Research Article

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Arsenic contamination of natural waters, soils and food products in Georgia

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Abstract— Arsenic contamination of natural waters, soils, and food products in Georgia is discussed in this paper. Samples of rivers and artesian waters, as well as suspended solids and bottom sediments, were taken and analysed. Soil samples were selected from polluted, agricultural, recreational and background sites. Arsenic content was determined in water and soil samples, as well as in food products. Furthermore, the hydrochemical and microbiological characterisation of rivers (Lukhuni and Tskhenistskali), artesian and spring waters in the vicinity of arsenic processing enterprises of Racha-Lechkhumi and Kvemo Svaneti region were conducted. Analyses were carried out using modern methods and equipment that meet and correspond to international standards. Based on the received data, a map of arsenic contamination of the soils of the Racha-Lechkhumi and Kvemo Svaneti regions was compiled in the GIS system. This review is undertaken to give an overview of the latest findings on the issue of soil, water and food products. The most vulnerable points of soil arsenic contamination have been identified in the areas adjacent to arsenic factories in the research region, From the agricultural fields to the villages of Abari and Likheti, where phytoremediation was carried out.

Keywords: arsenic, food products, natural waters, pollution, soils.

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I. INTRODUCTION

Environmental pollution is a global threat and a big risk factor for human health. Arsenic contamination is one of the most serious environmental problems, polluting natural resources, including water and soil, and posing a danger to the environment and public health. Arsenic is a natural component of the Earth's crust and is widespread in any ecosystem. It is present in nature in organic and inorganic forms, and the latter is very toxic [1]. It is established that arsenic can enter the body through the skin or the respiratory tract, but it still mainly enters the human body from food and drinking water. Arsenic becomes exceptionally toxic even at low exposure levels because of its high water solubility and bioaccumulation tendency in different environmental matrices. Organic arsenic species are most often found in marine products, and terrestrial products are mostly inorganic forms of 3-5 valent arsenic. Therefore, arsenic enters the food chain mainly from contaminated soil and water [2,3].

Arsenic pollution is a priority issue in Georgia, where it exists in both natural and anthropogenic sources. In particular, in the region of Racha-Lechkhumi and Kvemo Svaneti, arsenic ores were mined and processed, and arsenic-containing compounds were produced for decades. The development of the deposit, which is located in Ambrolauri municipality, began in 1938 in the village of Tsana, Lentekhi municipality. The main products were metallic (grey) arsenic and refined "white arsenic" (As2O3). Ore was mined at the Lukhumi deposit and processed - at the factory near the village of Uravi, which stopped functioning in 1991. During the last years, eight contaminated monolithic buildings in Ambrolauri municipality were dismantled, and two new sarcophagi were built to house arsenic-containing/mining waste, contaminated soil and inert material.

In the Lentekhi municipality, three sites for waste burial have been identified in the river valley. The first facility (Tsana 1) is located near the village of Mele, 5 km from the right bank of the Tskhenistskali river. The second facility (Tsana 2) is 5 km away from Tsana 1, where waste is dumped in damaged metal cylinders. This area is partly covered by land, scrub and forests. The third facility (Tsana 3) is 20 km away from Tsana 1 near the village of Tsana (in Khoruldashi) near the headwaters of the Tskhenistskali River.

In the villages of Uravi and Tsana, on the territory of the Samtochemical factory, toxic waste left over from the production of arsenic from the Soviet period is stored (more than 130 thousand tons containing 4-9% white arsenic and thousands of tons of arsenic-containing waste imported from Russia, among them, lying in the open air) [4]. Today, both deposits are conserved, and no arsenic is produced, but the problem is posed by arsenic-containing waste and the surrounding areas of former factories and soils.

Over the years, the main mechanism for the spread of arsenic waste has been associated with the leaching and transport of toxic waste by atmospheric precipitation and flood waters. They accumulate in the soil, where soil contamination with arsenic significantly exceeds the norm [5-8]. In the oxidation zone, after a certain time, arsenic from waste sulphide ores and incinerators can be transferred to a mobile (soluble) form [9], which is easily transported to plants and living organisms.

In addition, the Lukhuni and Tskhenistskali rivers are tributaries of the Rioni River, which is the main source of drinking water for the city of Kutaisi and is also used for irrigation. At the same time, this region is one of the most important tourist regions of Georgia, which significantly determines the scale of the disaster.

II. METHODOLOGY

Hydrochemical and microbiological characterisation of the rivers (Lukhuni and Tskhenistskali), artesian and spring waters in the vicinity of the arsenic processing enterprises of Racha-Lechkhumi and Kvemo Svaneti region is planned in the paper. It is also planned to study soil and food product contamination with arsenic. To solve the set tasks, the first fieldwork was carried out in Racha-Lechkhumi and Kvemo Svaneti region in 2022: natural water sampling points from the background and polluted areas and soil sampling points from polluted, agricultural, recreational and background areas of soil 0-5 and 5-20 cm deep were selected. Samples were taken for arsenic determination of suspended particles, bottom sediments and food products.

In the water samples taken, the following hydrochemical and microbiological parameters were determined, namely: pH, electrical conductivity, biogenic substances - NO2-, NO3-, NH4+, PO43-, basic ions, mineralisation, BOD5, total coliforms, E-coli and faecal streptococcus [10, 11]. The content of the total form of arsenic was determined in the collected water samples and soil samples [10,12].

