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Assessment of the Soil Cover Quality in the Adjacent Areas to Landfills Based on the Study of Changes in Heavy Metals Concentration

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ABSTRACT

Heavy metals are an urgent environmental problem, since their high concentrations have a negative impact on soil chemistry. Solid domestic waste landfills are a direct source of heavy metals accumulation in soils. Landfills pollute and poison large areas around them. Heavy metals are concentrated in the surface layer of the soil 0–10 cm deep, and can later migrate into plants and further into living organisms. The article examines soil pollution by the total content of heavy metals (Pb, Cd, Cu, Zn, Ni, Co, Mn) in the areas adjacent to Tbilisi and Telavi (Georgia) landfills and on illegal landfill in the village of Anaga (Sighnaghi municipality). The results show that the soil cover of the territories adjacent to solid domestic waste landfills and illegal landfills is contaminated with heavy metals. The data obtained confirm the migration of heavy metals mainly in terms of the distance from the landfills. High concentrations of heavy metals in soils are characteristic of lead and cadmium. There is also a tendency towards a decrease in the content of lead, cadmium, copper, zinc with distance from the landfill of solid domestic waste.

Keywords: soil pollution, heavy metals, concentration, polygon, illegal landfill.

INTRODUCTION

Household, industrial and agricultural waste contains toxic chemicals. As a result, the soil on which debris was located becomes unsuitable for further use. Landfills for solid domestic waste (SDW) occupy large areas and are dangerous sources of environmental pollution. Heavy metals constitute some of the known hazardous chemicals that always find their way into the landfills. As such, they are always a subject of study for landfill as markers of landfill-linked pollution. These are more serious,ince they do not decompose as opposed to the organic counterparts that, despite some being persistent, do end up being decomposed at some point [Moshoeshoe et al., 2018]. Solid waste landfills are a direct source of heavy metals accumulation in soils. Landfills pollute and poison soils, grounds and groundwater to great depths and over a large area. Even in the absence of fires, the landfill pollutes the atmospheric air due to the emission of extremely toxic gases from the landfill body, which are formed during the anaerobic decomposition of organic matter, as well as the spraying of a fine fraction of the landfill material under the influence of wind. Thus, a solid waste landfill can have a detrimental effect on distant areas and, accordingly, on the population [Popova, 2015].

Heavy metals are not only pollutants, but also natural micro components of soils. Their contents are caused by the mechanical and chemical composition of the soil breed and also by the nature of soil creating processes. The background maintenance of these elements corresponds to their natural concentration in various soil and climatic zones which are not under any anthropogenic influence. The elements of anthropogenic processes are always in the soil and the question of background maintenance can be considered only conditionally, as this total background has both a natural and anthropogenic component [Blokhina et al., 2019].

The forms of finding HM in household waste are quite diverse. They are presented in the form of pure metals or their alloys, as well as stearates, acetates, molybdates, sulfur compounds, chlorides or oxides. For example, copper is formed exclusively from wood, printing ink, electrical wires, and electronic materials. Zinc is formed mainly from batteries, leather and rubber. Sources of lead are batteries, electrical wires, paint for painting or dyes for plastics, and PVC. Cadmium is mainly used as a stabilizer in the manufacturing of polyvinyl chloride, it is also present in electrode batteries, semiconductors, photographic films and electrical equipment [Egorova et al., 2013]. Considering how many people use it and how much it accumulates in landfills, then the problem is serious.

