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Chiatura Municipality Drinking Water Monitoring

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The monograph "Chiatura municipality drinking water monitoring" introduces the results of the karst-speleological survey conducted in Chiatura structural plateau. The complicated geo-ecological conditions created in Chiatura municipality and adverse consequences related to it are represented.

Based on field, laboratory and experimental studies the basic centers and causes of turbidity-pollution of karst springs involved in the water supply system of Chiatura town and adjacent villages are revealed. The results of the survey and the recommendations developed based on them will provide significant assistance in solving problems existing in water supply to Chiatura town and adjacent villages, which are still topical for the region.

These studies were carried out with the active support of the Slovak Embassy within the framework of the project "Monitoring Chiatura's polluted drinking waters" (Small Grants: № SAMRS/2016/SG/04/GE), financed by the Slovak Agency for International Development Cooperation.

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Foreword

Study of the Chiatura (Zemo Imereti) Plateau karst complex is dictated by the interests of rational management of the economy in this region. Anthropogenic effect (mining, construction, agricultural activities, etc.) on environment have increased greately, which is being enhanced over time. The consiquences of human intense impact on nature is largely negative and is expressed by the sharp transformation of landscape components. This process is revealed especially intensively in the karst areas, namely regarding the karst waters.

Karst waters are dominated in water supply of the population of Chiatura town and adjacent villages and entirely satisfy the demand on drinking and technical waters today, though due to frequent and some times catastrophic turbidity-pollution, their utiliation is hindered and the population remains without water for a certain period.

It is noteworthy that during the normal operation of water supply, drinking water is unreliable and contains some admixtures in increased amount. Many times the researchers discovered colibacteria (intestinal bacillus), sulfur hydrogen and other elements dangerous for human health. It has been 3-4 decades that the population of Chiatura town lives with these problems.

Based on this, the works, carried out by the financial support of the Slovak Agency for International Development Cooperation, were aimed at improving the water supply of Chiatura municipality, which is vitally important for the region, which experiences difficulties in socio-economic development.

In the process of working, we applied the methods that are tested in studying classical karst territories. The field geologic, geomorphological and karst-speleological study of the research territory was carried out by us. In material generalization we used the cartographic method of research and decoding

aerial images. Using a structural decoding of aerial imagry, a detailed scheme of the fault dislocations is drawn up and the regularities of the karst forms distribution are adjusted. The borehole data and cartographic material analysis were the basis of the general scheme of hydrogeological situation, which was demonstrated by indicator experiments as well. On some of the karst springs the regime observations and their hydrochemical research were carried out. The main centers and factors of turbidity-polluting of karst waters have been identified.

The network of karst collectors has been studied by the tracing method (indicator experiment) of underground streams and the scheme of their distribution has been compiled. The use of tracing method enabled us to find the feeding basins of underground water streams, their movement routes and the discharging centers. On the basis of indicator experiments, the feeding basins of karst springs used for Chiatura water supply were considerably specified.

Field and laboratory investigations have demonstrated an active role of technogenic factor in karst genesis, turbidity-pollution of springs, provoking and activating other exodynamic processes. Practical recommendations have been developed to minimize the intensity of exodynamic phenomena provoked by technogenic processes and to prevent the pollution of karst waters.

Based on the research, the scientific article was prepared, which will be published in the peer reviewed journal; and the recommendations, elaborated within the project, will be handed to the local authority bodies.

The mentioned studies were carried within the framework of the project "Monitoring Chiatura's polluted drinking waters" (Small Grants: № SAMRS/2016/SG/04/GE), financed by the Slovak Agency for International Development Cooperation, with the support of TSU Vakhushti Bagrationi Institute of Geography and the Speleo Club of Georgia; its members are the key participants–Academic Doctors of Georgaphy: Zaza Lezhava, Kukuri

Tsikarisvili nd Nana Bolashvili, and the assistant personnel: Lasha Asanidze-Academic Doctor of Geography, Nino Chikhradze-Doctoral student and George Chartolani-Lab fellow (Figure 1.)

Figure 1. Project participants and the representatives of local municipality

Introduction

The Chiatura municipality is an administrative-territorial unit (Figure 2) in the Imereti region of Georgia (Figure 2).

Figure 2. Chiatura municipality location in the schematic map of Georgia

To the north-east the Chiatura municipality is bordered by Sachkhere municipality, to the southwest – by Kharagauli municipality, to the west – by Zestaponi and Terjola municipalities, and to the northwest – by Takibuli and Ambrolauri municipalities. The total area of the territory is 542.5 km^2, The center is a town of Chiatura, covering 60 villages and settlements (Figure 3).

The Chiatura municipality is located on Zemo Imereti Plateau, which includes the easternmost part of the western Georgia limestone belt. The limestone plateau is characterized by peculiar natural conditions (relief, tectonics, climate, surface and surface area) and represents one of the most

important regions of platform karst in the entire Caucasus (Maruashvili, 1961; Tintilozov, 1976; Lezhava, 2015; Asanidze et al., 2017).