The following formula was used to calculate the hazard index [13]:

$$HQ = MC / EQS_{SW,DW,Soil} \quad (1)$$

HQ - Hazard Index;
MC - Measured Concentration;
EQS – Environmental Quality Standard of surface water, drinking water and soil.
If HQ >1.0, arsenic is considered a potential risk to the aquatic environment and public health.
The following EQS thresholds will be used:

- Surface water: 0.05 mg/l (maximum permissible concentrations (MPC) on the approval of the technical regulations for the protection of surface water pollution of Georgia, Decree No. 425) [14].
- Drinking water: 0.01 mg/l MPC Georgia on the approval of the technical regulations to protect drinking water pollution, Decree No. 58) [15].
- Soil: MPC of arsenic - 2.0 mg/kg; Clark - 1.7 mg/kg; Decree of the Government of Georgia No. 297/n) on the approval of norms of the qualitative state of the environment [16].

Analyses were carried out using modern methods and equipment that meet and correspond to European standards, namely:

1. Spectrophotometric method – SPECORD-205; ISO 7150-1:2010;
2. Membrane filtration method - ISO 9308-1; ISO 7899-2;

3. Plasma-emission spectrometer - ICP-OES; EPA method 200.8;
4. Soil Destroyer - Milestone – Start D Microwave system;
5. Field portable equipment - Hanna Combo pH/EC/TDS/PPM Tester HI98129;
6. pH meter - Milwaukee-Mi 150.

III. DISCUSSION OF RESULTS

Eleven surface water samples and 30 soil samples were taken.
Table 1 and 2 shows the hydrochemical and microbiological analysis results in natural water samples.

Table 1: Results of hydrochemical analysis of the studied rivers, May - October 2023.

#	**Ingredients**	**Lukhuni Uravi Upper**	**Lukhuni (100 m below the sarcophagus)**	**Tskhenistskali Upper Tsana**	**Tskhenistskali Below Lentekhi**	**Shaori reservoir**	**Rioni-Utsera**	**MPC ***
		X-360228 Y-4722971	X-358975 Y-4721438	X-345623 Y-4741481	X-313988 Y-4737237	X-3340808 Y-4699495	X-380725 Y-4721383	
		May						
1	pH	7.5	8.2	7.3	7.5	8.1	8.2	6.5-8.5
2	Electrical conductivity, µsms/cm	210	160	280	300	172	230	
3	BOD$_5$, mg/l	1.75	1.25	2.10	2.00	1.97	1.15	6.0
4	Hardness, mg.seq./l	1.60	1.78	3.04	2.72	2.01	2.80	
5	Ammonium, mgN/l	0.358	0.107	0.130	0.202	0.086	0.090	0.39
6	Nitrites, mgN/l	0.099	0.156	0.138	0.154	0.160	0.206	1.1
7	Nitrates, mgN/l	0.662	3.702	0.090	0.080	0.217	2.970	10
8	Phosphates, mg/l	0.060	0.187	0.018	0.027	0.251	0.137	3.5
9	Sulfates, mg/l	20.4	13.14	12.0	19.4	12.88	22.03	500
10	Chlorides, mg/l	4.43	6.40	4.05	2.21	1.84	3.56	350
11	Bromine, mg/l	0.107	0.152	0.137	0.099	0.125	0.210	
12	Fluoride, mg/l	0.121	0.160	0.082	0.115	0.020	0.033	
13	Hydrocarbons, mg/l	98.2	96.38	183.0	167.8	124.44	147.62	
14	Potassium, mg/l	13.8	7.5	8.0	11.8	5.5	5.5	
15	Sodium, mg/l							
16	Calcium, mg/l	20.8	22.87	46.7	31.1	38.72	38.72	
17	Magnesium, mg/l	6.9	7.84	8.6	14.3	10.53	10.58	
18	Mineralization, mg/l	166.2	158.14	262.5	292.2	168.81	231.42	
19	Arsenic-As, mg/l	0.0020	0.0070	0.0068	0.0054	0.0025	0.0091	0.05
		October						
20	Arsenic-As, mg/l	0.0054	0.0116	0.0037	0.0043	0.0117	0.0021	0.05

Source: Own elaboration.

MPC * -The maximum permissible concentrations by the technical regulation of surface water (Decree of the Government of Georgia N 425, December 31, 2013, Tbilisi) [14].

As can be seen from Table 1 in the river waters, in the samples taken from both the background and polluted areas, none of the determined components, namely, biogenic compounds, main cations and anions, etc., do exceed the MPC and are within the norm. Figure 1 shows the mineralisation content in river waters. The water mineralisation of all rivers ranges from 158.14 to 292.2, and that of the Shaori reservoir is within 168.81 mg/l, which indicates that these waters belong to the category of slightly (< 200 mg/l) and medium (200-500 mg/l) mineralised waters [17].

