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# Impact of Anthropogenic Factor on Karst Landscape (Zemo Imereti Structural Plateau Case Study), Georgia, Caucasus

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## Abstract

The Zemo Imereti (Chiatura) Structural Plateau covers the easternmost part of the western Georgia limestone belt and is the only region of the platform karst in the entire Caucasus. Zemo Imereti Plateau's complex structural studies revealed that the karst landscape has been completely transformed due to human strong economic activities, mainly related to the manganese unplanned, predatory extraction. The ore mining process completely destroyed the soil and vegetation cover thus creating "anthropo-badlands". Due to manganese open-cast mining, the layers located over limestones are almost totally removed and heavy rains stipulate intense washout of substances from loose rocks. Intense washout of manganese extracted from mines and high contamination of river water streams take place directly in the river beds. Karst sinkholes and wells are common in the plateau, which are often used as waste fills-storages by the local population. Contaminated underground karst waters flowing into the above mentioned landforms are directly related to the karst springs used by the population and occasionally cause their turbidity and contamination, which is also confirmed by our indicator tests. As a laboratory study of the samples showed, mineralization of underground karst waters in the study area is 1.5 - 3 times higher than similar values in neighboring karst areas, which should be explained by the widespread of manganese open pits in the feeding basins of underground karst waters. According to the materials obtained from our surveys and calculations carried out, karst (chemical) denudation (surface 64.2 - 190.6 m<sup>3</sup>/km<sup>2</sup>/year, underground 1.5 - 117.0 m<sup>3</sup>/km<sup>2</sup>/year) has been increased in the study area than in other karst regions of Georgia, which is also related to technologic factors.

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## Keywords

Karst, Anthropogenic Factor, Geoecology, Georgia

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## 1. Introduction

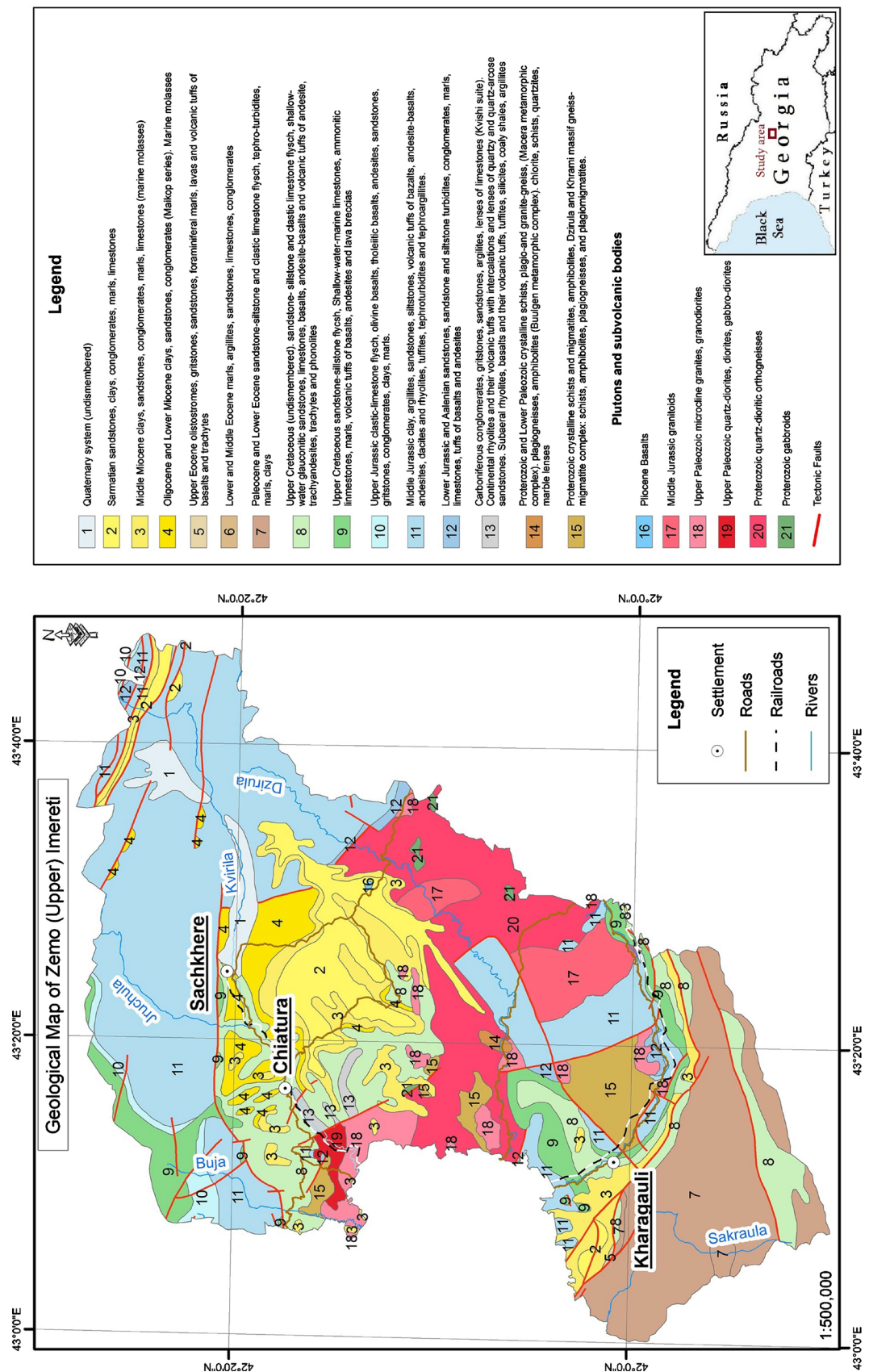
For decades, in Georgia, predatory and immature approach to natural resources, primarily, the mass destruction of forests, the asystematic usage of land and minerals, has led to an irreversible degradation of the geological-geographical environment balance and intensification of catastrophic processes. Especially noteworthy in this regard is Zemo Imereti structural plateau, which is completely transformed due to strong economic activities. Here, in the manganese deposit zone, the rate of technogenic impact on nature has long exceeded the permissible norms. Predatory exploitation of manganese has led to a sharp expansion of agricultural areas involved in agricultural activities and therefore intensification of negative phenomena related to karst. The deformation of the land surface in the manganese distribution area became systematic. Exodynamic processes have been unusually activated. Contamination of sources used for drinking has reached a dangerous level.

