



Heavy Metal Content in Roadside Soils in Some Settlements of Eastern and Southern Georgia

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SUMMARY

The paper discusses scientific results obtained in recent years on the content of heavy metals in soils located along highways in the eastern and southern regions of Georgia. It is shown that their levels vary significantly across regions. The exceedances of permissible levels for individual metals are estimated by region. The authors consider periodic monitoring to be necessary in regions where metal levels are well above the maximum permissible limits.

Keywords: Georgia, Caucasus, ecology, geochemistry, heavy metals.

INTRODUCTION

It is known that soil is the source of life, that it is a mixture of minerals and organic substances that determines the germination and growth of plants. Soil affects the food that not only animals but also humans eat; it affects the drinking water that people drink; the air that people breathe; It also affects the origin of flora, fauna, and ultimately human health. Therefore, its pollution causes chain reactions and negatively affects other components. With the growth of industrialization, the harmful effects of industrial waste on the environment are significantly increasing, especially on water and soil, where heavy metals accumulate. Serious worldwide contamination of soil and water by heavy metals is a significant issue. Dealing with soil contamination involves considerable time, resources, and exertion.

Soil is a particularly informative component of the landscape because it is formed by the interaction of all other elements of the landscape. Thus, all anthropogenic and natural processes occurring in a particular ecosystem are reflected in the soil (Felix-Henningsen et al., 2007; Kalandadze and Matchavariani, 2019). The three important components that plants absorb from the soil are: water, nutrients, and air. As the population grows, the demand for food increases, which cannot be produced without soil. Healthy soil means healthy food, so it is important to pay close attention to caring for the soil and its fertility, especially today, when the problem of soil pollution is so urgent throughout the country.

Soil typically contains a range of naturally occurring heavy metals. However, heavy metals produced by human activity can reach concentrations that lead to increased risk of exposure. Therefore, targeted cleanup methods are necessary. Soil generally includes various naturally occurring heavy metals. Concentrations of heavy metals from human activity can rise to levels that enhance exposure dangers. Targeted cleaning techniques are thus required.

The three main metals found in contaminated soils are lead, arsenic, and cadmium. Arsenic can be naturally present in phosphates used as fertilizers. Cadmium is enriched during zinc mining. Finally, lead can enter the soil from leaded gasoline and paint. Soils can have naturally high background levels as a result of decades of gasoline burning and peeling lead paint from old buildings. Heavy metals are highly carcinogenic; Arsenic causes skin cancer because it binds to proteins in skin tissue and destroys them. Lead affects brain development. Cadmium promotes the development of kidney cancer and also disrupts bone development. This circumstance becomes especially relevant for soils located along highways and repair facilities.



The active movement of macro and micro elements depends on the physicochemical form of the soil and the state of the local environment. The migration of metals in soil has various factors, and different keys may be adapted for the soils of each region, which are characteristic only for a certain region. To find this key, a complete study of the physicochemical characteristics of soils is necessary (G.Avqopashvili, 2016).

The behavior of heavy metals in soil also depends on its oxidation-reduction conditions and acidity. The migration capacity of Cu, Ni, Co, and Zn in a reducing environment is reduced by 1-2 orders of magnitude compared to an oxidizing one. In an acidic environment, most metals are more mobile. The most unfavorable conditions in this regard arise in ash soils, which have unfavorable physical and chemical properties due to increased acidity and the content of aluminum ions in the soil absorption complex (SAC). These conditions contribute to the transition of metals into biological tissues, increased migration of heavy elements, deterioration of the vital activity of nitrifying and nitrogen-fixing bacteria, and often cause a decrease in soil fertility.

SAMPLING METHODOLOGY

In recent years, particular attention has been paid to the problem of environmental pollution by heavy metals and other toxic elements. Due to the increasing scale of man-made environmental pollution, a number of heavy metals and toxic elements have been included in international and domestic lists of pollutants subject to monitoring.

Selecting the appropriate packaging material to prevent heavy-metal contamination of field-collected samples warrants careful attention. Soil samples were placed in bags made of bleached cotton fabric. Wet samples were collected in polyethylene bags and, upon return from the field, were immediately dried in a ventilated room.