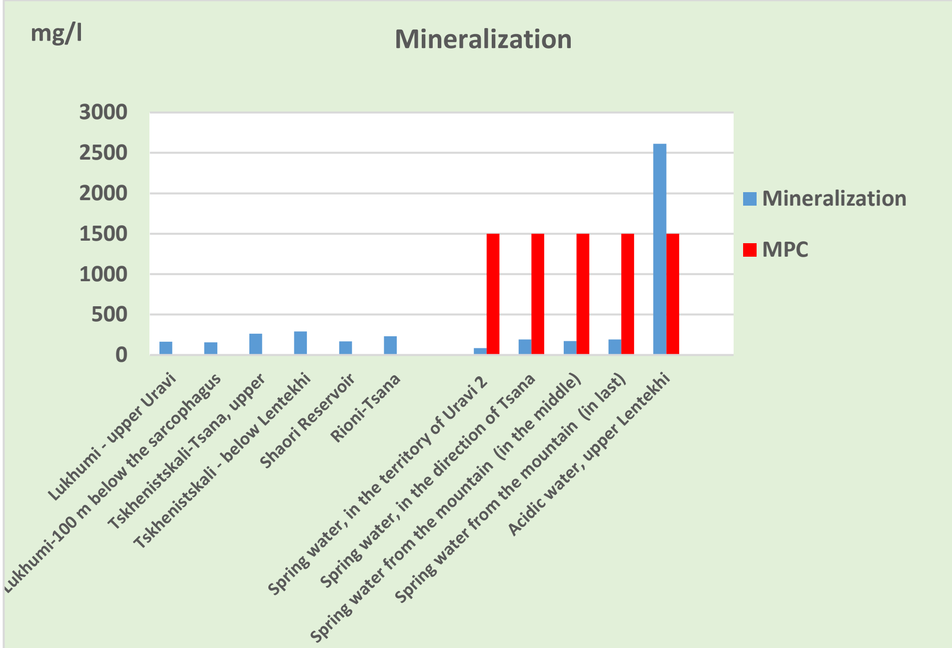


Figure 1: Mineralisation content in natural and spring waters, May 2023.
Source: Own elaboration.

As can be seen from the obtained results (Table 1, Fig. 2), arsenic concentrations were detected in the river waters (Lukhuni River and Tskhenistskali River), both in the background and in the samples taken below the pollution level. However, they did not exceed the maximum permissible concentrations in either case. Since all measured concentrations in surface waters were below the MAC indicator, the hazard index is, therefore, low (HQsw<1), and they are not at risk.

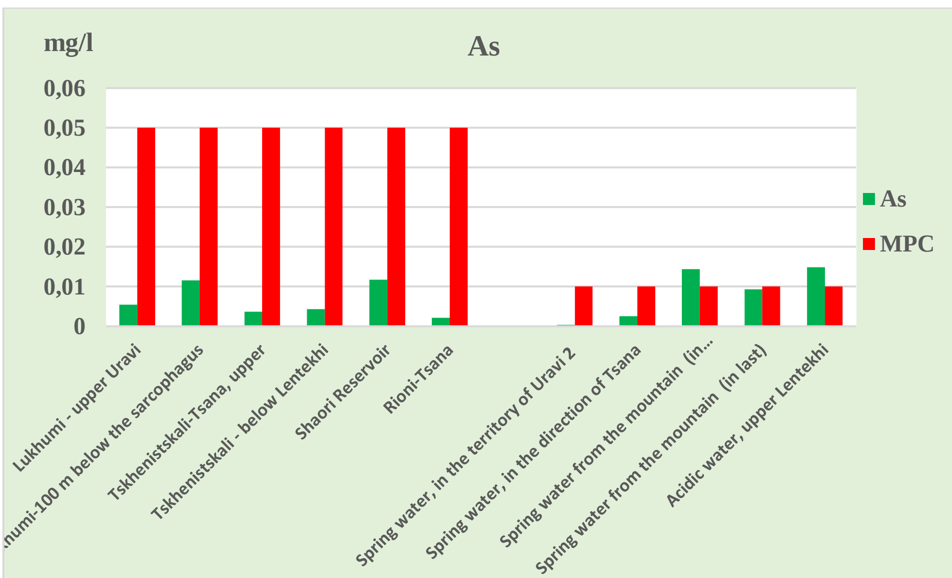


Figure 2: Arsenic concentration content in rivers, artesian and drinking waters, October 2023.
Source: Own elaboration.

There is a different picture according to the hydrochemical indicators of artesian and drinking spring waters (Table 2). Acidic spring water is especially distinguished, where the increase of water hardness (18.44 mg.eq/l) concerning MPC is noted. The content of hydrocarbons is - 1526.2, Ca++ - 291.71, Na++K+ - 333.88 and Mg++ - 47.26 mg/l.

Table 2: Hydrochemichemical and microbiological analysis results of artesian and drinking waters, May - October 2023.