## 2. Study Area

Georgia is a home to multiple, widespread karst areals with well developed karst processes [1] [2] [3] [4]. Karst landscapes are particularly well represented in western Georgia [2]. The Zemo Imereti Structural Plateau comprises the easternmost part of the western Georgia's limestone belt [5] [6] [7] [8], characterized by peculiar natural conditions (karstified terrain, tectonics, climate, surface waters and underground waters) and is the only region of platform karst in the Caucasus, where a variety of surface and underground karst landscapes are represented [9] [10] [11] [12].

The main morphological features of the study region are determined by the geological structure. It is the highest part of the clod of Georgia. Plateau relief carries many signs of individuality. Throughout Georgia, only there can be found significant elevated denudation-structural plateau-like surfaces with a quiet, tectonically nearly undisturbed extension of layers [13]. The study region, as part of the clod of Georgia, geologically and structurally is represented by two structural levels such as pre-Cretaceous basis and Cretaceous-Neogene platform cover [14]. The latter is divided into two subhorizontal sub-levels: 1. Cretaceous, built of carbonate rocks, and 2. Neogene, built of terrigenous material (**Figure 1**).

In its turn, the unified structural plateau is dissected into rather deep (100 - 300 m) canyon-like gorges and small size plateaus by the Kvirila River and its tributaries (Jruchula, Nekrisa, Bogiristskali, Rganisghele, Katskhura, Buja, Sadzalekhevi, etc.). These river valleys separate from each other steep sloped plateaus with flat



surfaces with an absolute altitude of 500 - 800 m above sea level. Among them are notable Sareki, Darvkheti, Zodi, Mghmivevi, Bunikauri, Tabagrebi, Rgani and Perevisa, Shukruti, Itkhvisi, Sveri, Merevi and etc. On the surfaces of the plateaus a water absorption dense network of the relief is developed, and caves are disposed in levels. At present, the modern plastics and geocological situation of the structural plateau terrain are substantially altered by the influence of technogenic factors.

### 3. Research Methods

The paper uses field, experimental and laboratory research methods. During the research period, karst-speleological and geocological study of the research area was carried out. Feeding basins, traffic routes and discharge centers of underground waters were studied using the tracing method (indicator test). Connections of contaminated underground karst streams with karst springs were identified. The chemical composition and hydrochemical regime of karst waters (in particular, surface streams, karst springs and cave streams) have been studied by station observations and laboratory research. Accordingly, based on the materials of research carried out by us, the intensity of karst (chemical) denudation was calculated by the formula (1968; 1971) suggested by M. Pulina [16] [17].