Soil sampling was conducted in accordance with the requirements for sampling in cases of general and localized contamination, as well as the "Methodological Guidelines for Conducting Field and Laboratory Studies for Monitoring Environmental Metal Contamination". Soil samples were collected twice a year: in summer and autumn. Soil sampling for heavy metal contamination monitoring was carried out over a period of two years.

As we were interested in soil contamination along highways, samples were collected from soil located no more than 25 meters from roads situated near populated areas. Each composite sample consisted of at least five individual point samples taken from a sampling plot established at a distance of at least 2 meters from the central sampling point. When collecting soil samples with a spade, the sampling points were arranged in a "quincunx" pattern (four points at the corners of the plot and one in the center). Additional sub-samples were taken around each of the five points; thus, the composite sample comprised multiple individual point samples.

Heavy metals in the soil were determined using atomic absorption spectrometry with flame and flameless atomization.

Factual material and its evaluation

The aim of this study was to investigate the content of chemical elements (mainly heavy metals) in soils of southern and eastern Georgia, located along major highways. Analyzing this material will allow us to assess the degree of soil contamination in particularly sensitive areas.

Sampling was carried out along roads and highways (max. 25m apart) in and between all settlements (Fig. 1) to create a complete picture of the chemical state of the soil. Samples were collected from a depth of 5 to 35 centimetres. The sample was placed in a special sampling bag, which was transported to the laboratory. An average sample was prepared in laboratory conditions. Then, it was dried, cleaned, and the heavy metals in it were determined. The determination of heavy metals in soil is carried out as follows: roots, stones, and various foreign impurities are removed from a dried soil sample.



Fig.1. Soil sampling process near a highway

Heavy metal pollution has the highest environmental pollution index. The main factors causing soil pollution are subject to anthropogenic impact: industrial production, ore or oil extraction, electricity generation, industry, transport, utilities, agricultural activities (farming, livestock farming), household waste (landfills), acid rain, etc. (Ainsworth C.C. et al. 1994.; Kuparadze D., Pataridze D. 2024). However, as practice shows, in large industrial cities, the main source of environmental pollution with lead, zinc, and cobalt is automobiles. 260 thousand tons of lead are deposited on Earth annually through transport emissions, which is three times the amount of lead deposited in the soil from metallurgical plants (Guo G. et al., 2006).

The maximum permissible concentrations (MPC) and norms of heavy metals in soil according to Georgian legislation are: for copper (Cu) 132 mg/kg (ppm), for manganese (Mn) 500 mg/kg, for cadmium (Cd) from 0.5 to 2 mg/kg, for lead (Pb) 32 mg/kg, for zinc (Zn) 300 mg/kg, for nickel = 40 mg/kg, and for Co = 8 mg/kg. (On Approval of Environmental... Norms. 2001).

Copper tends to concentrate primarily in the uppermost several centimeters of soil, where it adsorbs and binds with organic matter, carbonates, manganese, and iron to form compounds. The behavior of Cu in soil is highly dependent on the compounds and species present in the soil. The concentration of Cu in the soil solution should range from 0.5 to 135 $\mu\text{g/L}$. Soil contamination with copper compounds has been the subject of detailed research for several years (G. Avqopashvili, A. Gongadze. 2022; D. Kuparadze, D. Pataridze. 2024, 2016; M. Kvinikadze et al. 2006, D. Pataridze et al. 2023.).

Recently, significant sources such as fertilizers, sewage sludge, agrochemicals, industrial products, wastewater, and irrigation water have contributed to the increase in copper levels in agricultural soils. Today, copper-containing pesticides - copper chloride, sulfate, and hydrogen oxide - occupy a large place in the integrated plant protection system in agriculture. According to official data from importing companies, these pesticides always contain various heavy metals as impurities, including arsenic ($<20 \text{ mg/kg}$). Accordingly, tens of tons of arsenic may be intentionally applied to agricultural land every year, along with the necessary pesticides. The situation is similar with mineral fertilizers.

Highly elevated Cu levels are observed in soils near copper mines and factories producing its alloys. In Georgia, highly contaminated soils with copper are observed in agricultural areas surrounding Kazreti, where the Madneuli deposit is being processed (Fig.2.).