#	**Ingredients**	**Spring water in the territory of Uravi 2 (150-200 m away)**	**Spring water from the mountain in the direction of Tsana**	**Spring water from the mountain (in the middle)**	**Spring water from the mountain (in last)**	**Acidic water (spring) above Lentekhi**	**MPC ***
		X-359777 Y-4722474	**X-316809 Y-4741183**	**X-316833 Y-4741198**	**X-316930 Y-4741232**	**X-313288 Y-4741009**	
					May		
1	pH	7.8	8.2	7.9	8.1	6.5	6-9
2	Electrical conductivity, µsms/cm	85	350	170	190	2558	

3	BOD5, mg/l	1.45	2.25	0.75	1.35	0.78	
4	Hardness, mg.seq/l	1.03	4.49	1.93	2.07	18.44	7-10
5	Ammonium, mgN/l	0.053	0.058	0.059	0.054	0.212	0.39
6	Nitrites, mg/Nl	0.095	0.216	0.052	0.126	132.0	1.0
7	Nitrates, mgN/l	0.320	0.237	1.304	1.202	0.084	10
8	Phosphates, mg/l	0.142	0.153	0.112	0.241	0.094	3.5
9	Sulfates, mg/l	2.86	78.89	4.22	12.28	24.40	250
10	Chlorides, mg/l	2.29	2.27	3.38	3.30	376.84	250
11	Bromine, mg/l	0.142	0.381	0.210	0.059	0.910	
12	Fluoride, mg/l	0.016	0.200	0.023	0.060	0.042	0.7
13	Hydrocarbons, mg/l	59.78	180.56	124.44	136.64	1526.22	
14	Potassium, mg/l	2.05	4.5	6.0	4.0	333.88	
15	Sodium, mg/l						
16	Calcium, mg/l	10.61	71.81	26.63	26.51	291.71	
17	Magnesium, mg/l	6.04	10.99	7.33	9.07	47.26	
18	Mineralization, mg/l	84.03	349.56	172.18	192.01	2612.22	1000-1500
19	Arsenic-As, mg/l	0.0086	0.0133	0.0092	0.0190	0.0022	0.01
		October					
20	E-Coli, in 250 ml	5	3	4	11	N.D	Not allowed
21	Total coliforms in 250 ml	11	8	10	21	N.D	
22	Fecal streptococci, in 300 ml	N.D	N.D	2	7	N.D	
23	Arsenic-As, mg/l	0.0004	0.0025	0.0144	0.0093	0.0149	0.01

Source: Own elaboration.

MPC* - maximum permissible concentrations by the technical regulation of drinking water
(Decree of the Government of Georgia N 58, January 15, 2014) [15].

Important components are biogenic elements (nitrogen, phosphorus), which reflect the quality of surface water pollution and are indicators of anthropogenic load. It is especially important to control the contents of their forms (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}) in water, which is characterised by the enhancement of such processes as faecal pollution caused by the discharge of municipal and agricultural wastewater. Among the nitrogen mineral forms, high contents of nitrite (132.0/132 MPC) forms were found, which is probably caused by the influence of faecal wastewater in it, which causes water pollution of the acidic source. The values of nitrates and phosphates do not exceed the respective maximum permissible concentrations. The mineralisation of this source is 2612.22 mg/l and belongs to waters with high mineralisation (>1000 mg/l). The spring water from the mountain, in the direction of Tsana, belongs to the average mineralised (172.18-349.56 mg/l) category.

In the samples taken from the spring waters in May (Table 2, Figure 2), the arsenic content in the spring water taken from the mountain in the direction of Tsana the concentration arsenic is 0.0133 mg/l and in spring water from the mountain (in last) - 0.0190 mg/l. The concentration of arsenic is 1.3 - 1.9 times higher than the permissible concentration. It is worth noting the fact that both these waters are intensively used for drinking by the population. The content of arsenic in the acidic spring water above Lentekhi is low, and its concentration is 0.0022 mg/l.

In October, a higher concentration of arsenic 0.0144 mg/l was observed in the spring water from the mountain in the direction of Tsana (in the middle) and acidic water - 0.0149 mg/l; in another case, the concentration of arsenic is within the norm.

Therefore, the hazard index (HQdw) in both months and artesian drinking water varies from 1.3 to 1.9 and represents a risk.

As a result of pollution, both the physical properties of water (colour, smell, turbidity), as well as chemical composition (organic, biogenic substances, heavy metals, etc.) and microflora change. The bacteriological purity of river water is evaluated by the number of intestinal sticks (E-coli) in 1 litre of water (coli index). A high value of the Coli index is an indicator of faecal pollution of water (MPC 5000 in 1 dm3).

Microbiological analyses were determined only in drinking water. As can be seen from the results of our analysis, in October (Tab. 2, Fig. 3), the spring water in the territory of Uravi 2 and the direction of Tsana contains E-coli, total coliforms and faecal streptococcus, which is not allowed according to the legislation of Georgia, and in acidic water, No contamination according to microbiological indicators was observed.

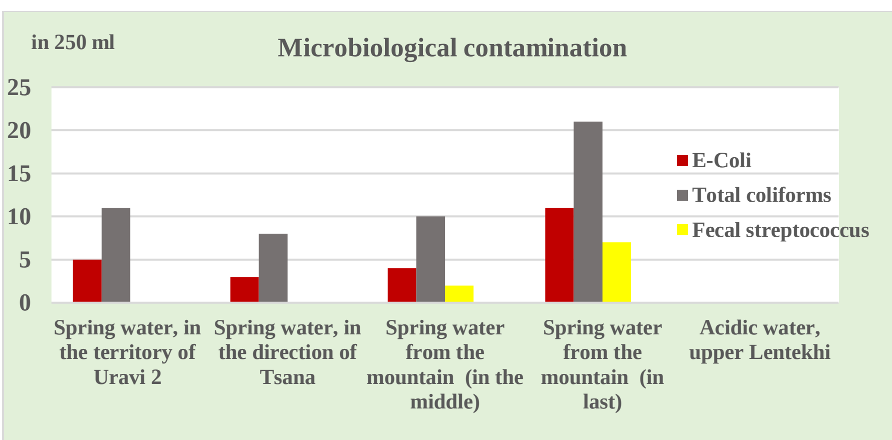


Figure 3: Microbiological contamination in source waters, October 2023.
Source: Own elaboration.