### 4. Results

Upper Cretaceous limestones over a significant area of Zemo Imereti structural plateau are covered by Oligocene-Miocene sandy-clay and manganese-bearing productive sediments, due to which the water circulation is somewhat complicated in depth and hence the rate of sedimentation should be slowed down. In the areas, where the sheet cover destruction takes place, karst processes are intense. The covers of areas, where the extraction of manganese is being carried out, are particularly affected by the destruction and disintegration.

Exploitation of manganese deposits in the study area has a history of more than 120 years. Frequent and strong explosions in mines significantly contribute to the expansion of cracks in limestones or formation of new ones and the activation of karst processes. In addition, abandoned mines are not conserved in accordance with proper regulations. Due to the decomposition of fixing beams in the abandoned mines, arches are collapsing frequently, resulting in fragmentation and destruction of massif constructed by Oligocene-Miocene age suites, strong deformation of terrain, development of landslide and erosion processes, as well as drying of water bearing horizons (especially Chokrakian ones) and drastic changes in the hydrodynamic situation of the region in general.

The capacity of the disorder zone caused by the collapse of the abandoned tunnels of the mines is tens of meters. Due to collapses, hydrodynamic connection of the water bearing horizons of Caragian-Konkian, Chokrakian and Oligocene-Miocene and Upper Cretaceous limestones became possible that enhanced influence of atmospheric precipitations, activated karstification processes

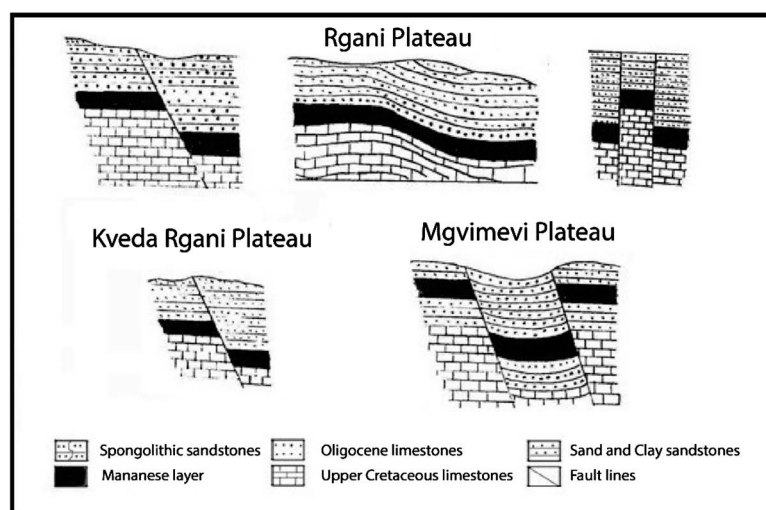
and led to turbidity-pollution of underground karst streams and springs. This process is particularly intense on the Perevisa and Rgani plateaus, where the manganese suites lie directly on the uneven surface of the Upper Cretaceous limestones (**Figure 2**). The development of collapsed fissures has led to the collapse and filling of ceilings of some of the caves developed in the plateau (Pirana Abyss, Kvatia Cave, etc.). In the Oligocene-Miocene sediments, wells dug by local population and springs too were also dried up.

Particularly vivid and widespread sunken forms are found in the central part of the Zeda Rgani Plateau, in the western part of the Mghvimevi Plateau and in the upper reaches of the Korokhnali and Samarkali river basins. Dense network of sunken cracks are also developed on the plateaus of Rgani, Mghvimevi, Itkhvisi and Perevisa. Here, the horizontal amplitude of the cracks varies from 0.5 m to 1.5 - 2 m, and the visible depth reaches 2 - 3 m.

Also, the open quarrying of ore has been underway on the Zemo Imereti Structural Plateau since the 1950s, which destroyed not only soil cover, forest massifs and pastures on vast areas, but also modified terrain.

Open quarrying of manganese is facilitated by disposition of quite thick horizontal and shallow (from 10 to 45 m depth from the surface) overbearing suites. In this way, the opening works conducted for manganese mining is followed by the removal of suites disposed over the limestones and activation of karst processes, which is manifested by the intense leaking of aggressive surface waters into newly opened fissures. Expansion of old fissures or the emergence of new ones is greatly facilitated by the powerful explosions produced there (**Figure 3**).