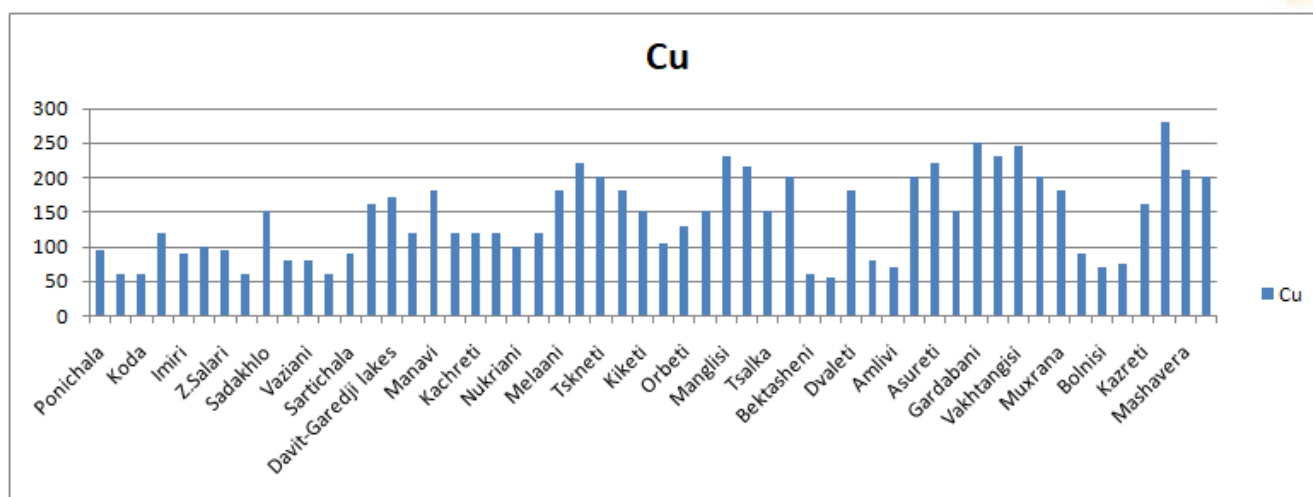


Fig. 2. Copper contents in the areas of the our studied settlements

This circumstance has led to the accumulation of copper and various metals in recent years, both in agricultural soils and especially in soils along highways. The soils of the villages of Ratevani and Nakhiduri have a very high content of heavy metals. The results obtained showed that copper is increased in the Abulmulk area, as well as in Kazreti and Balichi. According to data from these years, their composition is even close to that of ore-bearing soils. Pollution of roadside soils in these villages is mainly the result of absorption of industrial dust particles into the soil. Copper pollution is also observed in the Rustavi region and especially in the Gardabani area, which can be explained by the presence of various types of large-scale industrial facilities (metallurgical, chemical, etc.) in the region. High concentrations of Cu are also observed along roads in cities, especially in the outskirts of Tbilisi. This can be explained by the intensity of traffic.