The canyon-like gorge of the Kvirila River divides the karst region into the northern and southern parts. The uniform plateau surface is fragmented by the canyon-like narrow gorges of the tributaries (rivers of Jruchula, Nekrisa, Bogiristskali, Tabagrebisghele, Rganiseghele, Katskhura, Sadzalikhevi, etc.) of the Kvirila River. Among them are the morphologically separated limestone massifs (Sareki, Darkveti-Zodi, Mghvimevi, Bunikauri, Tabagrebi, Rgani, Perevisa, Shukruti, Itkhvisi, Sveri, Merevi, etc.), the absolute height of which is 550-800 meters above sea level (Figure 4).

Figure 3. Chiatura Municipality

Figure 4. Chiatura town (photo by Lado Mumladze)

Chiatura municipality is one of the important industrial districts of Georgia. Here the manganese mining has a history of more than 100 years, and this process is still underway. Unfortunately, ensuring reasonable management of anthropogenic influence on the environment is a difficult problem today.

Chiatura structural plateau is one of the most damaged regions in Georgia in terms of karst-geoecology, which is mainly related to wrong and predatory mining of manganese, which, accordingly, has led to a sharp expansion of the karst territories involved in economic activity and increased the karst related negative phenomena.

Deformation of the surface of the relief ecquired the systematic character in the region of manganese distribution; the exodynamic processes have been activated as well; the relief, surface and underground karst water regime and chemistry are modifies, and the most alarming is the fact that the drinking

springs are being polluted (Lezhava, et al., 1989; Lezhava, et al., 1990; Lezhava, 2015). The town of Chiatura and adjacent villages are mainly supplied with vaucluse karst waters and it is easy to imagine what serious problems are created in water supply of population.

CHAPTER 1
Main factors of formation of underground karst waters

Chiatura structural plateau is one of the most interesting parts of the karst relief evolution and it is the compound part of the karst belt of the intermountain lowland of Georgia. This karst region comprises the easternmost part of the karst belt of western Georgia and represents one of the most important regions of platform karst in the Caucasus. Geologically and structurally, as part of Georgia's block, it is represented by two structural levels: pre-Cretaceous foundation and Cretaceous-Neogene platform cover; paleogeographically the latter is divided into two subhorizontal sublevels: the Cretaceous carbonate and Neogenic terrigenous.

Structural-tectonic conditions and geological structure of the study area have been studied in order to determine the formation and direction of underground karst waters in the conditions of platform karst.

1.1 Structural-tectonic conditions

Field surveys and cameral treatments carried out by us, identified that the **structural-tectonic conditions** of the metioned territory play the important role in the formation and movement peculiarities of Chiatura region's underground karst waters.

For advanced study of tectonic situation we decoded the aerial images of Chiatura structural plateau, which enabled us to draft a detailed scheme of fault dislocations and specify the karst forms distribution regularities. On the basis of decoding, the dense network of the previously unknown faults and fissures of various directions was revealed. The fault dislocations seem to control the absorption of underground flows and the roads of their movement (Lezhava et al, 2015).. Especially noteworthy are the submeridional and

sublatitudinal faults and crossing places, to which the groundwater outlets are related and in general, the intensification of karst formation (Figure 5).

It seems that the leading role in the formation of Chiatura structural plateau's karst relief belongs to a block tectonics (Gamkrelidze, 1969; Lezhava, 2015), which is clearly seen by the structural decoding of aerial images as well. The same refers to the bed topography (Figure 6) of the upper tectonic stage (Mesozoic-Cenozoic) of the plateau, which we restored based on the analysis of the drilling wells and geological sections (Figure 7).