Ground, soil and vegetation cover reconstruction works on Chiatura structural plateau are almost suspended. The ore quarrying process completely destroyed the soil-vegetation cover and created “anthropo-badlands”. Among the technogenic landforms the following ones dominate: quarries, landfills of different forms and sizes, trenches, sinkhole-like and polje-like forms, wavy forms



**Figure 2.** Shearing dislocations and Upper Cretaceous limestones covered by manganese ore in the Zemo Imereti Plateau [1].





**Figure 3.** Karst relief modified as a result of manganese open pit extraction.



**Figure 4.** Technogenic landforms remaining after processing of manganese.

created by loose ground, etc. Accordingly, the Zemo Imereti Plateau is completely transformed by anthropogenic factors (**Figure 4**).

On the structural plateau, manganese suites are often located directly on the Upper Cretaceous fragmented limestones, making the water absorption process more intensified. In addition, during heavy rains, in the open quarries the intense washing of substances from the rocks and getting of contaminated waters directly into the karst springs through fissures takes place, which is often followed by turbidity-contamination of drinking waters in Chiatura. Such relations have been practically confirmed by our experiments with tracing of dyed waters ([1] [10] [18] [19]).

High mineralization and high values of chemical (karst) denudation of the structural plateau karst waters should also be associated with the manganese extraction works and technogenic factors as a whole.

We have studied several dozens of samples of surface and underground karst waters in our laboratory. At the same time, the chemical composition of the vaucluse springs and cave flows was checked periodically (according to the seasons of the year). Eight series of samples were studied, resulted in significant outcomes (**Table 1**).

**Table 1.** Chemical composition of karst waters of Georgia.

Location	Water s	Number of samples	pH		Mg.l <sup>-1</sup>						
Apkhazeti region	Sf	5	7.30 - 7.61 7.51	0.2 - 0.6 0.4	3.8 - 13.0 9.7	98 - 159 133	0.7 - 2.7 1.3	4.0 - 11.0 7.3	27.0 - 41.3 35.3	0.02 - 0.12 0.05	129 - 217 187
	Ks	7	7.18 - 7.56 7.47	0.2 - 0.5 0.5	4.2 - 9.4 8.8	94 - 159 139	1.3 - 1.8 1.4	5.1 - 10.0 6.0	25.0 - 43.3 37.4	0.02 - 0.08 0.04	132 - 211 193
	Uf	10	7.15 - 7.85 7.53	0.1 - 1.3 0.4	1.0 - 12.0 4.9	71 - 146 105	0.7 - 25.8 8.8	0.7 - 7.9 3.5	11.0 - 38.8 21.0	0.01 - 0.05 0.03	94 - 199 145
Lechkhumi region	Sf	6	7.36 - 7.66 7.53	0.8 - 1.5 1.2	4.2 - 7.5 5.5	59 - 165 134	1.4 - 5.1 2.9	1.4 - 9.5 6.7	15.2 - 43.1 33.7	0.02 - 0.07 0.05	85 - 225 184
	Ks	15	7.06 - 7.90 7.37	0.4 - 8.4 1.8	2.2 - 10.4 6.2	60 - 354 207	1.4 - 6.0 3.4	2.7 - 21.0 10.2	17.6 - 108 51.8	0.01 - 0.03 0.02	94 - 476 288
	Uf	8	6.75 - 7.50 7.08	0.1 - 1.1 0.6	3.0 - 5.0 4.0	166 - 339 245	10.2 - 18.0 14.4	4.9 - 10.1 7.1	41.7 - 95.3 60.7	0.01 - 0.03 0.03	264 - 460 337
Khvamli region	Sf	3	7.19 - 8.02 7.74	1.1 - 1.7 1.5	5.2 - 19.2 11.0	181 - 203 194	2.6 - 6.4 4.4	1.6 - 7.3 5.4	56.2 - 58.0 57.1	0.02 - 0.03 0.03	249 - 291 270
	Uf	5	7.31 - 8.05 7.76	0.5 - 0.8 0.6	2.6 - 7.0 4.4	159 - 203 185	0.5 - 4.1 1.9	2.8 - 7.4 5.0	41.8 - 57.0 52.9	0.01 - 0.03 0.02	212 - 275 255
Nakerala region	Sf	6	—	2.8 - 8.2 4.8	17.4 - 61.8 31.1	86 - 151 115	5.7 - 17.9 9.8	3.1 - 10.8 5.3	30.1 - 40.8 37.4	—	157 - 238 202
	Uf	10	—	2.7 - 5.0 3.8	2.9 - 37.2 9.7	107 - 184 135	1.4 - 13.1 5.5	4.3 - 12.0 7.3	25.8 - 46.2 34.5	—	147 - 290 193
Zemo Imereti Plateau	Sf	10	7.64 - 8.35 7.86	0.3 - 3.8 2.3	0.8 - 68.0 30.1	134 - 226 181	3.0 - 23.0 8.3	4.3 - 12.2 9.4	33.2 - 59.2 49.8	0.01 - 0.07 0.02	194 - 368 281
	Ks	78	6.82 - 8.30 7.53	0.2 - 14.8 4.0	0.5 - 460 40.3	112 - 397 259	3.2 - 58.0 11.3	2.4 - 82.0 18.4	18.0 - 196 63.0	0.01 - 0.22 0.03	160 - 1090 395
	Uf	78	6.62 - 8.26 7.72	0.5 - 56.6 10.6	1.2 - 1302 257	71 - 368 261	2.2 - 65.0 18.3	3.4 - 360 45.1	21.4 - 493 112	0.01 - 0.35 0.05	106 - 2290 704