(MPC - not allowed)

Table 3 shows the content of arsenic in the suspended solids and bottom sediments of the river, which changes accordingly within the following limits: 20.2 and 39.2 mg/kg for the Lukhuni River, and Tskhenistskali - within 12.5 and 32.8 mg/kg.

Table 3: As content in river-suspended solids and bottom sediments. May, 2023.

#	Sampling location	Coordinates	Result of the analysis
			mg/kg
	Suspended solid		
1	Lukhuni river - 100m below the sarcophagus	X-358975 Y-4721438	20.2
2	Tskhenistskali river - below Lentekhi	X-313988 Y-4737237	12.5
	Sediments		
1	Lukhuni river - 100m below the sarcophagus	X-358975 Y-4721438	39.2
2	Tskhenistskali river - below Lentekhi	X-313988 Y-4737237	32.8

Source: Own elaboration.

Arsenic is often absent in river water but is present in suspended particles and bottom sediments. The increase in the content of arsenic in bottom sediments compared to river water can be explained by the high density of arsenic-bearing ores: 3.4-6.2 g/cm3 and their tendency to sediment. Therefore, it is appropriate to determine the concentration of arsenic in them [9].

Cordian-carbonate, blown forest acid, mountain-meadow cordial soils, etc., are widespread in the research region [18, 19]. Soil samples were taken from the area adjacent to the source of pollution in the villages of the region (Ambrolauri, Lentekhi), agricultural, recreational zones and background places - at a depth of 0-5, 5-20 cm. Soil samples were processed: drying, pulverisation, and sieving. The pH and the total form of arsenic were determined in the soil samples.

A particularly high concentration of arsenic was recorded in the vicinity of Uravi-2 in October near the "container" 610.0 mg/kg and 550.0 mg/kg at depths of 0-5 and 5-20 cm (Fig. 4). The concentration of arsenic in Sori Valley was determined at 4 points and is 9.79 mg/kg at the depth of 0-5 cm and 15.02 mg/kg at the depth of 5-20 cm in June. The content of arsenic October varies from minimum to maximum in the following limits: 10.82-32.98 mg/kg at a depth of 0-5 cm and a depth of 5-20 cm - 5.01-25.33 mg/kg. It is worth noting that the concentration of arsenic is much lower at a depth of 5-20 cm compared to 0-5 cm (Fig. 5). There are approximately similar results in the Likheti village (24.17 - and 72.86 mg/kg at a depth of 0-5 cm, and a depth of 5-20 cm - 16.62-25.35 mg/kg in October (Fig. 5). In the Abari village, the concentration of arsenic was determined at 3 points and its maximum concentration was 34.00 mg/kg at a depth of 0-5 cm, while the concentration of arsenic in depth also decreased and was 30.0 mg/kg in October (Fig. 5). In Nikortsminda and Ambrolauri and on the coast of Shaori reservoir, arsenic concentration ranges from 7.79 to 28.15 mg/kg at both depths in both periods (Fig.6).

Background soil samples were taken from the following locations: Utsera, Shovi and Oni. The concentration of arsenic in Utsera village is 29.99 mg/kg and 21.88 mg/kg respectively at a depth of 0-5 and 5-20 cm in June, and in October - 35.32 mg/kg and 21.88 mg/kg respectively (Fig. 7). In village Shovi - 18.18 mg/kg at both depths in October (Fig. 7). City Oni - 17.57 mg/kg and 13.57 mg/kg in June at depths of 0-5 and 5-20 cm, and 35.39 mg/kg and 38.79 mg/kg respectively in October (Fig. 7).

As can be seen from the obtained results, a high content of arsenic in the soil is noted in the soil samples taken from the background areas.

As already mentioned, the arsenic contents and hazard indices in the soils of Ambrolauri municipality in June and October 2022. The highest hazard index is observed in the areas affected by arsenic factories and amounts to 40.68-46.00 at a depth of 0-5 cm and 22.67-40.00 at a depth of 5-20 cm; T.e hazard index in Uravi 2 is maximum and is 305.00 and 275.00 at 0-5 and 5-20 cm depth in October.

The obtained results showed us that the content of the common forms of arsenic in the soil samples taken from the agricultural fields (Sori, Abari and Likheti) is relatively less and, accordingly, the arsenic hazard index is also lower. In the recreational zone (Ambrolauri, Nikortsminda and Shaori reservoir coast) compared to agricultural fields, the arsenic hazard index in the soil is even lower, which is confirmed by the analysis data. Relatively high arsenic contents are noted in the soil samples taken from the background area (Oni, Utsera and Shovi), and the hazard index is also high. These points were selected in different directions in areas that are not affected by Uravi 1 and Uravi 2. Such a high concentration of arsenic may be due to its high natural content in the soil.

Thus, arsenic levels were detected in soil samples taken from industrial, recreational and background sites.