Heavy metals, as a rule, are concentrated in the near-surface soil layer with a depth of 0–10 (20) cm, where they are present in the form of exchangeable ions and in a non-exchangeable form, firmly fixed by the soil absorbing complex. The proportion of the water-soluble form is usually small, however, with severe pollution; the absolute amount of water-soluble HM becomes an independent environmentally hazardous factor. Subsequently, HM can migrate into plants, enter rivers and lakes as a result of washout, and then, through trophic levels, into living organisms. The accumulation of heavy metals in the soil disrupts the physicochemical balance of the natural system and gives impetus to a number of processes affecting soil properties. The pH value changes, the soil absorbing complex is destroyed, microbiological processes are disturbed, as a result of the destruction of the structure, the water-air regime worsens, the soil humus degrades, and ultimately the soil loses its fertility [Zherebtsov et al., 2014]. In Georgia, there are no approved standards that determine the values of MPC for heavy metals in soils. Taking into account the experience of normalizing the content of heavy metals in the EU countries, it is proposed to select the MPC for Georgia, taking into account the ecological danger of each metal. As a criterion of danger, it is proposed to use the data on maximum permissible additives (SDA) determined by Dutch ecologists. For highly dangerous Cd, it is suggested to use the minimum value of the MPC used in the EU. For low-risk metals – Zn and Pb –the maximum values of MPC used in the EU were employed. For moderately hazardous, i.e. Cu and Ni, the average value of the MPC used in the EU was adopted [Bakradze et al., 2018].

The purpose of this study was to assess the ecological state of soils based on the estimation of the concentration of heavy metals (HM) in the soil cover in the adjacent areas of various types of landfills in Georgia. In addition, the patterns and distribution of these pollutants at various proximities to landfills, according to the polar seasons of the year, were established.

STUDY AREA

The objects of the research were selected: an open sanitary landfill for solid domestic waste in the cities of Tbilisi and Telavi; illegal landfill in the municipality of Sighnaghi, Anaga village (Fig. 1). The Tbilisi solid waste landfill is located in the village of Lilo, Gardabani municipality (Fig. 2). The landfill area is 84 hectares, the year of opening is 2011. The Lilo landfill is located around the densely populated villages of Didi Lilo, Nasaguri, Norio and Tsinubani. The Telavi solid waste landfill (landfill area 10 hectares, opened in 2013) is located on the banks of the Turdo River, one and a half kilometers from the village of Gulgula (Fig. 3) Bank protection works were carried out on the Turdo river to eliminate the risk of waste entering the river in case of floods.

The main locations of illegal landfills are the areas adjacent to densely populated villages. For the most part, illegal dumps are located uncontrollably in ravines, canals, riverbeds. They are not isolated from the environment and the waste that is discarded into them is a serious source of environmental pollution. The gorge dividing the Anaga village in