(Sf-surface flow, Ks-karst source, Uf-underground flow; extreme data are given in the numerator, average data-in the denominator).

Mineralization of underground karst waters of the study area, as the laboratory study of the samples showed, is 1.5 to 3 times higher than similar indices in neighboring karst areas. This is mainly due to the wide distribution of open quarries of manganese ores in the feeding basins of underground karst waters. In the open quarry areas, as mentioned above, there is an intense wash-gout of substances from the rocks during the heavy rains. Due to the aforementioned reason, on the left bank of the Kvirila River, where open quarries are relatively less presented, karst waters are about twice less mineralized than on the right bank ( $\Sigma_i$  422 and 712 mg.l<sup>-1</sup> respectively). In addition, mineralization is particularly high in the vacluse springs and underground flows ( $\Sigma_i$  1052 - 2290 mg.l<sup>-1</sup>), in the water catchment basins of which the open quarry of manganese is currently being intensively carried out.

Strong disturbance of ground in the surface basins of feeding of karst waters adjacent areas, degradation of natural vegetation cover, destruction of meadows



and overplowing of surfaces significantly enhanced soil washout, increased solid runoff in streams and consequently karst denudation intensity. Based on our research and existing data, karst denudation was calculated for the study region according to the karst-hydrometric method (formula) of M. Pulina [17]. As calculations have shown, the karst denudation indices (surface: 64.2 - 190.6; underground: 1.5 - 117.0 m<sup>3</sup>/km<sup>2</sup>) of the Chiatura structural plateau exceed those of Apkhazeti (the values of surface and underground karst denudation in the zone of high karst are 75 - 108 and 30 - 45 m<sup>3</sup>/km<sup>2</sup> respectively and in the foothills - 38 - 58 and 12 - 0 m<sup>3</sup>/km<sup>2</sup> respectively) and Askhi (59 m<sup>3</sup>/km<sup>2</sup> per year) [20] [21] karst massifs.

In our opinion, high indices of chemical denudation intensity in the karst region of the structural plateau are mainly caused by high mineralization (mineralization of karst waters of manganese region is 1.5 - 3 times higher than that of karst regions of Georgia) of karst waters related to technogenic factors and intensive washout of substances.

Contamination of atmosphere, natural waters and soil cover with aggressive components of anthropogenic origin has substantial and permanent impact on the activation of karst processes. Above-mentioned industrial and agricultural wastes got in the air, water and soil, containing organic and mineral acids, phenol, nitrobenzene, sulfur and others substances, contribute to the sharp increase in aggressiveness of natural waters and, in particular, karst waters, which in turn results in the activation of karst processes. The aggressiveness index of karst waters in the region amounted to 6 - 8 g/l [22].