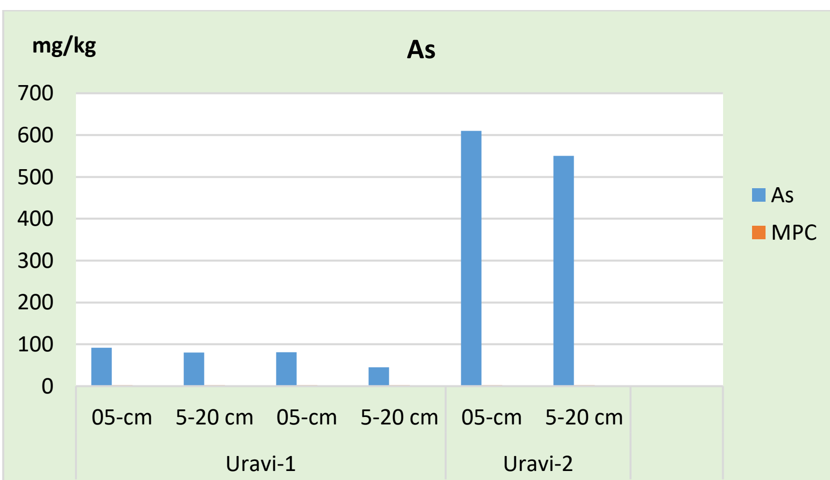


Figure 4: Arsenic content of Uravi-1 and Uravi-2 in soils at a depth of 0-5 and 5-20 cm.
Source: Own elaboration.

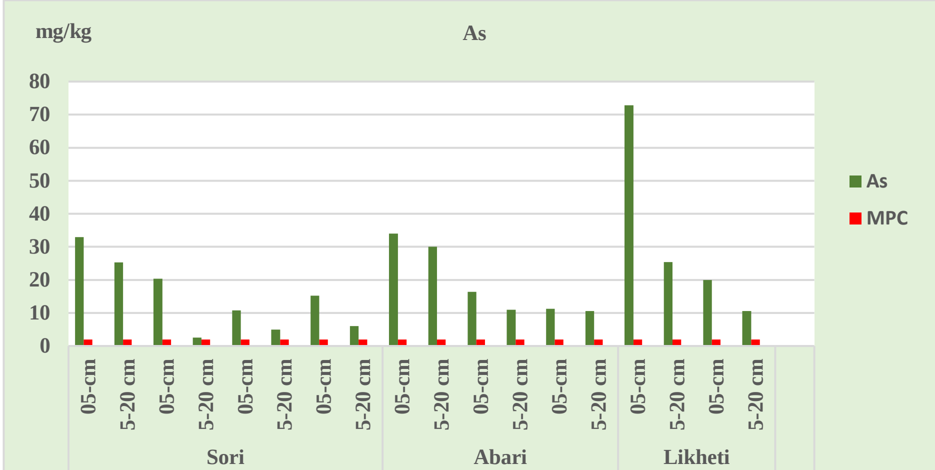


Figure 5: Arsenic content of Sori, Abari and Likheti in soils at a depth of 0-5 and 5-20 cm.
Source: Own elaboration.

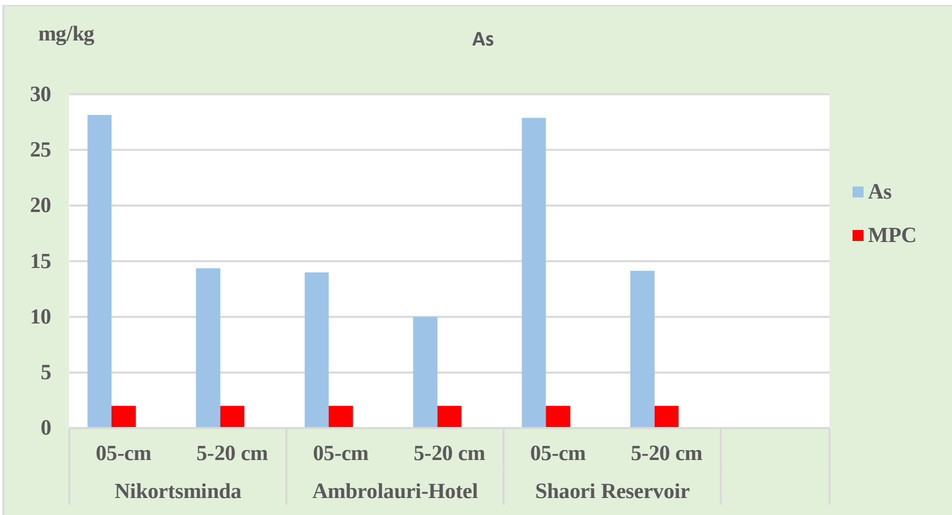


Figure 6. Arsenic content of Nikortsminda, Ambrolauri and in the soils of the coast of the Shaori reservoir at a depth of 0-5 and 5-20 cm.
Source: Own elaboration.