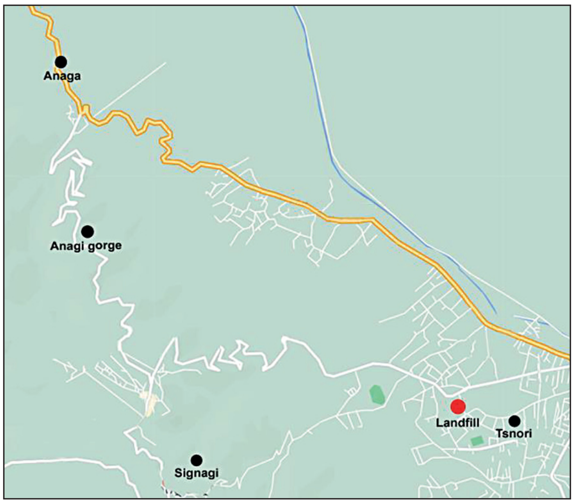

Figure 1. The map illegal landfill of the Anaga village

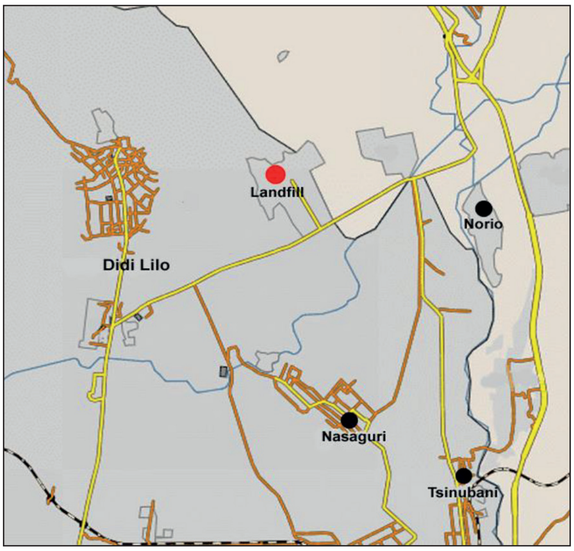

Figure 2. The map landfill of Lilo

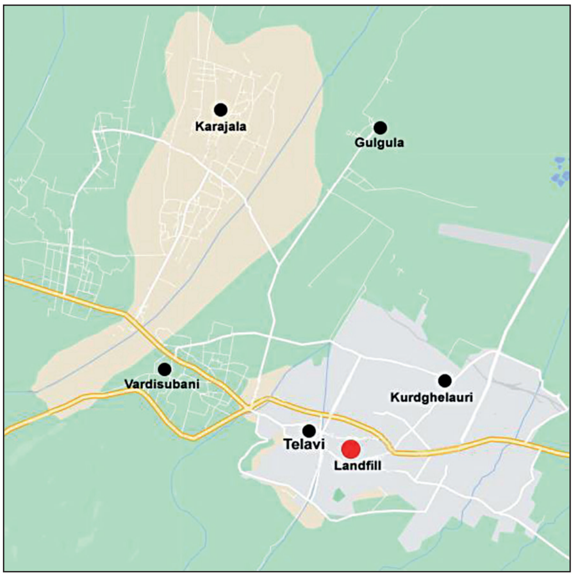

Figure 3. The map landfill of Telavi

the Sighnaghi municipality into two parts has been used as a dumping ground for many years. Unsanitary conditions are a source of environmental pollution and various infections that pose a threat to human health, especially during hot months.

METHODOLOGY

To assess the impact of landfills on the quality of the soil cover, environmental monitoring was carried out in the adjacent territories and physical and chemical studies were carried out. To take soil samples, the instructions for soil sampling, developed by the authors of this paper – in accordance with the international standard for soil sampling ISO 10381-8:2009. Soil quality. Sampling (Soil quality. selection of samples) – were adopted. For the pretreatment preparation of soil samples, the standard operating procedure (SOP) "Pretreatment preparation of soil samples for physical and chemical analysis" was used, which was developed in accordance with the international ISO standard 11464: 2006 « Soil quality - Pretreatment of samples for physico-chemical analysis").

Monitoring was carried out for the polar seasons of the year (winter and summer). To study the degree of soil contamination with HM, the samples were taken at different (250, 500, 1000 m) distances from the polygons, in the direction of the prevailing winds. The samples were taken from a depth of 0–5 cm, each weighing no more than 100 g. The area of soil sampling and its size depended on the soil cover, topography, geology and hydrology of the study area. Point samples at the test site were taken by using the envelope method. A pooled sample was made by mixing from five spot samples taken from one sample site. The soil samples were collected, dried, ground and passed through a 1 mm sieve. Afterwards, 10 g air-dry soil was weighed in a 250 ml conical flask and moistened by bidistilled water. Then, 40 ml of a mixture of HNO_3 and HCl (1:3) was carefully added to avoid any losses in the course of the reaction with the organic matter of soil. The sample was heated for 3 h on a sand bath. After cooling, it was transferred into a 100 ml flask and brought to volume with bidistilled water. The HM content in samples was measured, using flame atomic absorption spectrophotometry (spectrophotometer of firm Perkin-Elmer AAnalyst 200) in accordance with ISO 11466 and GOST P 53218-2008. The reagents used in the experimental studies had the qualification "analytical-grade", standard samples of the composition of solutions of metals of the GSO series and multi-element standard solutions ICP-MS-68A-A CP-MS-68A-B and ICP-MS-68A-C were used. [Kekelidze et al., 2017].

To determine the degree of soil pollution with heavy metals, the data obtained were compared with the standard concentrations of metals. Table 1 below presents the standards of the studied heavy metals for soils.