Frequent explosions in quarries in the study area have contributed not only to deformation of the terrain and appearance of cracks, but also to air pollution. For example, according to T. Kutsia [23], 4 tonnes of dust and manganese are emitted into the air daily by explosions in quarries. There are 5000 tons of drifted particles in the 180,000 m<sup>3</sup> of contaminated water mass flowing into the Kvirila River from manganese washing plants each year (Kutsia, 1989). The actual concentration of drifted particles and petroleum products in purified water (which is equivalent to 3995 m·g/l and 24 m·g/l, respectively) many times exceeds the maximum allowable rate (6.0 m·g/l and 0.3 m·g/l, respectively) [24]. Soil and ground themselves are often contaminated with industrial and agricultural waste. Directly in the riverbeds there is intense washing of manganese taken out from the mines as well as heavy contamination of water flows of the river [25] [26] (Figure 5).

The contaminated waters leaking out from the riverbeds, as confirmed by our indicative tests, are directly linked with the other karst springs involved in the water supply of Monastery and Chiatura city (Figure 6).

Karst sinkholes and wells widely spread on the structural plateau are often used as wastefills by local population. A big amount of such "storages" have been observed during our field surveys (Figure 7).

As a result of indicator tests conducted by us, their direct links with karst sources have been identified, a significant part of which is involved in water



**Figure 5.** Kvirila River pollution by manganese industry near the Chiatūra city.



**Figure 6.** To the left: Indicative experiment of water marking carried out in the polluted bed of the Rganisghele River. To the right: Dyed stream observed in the drinking water of the Monastery spring.



**Figure 7.** Karst sinkholes and wells used as landfills by the local population.

supply of Chiatura city and its adjacent villages. This fact creates a danger of organic and bacterial contamination of karst waters.

Content of manganese and boron (**Table 2**) in the karst waters studied by us have increased compared to the surface waters of the other regions of Georgia [27].

This fact should be explained by the wide distribution of manganese ore in the study area and the direct relationship between boron content and mineralization values in natural waters (correlation coefficient +0.84).

Based on the previously identification of acidity, it can be concluded that the content of organic substance in the cave streams and especially in the vacluse sources is negligible [1]. Only in two or three cases in the cave stream and karst source (Tuzi Cave, springs in the vicinity of Tuzi village) was observed the presence of sulfur hydrogen. This fact and a number of contaminated water absorption centers detected by us during our field surveys, and their direct links with karst sources (which have been identified by our indicator tests) do not exclude not only the contamination of drinking waters, but also the danger of their organic and bacteriological contamination.

## 5. Conclusions

Thus, the Zemo Imereti (Chiatura) structural plateau is completely transformed by the strong anthropological economic stress, which is mainly because of unplanned, so called predatory mining of manganese ore. The ore quarrying process completely eliminated the soil-vegetation cover and created “anthropo-badlands”. After the extraction of manganese in the study area, there is almost no restoration works carried out. Due to the decomposition of fixing beams in the abandoned mines, arches are collapsing frequently, resulting in fragmentation and destruction of massifs, strong deformation of terrain, as well as drying out of water bearing horizons and drastic changes in the hydrodynamic situation of the region in general.

In open quarry areas, during heavy rains, intense washing out of the substances from the loose rocks takes place and contaminated waters get directly

**Table 2.** Content of microelements (mkg·l<sup>-1</sup>) and acidity (mg·l<sup>-1</sup>) in the underground karst waters of Zemo Imereti Plateau.

Acidity elements	Karst springs		Cave streams		Surface waters of Georgia	
	Min.-Maxim.	Average	Min.-Maxim.	Average	Min.-Maxim.	Average
B	0.06 - 0.50	0.22	0.02 - 0.09	0.29	0.01 - 0.07	0.04
Sr	0.75 - 1.00	0.86	0.90 - 1.12	1.03	-	-
Al	0.03 - 0.08	0.06	0.03 - 0.10	0.04	0.01 - 0.08	0.03
Mn	0.05 - 0.14	0.09	0.08 - 0.15	0.12	0.00 - 0.19	0.02
Fe	0.01 - 0.22	0.03	0.01 - 0.35	0.05	0.00 - 0.37	0.06
Acidity	0.1 - 1.1	0.9	0.1 - 2.5	0.6	0.5 - 7.0	-

into the karst springs through fissures. Field, experimental and laboratory studies identified that as a result of impact of technogenic factors, the intensity chemical (karst) denudation in the Zemo Imereti structural plateau reached high rates. Mineralization of surface and underground karst waters substantially increased, and the turbidity and pollution of drinking karst waters reached dangerous limits.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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