the plants.

Our research allows us to conclude that pollutant heavy metals – copper, zinc and manganese – have an especially active negative impact on the soil characteristics, its composition and soil-formation processes, which causes the deterioration of hydro-physical potential of the soil. Balanced correlation between solid, liquid and air phases in the soil is violated. The characteristics and quantities of the soil components are changing dramatically; soil is degrading, the vital functions of agricultural crops are disrupted and bio-productivity is falling. The summation of the agro-physical parameters of slightly, averagely and highly polluted soils provides a clear evidence of that.

One of the important anthropogenic factors causing soil degradation is the irrigation of agricultural land plots with water polluted with heavy metals, which results in changed pH. When those heavy metals get into soil, they are absorbed by clay minerals, the carbonate system of the soil is a barrier for them; that is how surface accumulation of metals can be explained.

Among the important factors that increase the concentration of heavy metals in the soil we must also mention the agricultural activities – in particular, increased concentration of copper in vineyards and orchards as a result of use of various copper-based chemical pesticides there. Their movement in the lower portions of the soils is conditioned by the soil pH, volumes of precipitation, relief and other concrete circumstances.

The agro-physical characteristics of the soil are directly connected with the pollution of soil with heavy metals. The cementing processes are taking place in the highly polluted soils, which sharply increases bulk density of the soil, the porosity of the soil deteriorates and water permeability is critically low.

Use and effectiveness of mechanical, physical-mechanical, chemical methods of land reclamation depends on the climatic, bio-climatic, geoecological and soil-edaphon (granulometric composition and structure, humus concentration, absorption volumes, oxidation-restoration potential, pH etc.) factors.

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Author contribution

All works have been executed jointly. Mainly, the field works were supervised by Kalandadze B., while laboratory works – Matchavariani L.

References

Alekseev, Yu.V. (1987). Heavy metals in soils and plants, Moscow, Agropromizdat.

Blume, H.P. (2004). Handbuch des Bodenschutzes: Bodenökologie und belastung. Vorbe ugende und abwehrende Schutzmaßnahmen, Landsberg/Lech, Ecomed, 3rd ed.

BBodSchV (Bundes Bodenschutz und Altlasten-verordnung) (1999): 12. July 1999, Bundesgesetzblatt, Bundesanzeigerverlagsgesellschaft mbH, Köln.

DIN EN ISO 14688 – 1:2003-01 (2003): Geotechnical investigation and testing – Identification and classification of soil – Part 1: Identification and description. Deutsches Institut für Normung, Beuth Verlag GmbH, Berlin.

DIN ISO 10390 2005-12 (2005): Soil quality – Determination of pH. Deutsches Institut für Normung, Beuth Verlag GmbH, Berlin.

DIN ISO 16072: 2005-06 (2005): Soil quality – Laboratory methods for determination of microbial soil respiration. Deutsches Institut für Normung, Beuth Verlag GmbH, Berlin.

Dragicevic S., Nenadovic S., Jovanovic B., Mikanovic M., Novkovic I., Pavic D., & Liesevic M. (2010). Degradation of Topciderska River Water Quality (Belgrade). Carpathian Journal of Earth and Environmental Sciences, 5(2), 177 -184.

Felix-Henningsen, P., Urushadze, T., Narimanidze, E., Wichmann, L., Steffens, D., & Kalandadze, B. (2007). Heavy metal pollution of soils and food crops due to mining wastes in an irrigation district south of Tbilisi, eastern Georgia. Annals of Agrarian Sci., 5(3), 11–27.

Grabic J., Bezdan A., Benka P., & Salvai A. (2011). Spreading and transformation of Nutrients in the reach of the Becej-Bogojevo Canal, Serbia. Carpathian Journal of Earth and Environmental Sciences, 6(1), 277 -284.

Hanauer, T., Felix-Henningsen P., Steffens, D., Kalandadze, B., Navrozashvili, L. & Urushadze, T. (2010). In situ stabilization of metals (Cu, Cd, Zn) in contaminated soils in the region of Bolnisi, Georgia. Plant Soil, published online: DOI 10.1007/s11104-010-0634-5.

Kabata-Pendyas, A., & Pendyas, H. (1989). Microelements in soils and plants, Moscow, Mir.

Matchavariani, L. (2011). Time factor in soils of Georgia – mirror or memory of landscapes? Journal of Environmental Biology, 33(2), 393-400.

Pantelici, M., Dolinaji, D., Savici, S., Stojanovici V., & Nad, I. (2012). Carpathian Journal of Earth and Environmental Sciences, 7(2), 255 -264.

Vinogradov, A. (1957). Geochemistry of rare and absent-minded chemical elements in soils. Moscow, ASUSSR.

Vazhenin, I. (1987). Methods of Definition the microelements in soils and plants. Moscow, Kolos, 1987