To determine the extent of soil pollution, the content of elements was compared with the TPC

Table 1. Standards for Tentative Permissible Concentrations (TPC) for Georgia. Clarke, gram/ton of the earth's crust, according to S. Taylor and P. Vinogradov TM, for soils

HM	TPC, mg /kg, considering background	Clarke, gram/ton of the earth's crust to S. Taylor (1964)	Clarke, gram/ton of the earth's crust to P. Vinogradov (1962)
Pb	32	12,5	16
Cd	0.5-2.0	0.2	0.13
Cu	132	55	47
Zn	220	70	83
Ni	80	75	58
Co	-	25	18
Mn	-	950	1000

or Clarke content of elements in the Earth's crust. The concentration factor of the pollution hazard is expressed by the formula:

$$C_p = C_r/\mathrm{TPC} \quad (1)$$

where: C_p is the concentration factor of the pollution risk; C_r is the real concentration of the element; TPC is Tentative Permissible Concentration.

The higher the C_p coefficient by 1, the higher the risk of negative soil contamination. Compared to Clarke, the soil is considered slightly polluted if the ratio of elements to Clarke is less than 10, and heavily polluted if the value than 30 [Supatashili, 2009].

RESULTS AND DISCUSSION

As part of the environmental monitoring, the soil of the above-mentioned territories was studied to determine the contents of the following heavy metals: Pb, Cd, Cu, Zn, Ni, Co, Mn.

Table 2 below shows the total contents of heavy metals (C, mg/kg) in the soil cover samples at different distances from the landfills (D, m) by polar seasons of the year (winter, summer). Figures 4–6 present the histograms of changes in the total content of heavy metals at different distances from the landfill for the polar seasons of the year (winter, summer).

Table 2. Total content of heavy metals in the soil cover

Research area	Season	D, m	*C,mg/kg*						
			Pb	Cd	Cu	Zn	Ni	Co	Mn
Lilo	Winter	250	250.0	7.0	110.0	230.0	30.0	19.0	1400
		500	152.0	3.8	90.0	150.0	20.0	14.0	1200
		1000	62.0	1.4	65.0	70.0	18.0	13.0	1400
	Summer	250	290.0	10.0	180.0	250.0	30.0	25.0	1400
		500	240.0	5.4	100.0	170.0	20.0	18.0	1200
		1000	96.0	1.9	85.0	80.0	20.0	15.0	1400
Telavi	Winter	250	200.0	8.9	86.0	129.0	35.0	31.0	1700
		500	160.0	6.4	78.0	103.0	30.0	26.0	1700
		1000	68.0	1.4	47.0	73.0	18.0	23.0	1800
	Summer	250	230.0	10.0	150.0	231.0	40.0	33.0	1720
		500	200.0	8.0	95.0	140.0	30.0	29.0	1800
		1000	89.0	2.9	60.0	80.0	20.0	27.0	1700
Sighnaghi, Anaga village	Winter	250	19.0	7.9	179.0	60.0	29.0	20.0	1300
		500	35.0	1.4	80.0	83.0	35.0	20.0	1250
		1000	13.0	0.5	45.0	56.0	20.0	18.0	1050
	Summer	250	40.4	20.0	20.2	230.0	20.0	21.0	1350
		500	30.0	1.5	40.0	80.0	30.0	23.0	1100
		1000	12.0	0.6	47.0	60.0	20.0	19.0	1000