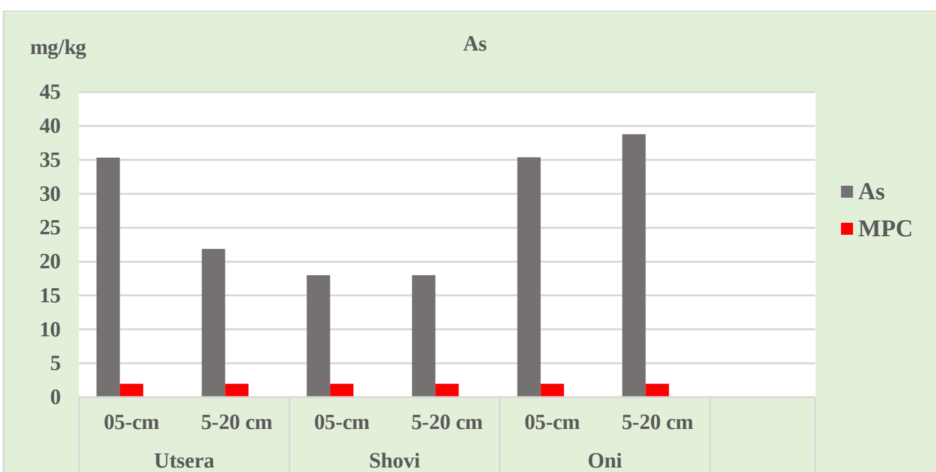


Figure 7. Arsenic content of Utsera, Shovi and Oni in soils at a depth of 0-5 and 5-20 cm.
Source: Own elaboration.

Table 4 shows the total form of as content in soil samples of Lentekhi municipality. As can be seen from the data, the concentration of arsenic in the soil samples of Lentekhi municipality is much higher than that of Ambrolauri municipality, which may be related to the amount of arsenic extraction and processing, waste storage conditions and other factors.

Table 4: Arsenic content in soils of Lentekhi municipality, October 2022.

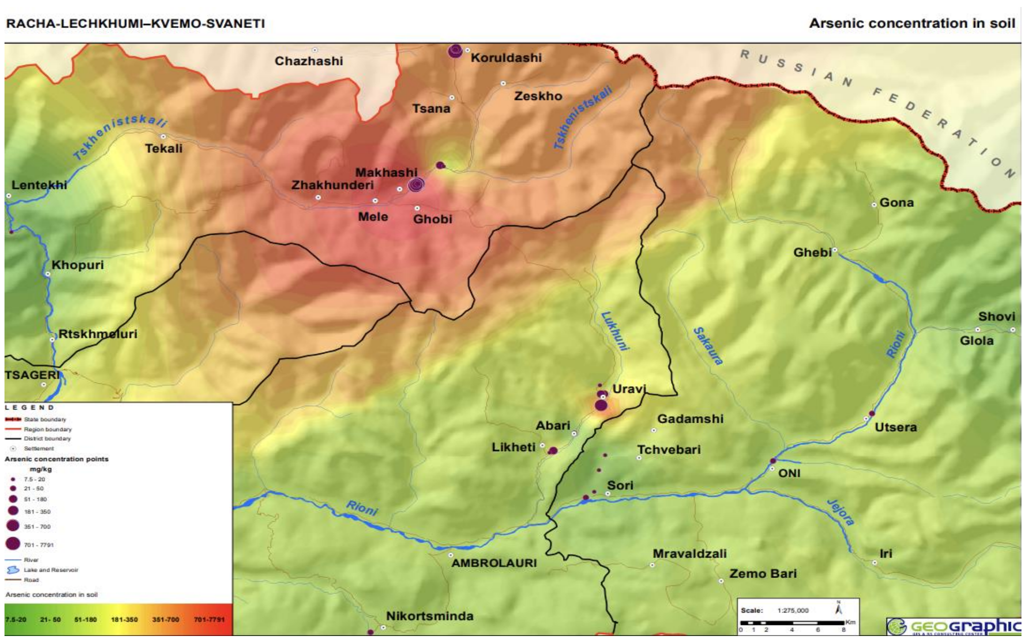
#	Sampling location	Coordinates	Analysis result mg/kg	Hazard index	pH
1	Tsana-1	X-0345498 Y-4741455	32.03	16.0	5.0
2	Tsana-1	X-0345462 Y-4741440	7791.04	3895.5	5.1
3	Tsana-1	X-0345365 Y-4741430	52.86	26.4	5.1
4	Tsana-1	X-0345393 Y-4741381	351.10	175.6	5.2
5	Tsana-1	X-0345333 Y-4741324	4511.02	2255.5	5.2
6	Tsana-2	X-0347216 Y-4743096	109.22	54.6	5.3
7	Tsana-2	X-0347504 Y-4742978	19.52	9.8	5.2
8	Tsana-3	X-0348407 Y-4753032	721.97	361.0	5.3
9	Tsana-3	X-0348400 Y-4753168	27.28	13.6	5.4
10	Tsana-3	X-0348469 Y-4753251	182.43	91.2	5.4
11	Tsana, Tskhenistskali coast, 0-5 cm	X-313988 Y-4737237	7.51	3.8	6.8

Source: Own elaboration.

As can be seen from Table 4, the samples taken from the surrounding areas of Tsana have high concentrations of arsenic. These concentrations are particularly high in Tsana-1 territory and amount to 4511.2-7791.04 mg/kg; in the territory of Tsana 2 - 19.52-109.22 mg/kg; and Tsana 3 - 27.28-721.97 mg/kg. Accordingly, the hazard indexes are also high. In soil samples on the banks of the Tskhenistskali River below Lentekhi, the concentration of as is much lower (7.5 mg/kg), and the hazard index is 3.8.