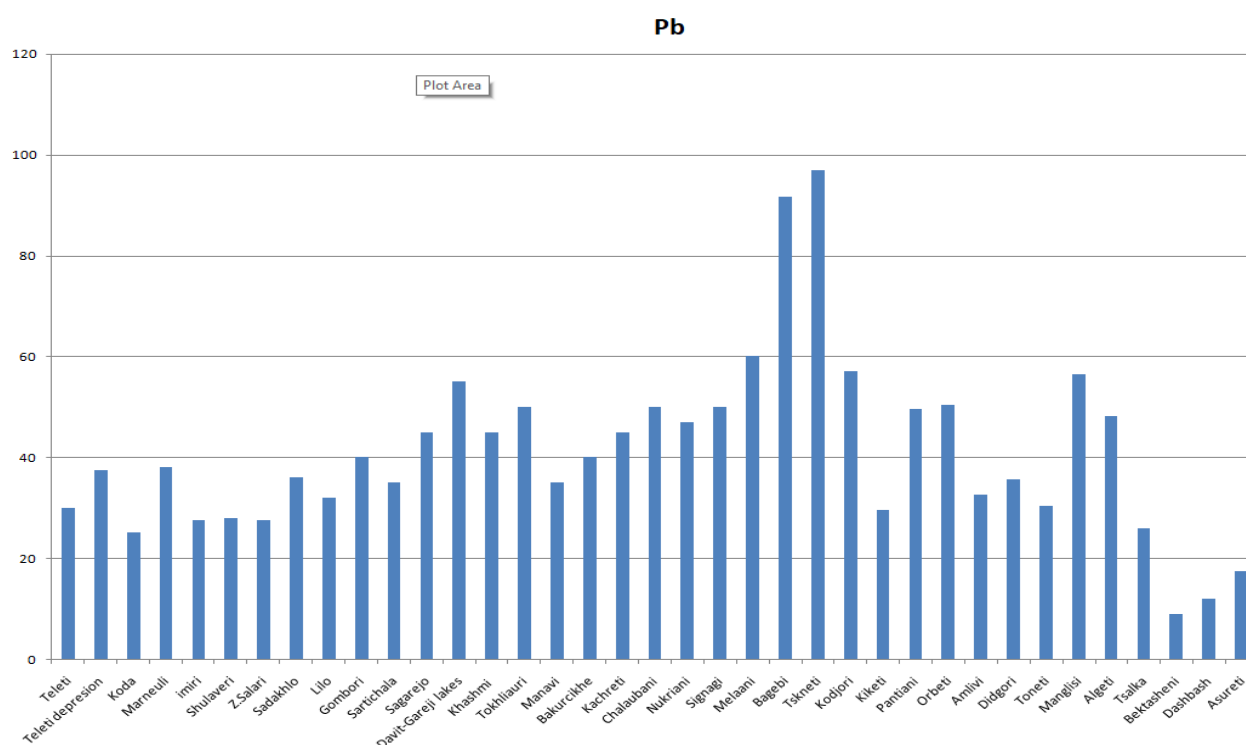


Fig. 3. Lead content values in the areas of populated villages and cities we studied.

After analyzing the graph (Fig. 3) (where the content of chemical elements is given in mg/kg), we can conclude that lead pollution along roads is observed in almost all settlements and reaches particularly severe pollution in the vicinity of Tbilisi. Elevated levels of lead are also found along all transportation highways, in and between cities, and in some old mining and industrial areas. Lesser, but still significant, pollution is

observed in some areas of Kakheti (Sagarejo district) in eastern Georgia. For example, the lead content in a roadside sample from Telavi was found to be equal to 1.7 ppm. As is known, this part of Georgia is known for its abundance of agricultural products, the most important of which is grape and wine production. Therefore, attention should be paid to the use of poor-quality transport fuel in this region and possibly other conditions in order to eliminate this problem in this important region.

Samples were taken from the villages of Aspindza and Akhaltsikhe in southern Georgia, and showed lead levels of 110 and 155 mg/kg, respectively, which significantly exceed the maximum permissible levels.

When analyzing laboratory data, to our surprise, in those regions of southern Georgia (Orbeti, Manglisi, Algeti), where, according to our research, “absolutely clean environmental conditions” should exist, lead contamination is observed along and near highways. This circumstance surprised us, but it seems that these results must be caused by the use of poor-quality and uncontrolled fuel for many years, which has existed in this region for many years, and it should also be noted that these roads still constitute a significant source of heavy traffic in the Georgia-Armenia and Georgia-Turkey directions.

Lead contamination is also observed in roadside soils in the Bolnisi region. Horticulture is well developed in this region. The Mashavera and Poladauri rivers, which are polluted by industry, are used in the reclamation system, the water of which is practically everywhere. Vegetables absorb large amounts of cancer-causing heavy metals – lead and cadmium. These products enter the market without any control. This problem poses a great threat to both local and urban populations, which rely on these vegetables for their supply.

Zinc is a vital microelement for both plant development (it aids photosynthesis) and the human body. However, both its deficiency and excess in the soil have a negative impact on the quality of the environment and the food chain.

Zinc (Zn) contents in roadside soils in the southern and eastern regions of Georgia are diverse and depend on the region, soil type, and anthropogenic factors. In general, the natural amount of zinc in the soil varies, although both a deficiency of this microelement and its alarming, toxic increase have been detected throughout the region.

Studies examining soil ecology in the Samtskhe-Javakheti and Kakheti regions show that household trash and unmanaged landfills pollute the soil with heavy metals, such as zinc.