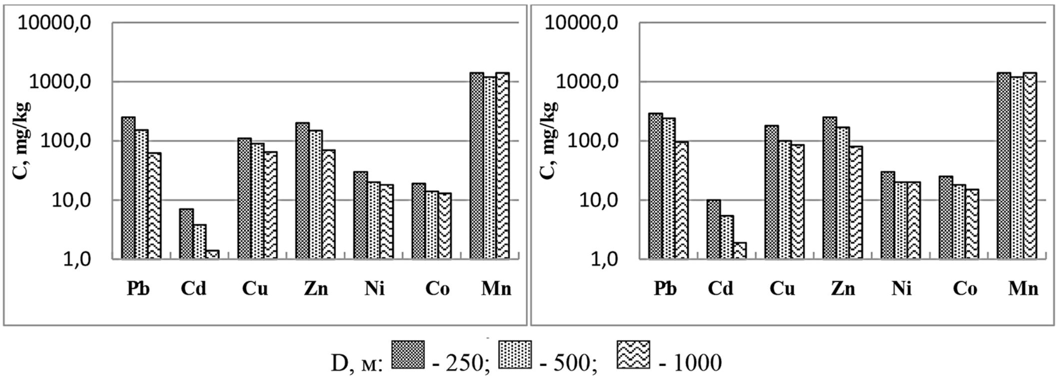

Figure 4. Histogram of changes in the total content of heavy metals at different distances from the Lilo polygon for the polar seasons of the year in winter 2020 (left) and summer 2021 (right)

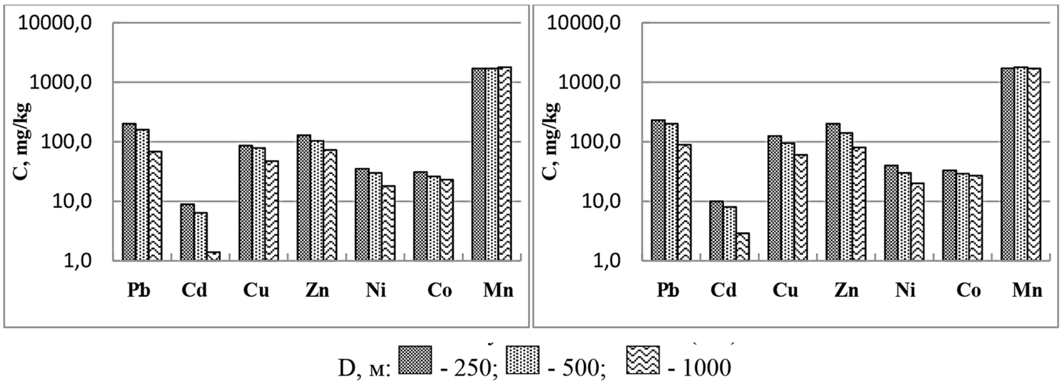

Figure 5. Histogram of changes in the total content of heavy metals at different distances from the Telavi polygon for the polar seasons of the year in winter 2020 (left) and summer 2021 (right)

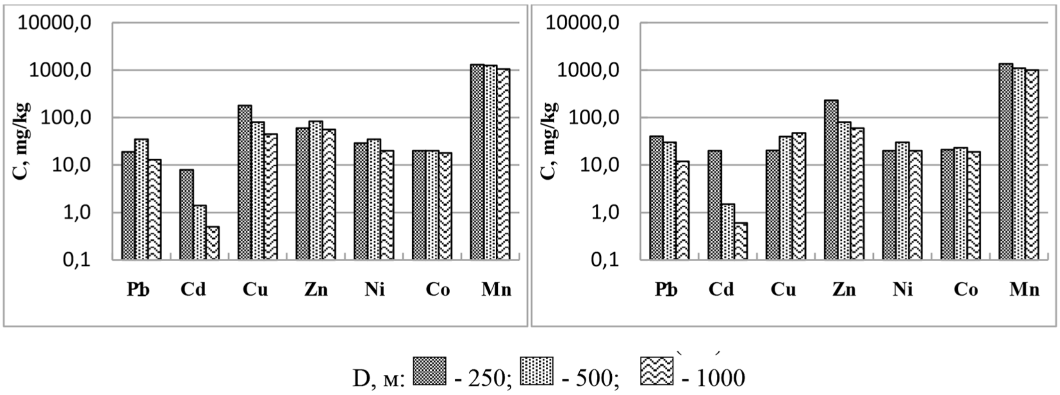

Figure 6. Histogram of changes in the total content of heavy metals at different distances from the Anaga landfill for the polar seasons of the year in winter 2020 (left) and summer 2021 (right)