Map 1 plots arsenic concentrations in soil samples to identify arsenic hotspots.

For visualisation, the interpolation tool IDW (Inverse Distance Weighting method) of the Spatial Analyst Tool extension of ArcGIS was used in a logarithmic scale.



Map 1: Soils of Racha-Lechkhumi and Kvemo Svaneti region Vulnerable points of arsenic contamination.
Source: Own elaboration.

Food products (beets, potatoes, carrots, onions, corn, beans, grapes, apples, greens and milk) were taken once a year in the municipalities of Ambrolauri, and the total form of arsenic was determined (Table 5).

Table 5: As content in food products Ambrolauri municipalities October, 2023.

#	Ingredients	Ambrolauri municipality As, mg/kg	MPC
1	Herbs	0.15	
2	Onion	2.30	
3	potatoes	1.12	
4	Apple	1.35	
5	Beetroot	0.95	0.2
6	carrot	1.25	
7	corn	0.88	
8	grapes	1.25	
9	bean	1.55	

Source: Own elaboration.

Order N301/N of August 16, 2001, on the approval of sanitary rules and norms
for the quality and safety of food raw materials and food products [20].

The results of the determination of As in food products show that the content of arsenic in almost all products (Ambrolauri municipality) exceeds MPC (0.2 mg/kg).

IV. CONCLUSION

- As the results of the conducted analyses show, rivers' pH ranges from 7.3 to 8.2, and artesian and spring waters - from 7.8 to 8.2. It should be noted that the reaction of the acidic water source deviates in the acidic (6.5) direction, while the reaction of other source waters is in the alkaline direction (8.0);
- In the river waters, in the samples taken from both the background and polluted areas, none of the determined components, namely, biogenic compounds, basic cations and anions, and arsenic, do not exceed the MPC and are within the norm. Mineralisation of river water belongs to the category of slightly (<200 mg/l) and medium (200-500 mg/l) mineralised waters;
- Artesian and drinking spring waters belong to waters with medium mineralisation. An exception is acidic spring water, where an increase in water hardness (18.44 mg.eq/l) is noted about MPC, And its mineralisation belongs to the category of highly mineralised (>1000 mg/l) waters.
- Among the polluting ingredients, we can distinguish ammonium ions from mineral forms of nitrogen, the content of which exceeds the maximum allowable concentration by approximately -1.2 times, and the content of nitrites - 132 times, the amount of nitrates does not exceed the limit in any case. The content of phosphates is also low;
- In May, the arsenic content in the spring water taken in the territory of the mountain (in the middle) is almost equal to 1 MPC, and in the spring water from the mountain, in the direction of Tsana, the concentration of arsenic is 1.3 times higher than the MPC and Spring water from the mountain (in last) - 1.9 times. In October, the arsenic content in the spring water taken in the territory of the mountain (in the middle) is 1.4 times higher than the MPC, and in the Acidic water (spring) above Lentekhi, the concentration of arsenic is 1.5 times higher than the MPC;
- In October, spring water in the territory of Uravi 2 and the direction of Tsana contained E-coli, total coliforms and faecal streptococcus, which is not allowed according to the legislation of Georgia, and no contamination was observed in acidic water according to microbiological indicators;
- The arsenic hazard index (HQ_{sw} < 1) in the river waters (Lukhuni and Tskhenistskali rivers) is not at risk;
- Hazard index of arsenic in artesian and drinking waters (HQ_{Dw} >1), i.e. These waters are at risk;
- The total content of As in the suspended solids of the river is quite high: About 100 m below the Lukhuni-sarcophagus, its content in weighted particles is 20.2 mg/kg, and below the river Tskhenistskali-Lentekhi - 12.5 mg/kg;
- The content of arsenic in the bottom sediments of the studied rivers is 39.2 mg/kg and 32.8 mg/kg, which can be explained by the high density of arsenic-bearing ores and their tendency to sedimentation;
- The soils of Uravi-2 are the most contaminated with arsenic, and in Lentekhi - Tsana-1 soils;
- An average level of arsenic contamination is noted on agricultural plots in Ambrolauri municipality; There is even less arsenic contamination in recreational areas. Relatively high levels of arsenic are noted in the background areas, such a high concentration may be caused by the natural presence of arsenic in the soil;
- 30 at-risk soil sampling facilities (in both municipalities) were identified, where the hazard index (HQ_s >1) due to high arsenic concentrations;
- The content of arsenic is higher in the upper soil (0-5 cm depth) than in the lower layer (5-20 cm depth);
- The results of the determination of As in food products show that the content of arsenic in almost all products (Ambrolauri municipality) exceeds MPC (0.2 mg/kg).

Based on the received data, a map of arsenic contamination of the soils of the Racha-Lechkhumi and Kvemo Svaneti regions was drawn up in the GIS system (Map 1) to identify the vulnerable points of contamination. The most vulnerable points have been identified in the areas surrounding the arsenic factories (Tsana-1, Tsana-2 and Tsana-3; Uravi-1 and Uravi-2). In 2023, phytoremediation was carried out on the agricultural fields of Abar and Likheti villages to reduce soil arsenic contamination.

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