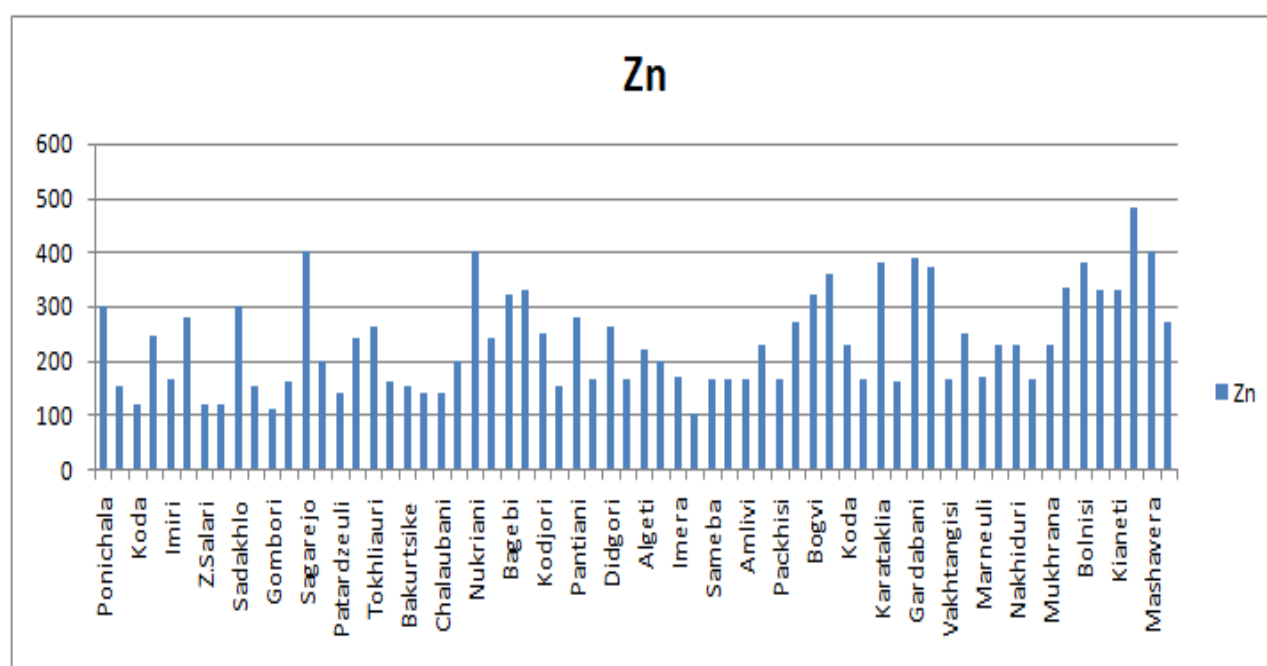


Fig.4. Zinc contents for some settlements

Zinc levels exceeding the maximum permissible values (Fig. 4) are observed in the Kakheti region of eastern Georgia in the villages of Sagarejo and Nukriani and the Signaghi region. Further south in the Marneuli-Karajala areas. For example, in the village of Nukriani, copper and zinc concentrations exceeded the maximum permissible concentrations by almost 3 times.

Zinc concentrations have also increased in the Tbilisi area, for example in areas such as Bagebi and Tskneti. However, the most polluted area appears to be the Bolnisi region in southeastern Georgia, and especially the areas surrounding the village of Kazreti, where the Zn content in some places reaches 500 mg/kg. This situation can probably be explained by the proximity of the gold-copper-polymetallic deposit and the processing plant. Here, zinc is very high and equals: in Abulbuk (1076 mg/kg; norm is 300 mg/kg) and in Ratevni (1014 mg/kg). And in the samples near Balichi and Kvemo Bolnisi, its concentration exceeds the maximum permissible concentration in the first case by 219 units (519.82 mg/kg), and in the second case – by 15 units (315 mg/kg) (Fig.5)