Soil pH (ranges from 5.5 to 8.7) significantly affects the solubility and mobility of heavy metals, since most of them are soluble in acidic soils, rather than in neutral and slightly alkaline soils. The Pb concentration in the winter season in the soil covers at a distance of 250 m is 250 mg/kg ($C_p = 7.8$), at a distance of 500 m is 152 mg/kg ($C_p = 4.75$), at a distance of 1000 m, it decreases to 62 mg/kg ($C_p = 1.9$). In the summer season 290 mg/kg ($C_p = 9$), – 240 mg/kg ($C_p = 7.5$), – 96 mg/kg ($C_p = 3{,}3$). The concentration of Cd in the winter season in the soil covers at a distance of 250 m is 7.0 mg/kg ($C_p = 3.5$), at a distance of 500 m 3.8 mg/kg ($C_p = 1.9$), at a distance of 1000 m it decreases to 1.4 mg/kg. In the summer season 250 m – 10.0 mg/kg ($C_p = 5$) – 5.4 mg/kg ($C_p = 2.7$) – 1.9 mg/kg (permissible norm). The concentration of Cu in the winter season in the soil cover at a distance of 250 m is 110 mg/kg (permissible norm), at a distance of 500 m is equal 90.0 mg/kg (permissible norm), at a distance of 1000 m it decreases to 65 mg/kg (permissible norm). In the summer season – 180 mg/kg ($C_p = 1.4$) – 100 mg/kg, 85 mg/kg is permissible norm.

The data obtained confirmed the migration of HM mainly in terms of the distance from the polygon. Such a distribution of these metals can be explained by their areal emissions and storage in the open state, they could also infiltrate into the soil cover under the influence of natural processes, such as wind and precipitation. The concentration of Pb, Cd, Cu, and Zn always increases nearer the landfill and decreases further from it. High concentrations of Pb, Cd are characteristic of the soil covers of the adjacent territories around the landfill at a distance of 250, 500 meters, and they are a dangerous zone, since they can later migrate into plants, enter rivers and lakes. A similar tendency of changes in the HM content in the process of moving away (250, 500, 1000 m) from the landfill according to the polar seasons of the year are also observed at the Telavi polygon. Distribution of the total HM content in the territories adjacent to the illegal dump with Anaga has a mosaic character, and for this reason it is rather difficult to give an ecological assessment of the impact of HM. Some areas at a distance from the dump up to 250–500 m are contaminated with Pb, Cd, Cu, and Zn. The reasons for this spread of pollution are, firstly, the complex nature of the territory, which allows local winds to carry aerosol emissions of heavy metals from the landfill and secondly, the clay and loamy composition of soils, which actively adsorb Pb and Cd. Of particular note are the high content of Mn and the low content of Ni and Co according to S.R. Taylor's Clarke in soils. For these metals, there are no clear distribution patterns with distance from the polygon. This fact indicates their natural and not anthropogenic origin in soils. In comparison with S.R. Taylor's Clarke, the soil covers at distances of 250 and 500 m from the Lilo, Telavi polygons and the illegal landfill of the Anaga village turned out to be heavily contaminated with cadmium (> 30) in both winter and summer.

CONCLUSIONS

The results of the study showed that the soil cover of the territories adjacent to solid domestic waste polygons and landfill are contaminated with heavy metals. HM have a high capacity for a variety of chemical, physicochemical and biological reactions. Almost all of them have a variable valence and take part in redox processes. HM and their compounds are able to move, i.e. migrate. The data obtained presented in the work confirm the migration of HM mainly in terms of the distance from the polygons. High concentrations of heavy metals in soils are characteristic of lead and cadmium. There is also a tendency for the content of lead, cadmium, copper, zinc to decrease with distance from the solid domestic waste polygon. For nickel, cobalt and manganese, there are no clear patterns of distribution in terms of distance from the polygon. This fact indicates their natural, rather than anthropogenic origin in soils. The soil cover of the adjacent territories around the landfills at distances of 250 and 500 meters is a dangerous zone of contamination and poses a risk of soil contamination with heavy metals. The next stage of this study will be the development of a program for monitoring the environment around landfills, which includes periodic studies of territories with sampling of soil, ground and surface water, as well as plants that accumulate.

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