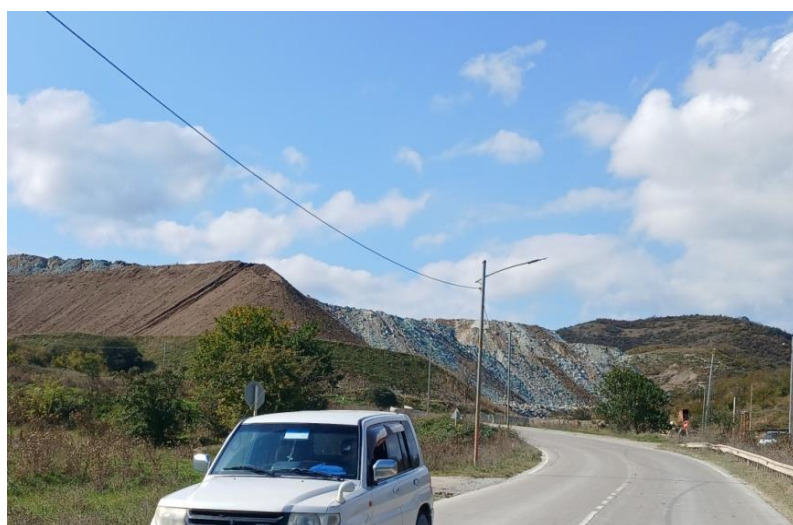


Fig.5. Abulmulk. Sakdrisi. Bolnisi district.

The photo was taken by us near the new gold-copper-polymetallic processing quarry, on the side of the main road.

As is known, cadmium is in the same group in the periodic table as zinc and mercury and occupies an intermediate position between them, which is why some of the chemical properties of these elements are similar. The sulfides and oxides of these elements are practically insoluble in water, and therefore their transport by water currents is less noticeable. Cadmium (Cd) concentrations in the samples we collected along the roads are generally equal to the upper limit of permissible values.

For eastern Georgia, this element shows the highest values around the city of Sagarejo, in the Kakheti region, and there it exceeds the permissible values twice. It is also worth noting the 5-fold higher (10.7 mg/kg) levels of this element along the roads of the village of Ruisbolo (near the border with Azerbaijan) in the Gardabani region. In roadside soils in southeastern Georgia (Fig. 6), Cd exceeds permissible limits, putting several villages at high ecological risk. This is especially noticeable for regions such as the copper-gold-polymetallic processing complex and quarries in the Bolnisi district. Their values there are: Tsugrugasheni-3.9 mg/kg; Ratevani-3.55 mg/kg; Balichi-2.85 mg/kg; Kveshi-3.2 mg/kg.

It is worth noting that roadside soils are also characterized by medium and high cobalt contamination factors. High cobalt contamination coefficient (from 6 to 20 mg/kg) is observed in the Kakheti region on the S5 highway from Manavi to Tsnori. (D.Pataridze et., 2026). The road leads to the Lagodekhi border crossing (border with Azerbaijan). It is likely that this is an echo of the presence of the 430th engineering ammunition depot of the Transcaucasian Military District in Sagarejo.

Nickel concentrations in roadside soils correspond to the low and medium levels of the maximum permissible levels. Its doubled value is observed only in Tbilisi's wet areas, in Bagebi.

The main anthropogenic sources of manganese in the environment are industrial activities such as metal smelting and processing, agriculture (use of fertilizers, fecal waste, etc.), the presence of transport infrastructure, and atmospheric emissions from the burning of petroleum products and waste. As is known, Georgia is known for its large manganese deposits. Therefore, the issue of transporting and exploiting manganese ore, once it begins to be mined, is one of the most difficult aspects of production. However, deposits of this element are mainly located in the territories of western Georgia (D. Kuparadze, D.Pataridze, 2024), although it's small deposits are also noted in southeastern Georgia (village of Samshvilde and others); In eastern Georgia, manganese concentrations in soils (near road infrastructure) in most cases fluctuate within the maximum permissible values.

Fig. 6. Soil data investigated in recent years in Bolnisi and Dmanisi districts. mg/kg

(M. Avkopashvili. 2022.)

	Cd	Cu	Mn	Zn	Pb
Nakhiduri	2.0	153.3	746.4	182.4	8.9
Mtskneti	2.6	91.2	504.3	122.6	20.4
Poladauri	2.2	29.8	527.2	59.7	13.7
QvemoBolnisi	1.5	24.1	571.4	58.8	15.2
Ratevani	4.8	145.7	516.1	619.7	14.0
Mushevani	1.5	42.9	629.8	72.7	25.5
Akaurta	3.2	25.5	334.9	43.0	28.0
Gomareti	2.9	27.3	481.4	40.5	25.0
Gantiadi	1.9	27.4	582.2	44.3	18.4
Vardisubani	1.7	32.5	617.5	58.1	34.5
Mamishlo	1.2	26.1	466.7	54.4	35.1
Patara Dmanisi	1.2	25.8	494.3	66.1	39.4
Abulmulki	2.2	168.3	712.2	628.2	80.7
Balichi	3.3	142.6	671.5	300.6	90.1
Tandzia	2.5	85.2	605.5	59.6	57.8
Darbazi	2.2	32.3	550.2	70.1	62.8
Potskveriani	2.2	45.0	616.5	72.0	68.5
Kazreti	2.8	66.3	600.1	82.5	91.3
Balichient.	2.8	145.5	572.1	93.4	86.9
Balichi mid.	3.1	109.2	499.1	233.0	73.3
Balichi high.	1.3	65.4	609.3	120.5	98.0

Based on the analysis of the samples we took, elevated levels of manganese are observed along the roads of villages in the Kakheti region in the Tokhliauri-Sagarejo-Bakurtsikhe area and range from 996-1995 mg/kg. Also, high concentrations of this element are recorded in the villages of Gardabani district (especially in the village of Ruisbolo), where its value reaches 3635 mg/kg. This circumstance should be related to the presence of powerful iron and steel production and chemical plants in the region.

Exceedance of heavy metals in soils in relation to the maximum permissible norm, for example, in the village of Dmanisi, samples with the maximum permissible value of Cd are only 7% of the norm, Cu is only 22% of the norm in the entire district, and Mn is 128% of the maximum permissible norm, which exceeds the norm by 28%. The problem of heavy metal pollution is most acute in the village of Nakhiduri, where Cd, Cu, Mn and Zn exceed the permissible norm.

Based on the comparison, the content of heavy metal elements in the region has increased compared to previ-



ous years, and in all examined samples, an excess of some element is noted in relation to the norm. It seems that the problem of lead pollution is most acute in the village of Balich (exceeds the norm), cadmium - in the village of Ratevan (exceeds the norm), copper - in Abulmulk, manganese - in Nakhiduri, and zinc - in Abulmulk.

In some regions of the study area, located along major transportation routes, there is a noticeable increase in heavy metals, which is caused by anthropogenic impacts. This in itself exposes several villages to high ecological risk.

As for the Bolnisi district of southeastern Georgia, the pollution of soil and rivers with heavy metals is caused by the opening of old and new deposits and their intensive production. In contrast to the increase in heavy metals in this region, a significant decrease in elements essential for human life is being recorded in the soil. Soil contamination in the study region: in the village of Ratevani – cadmium, in Kazreti and Balichi – lead levels exceed the permissible norm by 2-3 times.

ANALYSIS AND RESULTS

The magnitude of pollution described in this article is not unique to Georgia. It is a global problem. Such studies are particularly relevant for transit States. According to the World Bank, freight traffic through Georgia's Middle Corridor will increase by 52% until 2030 (World Bank Report, 2023). Based on this forecast, much greater attention will be paid in the future to heavy metal pollution of roadside soils and, consequently, crop fields in Georgia adjacent to roads.

As is known, the mobility of chemical elements in nature depends largely on its atomic mass. The lower the atomic mass of an element, the further it can move in an environment. Further research and permanent monitoring are needed to better understand the problems associated with heavy metal distribution in areas adjacent to motorways and roadsides.

The main point is to identify the main sources of heavy metal pollution. Apart from the substandard fuel used by lorries, there are also faulty catalysts and poor tire quality and incorrect traffic patterns and many other environmental factors that complicate the environment.

In our opinion, besides geochemical studies, it is necessary to study the radiation environment, as more difficult environmental conditions may be present for cargo along the transport corridor.

We believe that comprehensive studies of the existing geoecological, geochemical potential should be carried out at least every two years. This will help to provide a timely solution for improving the environment and preventing the growing contamination of soils and plants with heavy metals and toxic chemicals in areas adjacent to international roads.

In addition, the results of such studies should be taken into account when designing and constructing new roads that would have minimal environmental impact.

In addition, the results of such studies should be taken into account when designing and constructing new roads with minimal environmental impact. This will help: in choosing optimal routes and profiles of new highways; environmental impact assessment; determining the economic potential of road transport, etc

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