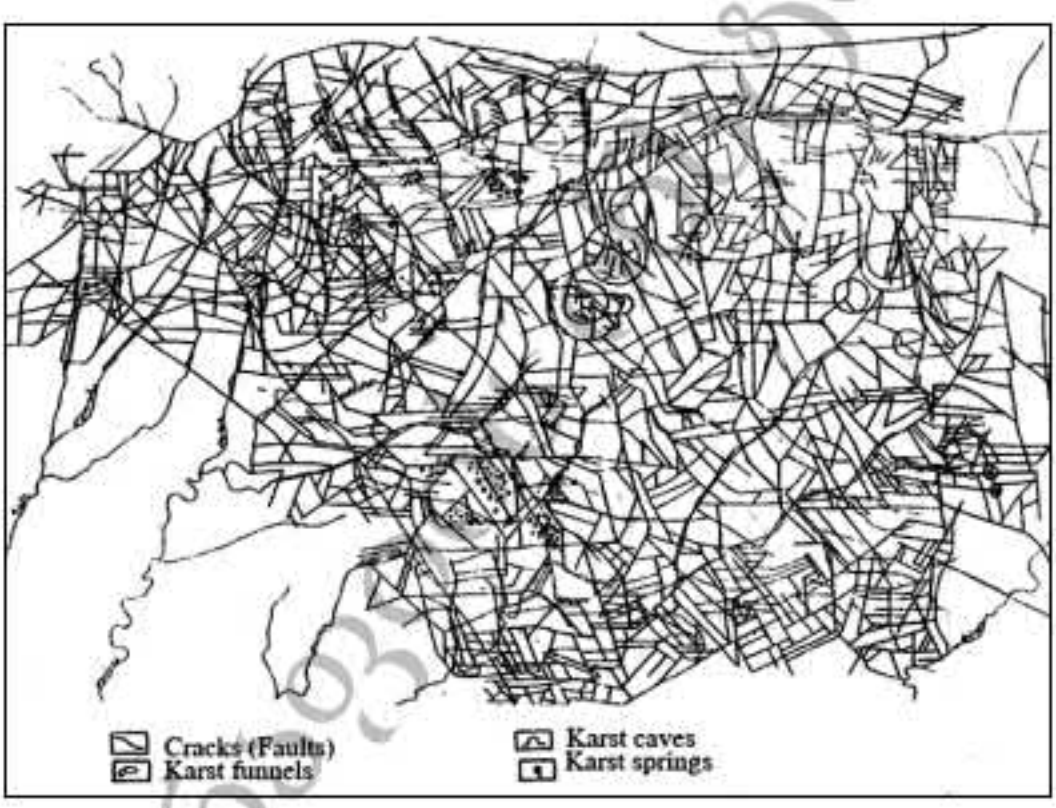

Figure 5. Fault dislocation scheme of the Chiatura structural plateau
(Compiled by decoding of the aerial images)

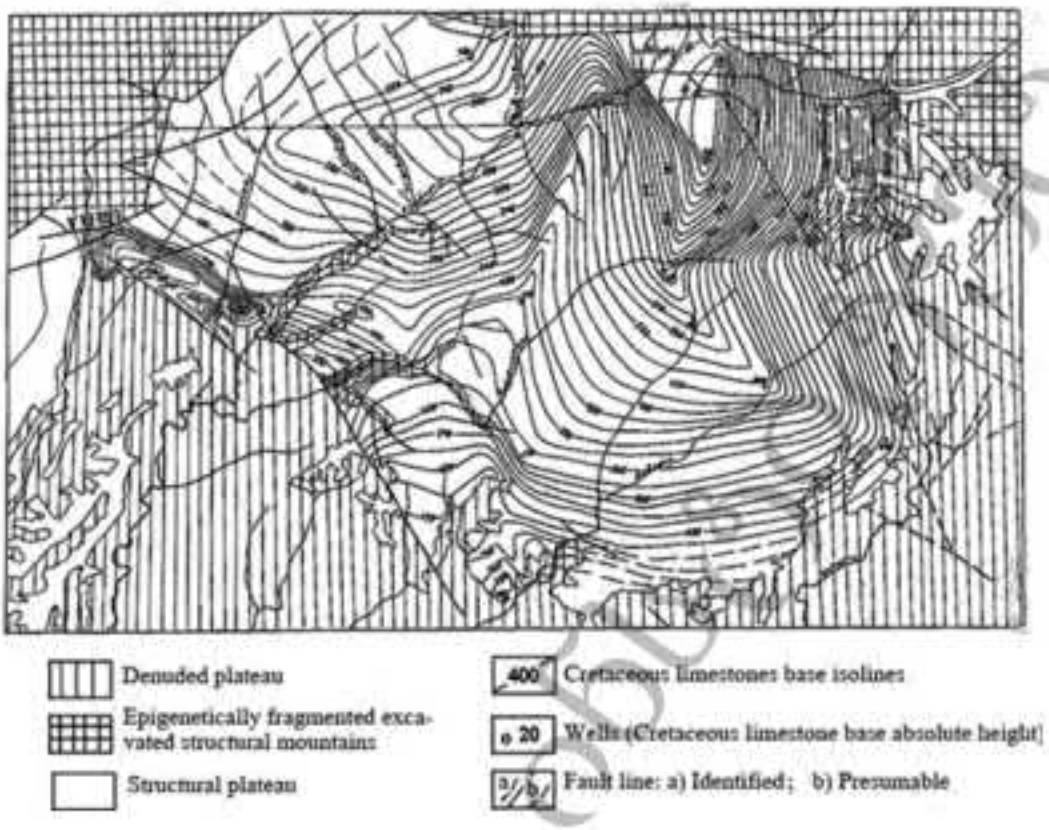

Figure 6. Topography of the upper tectonic stage (Mesozoic-Cenozoic) underlayer of the Chiatura structural plateau

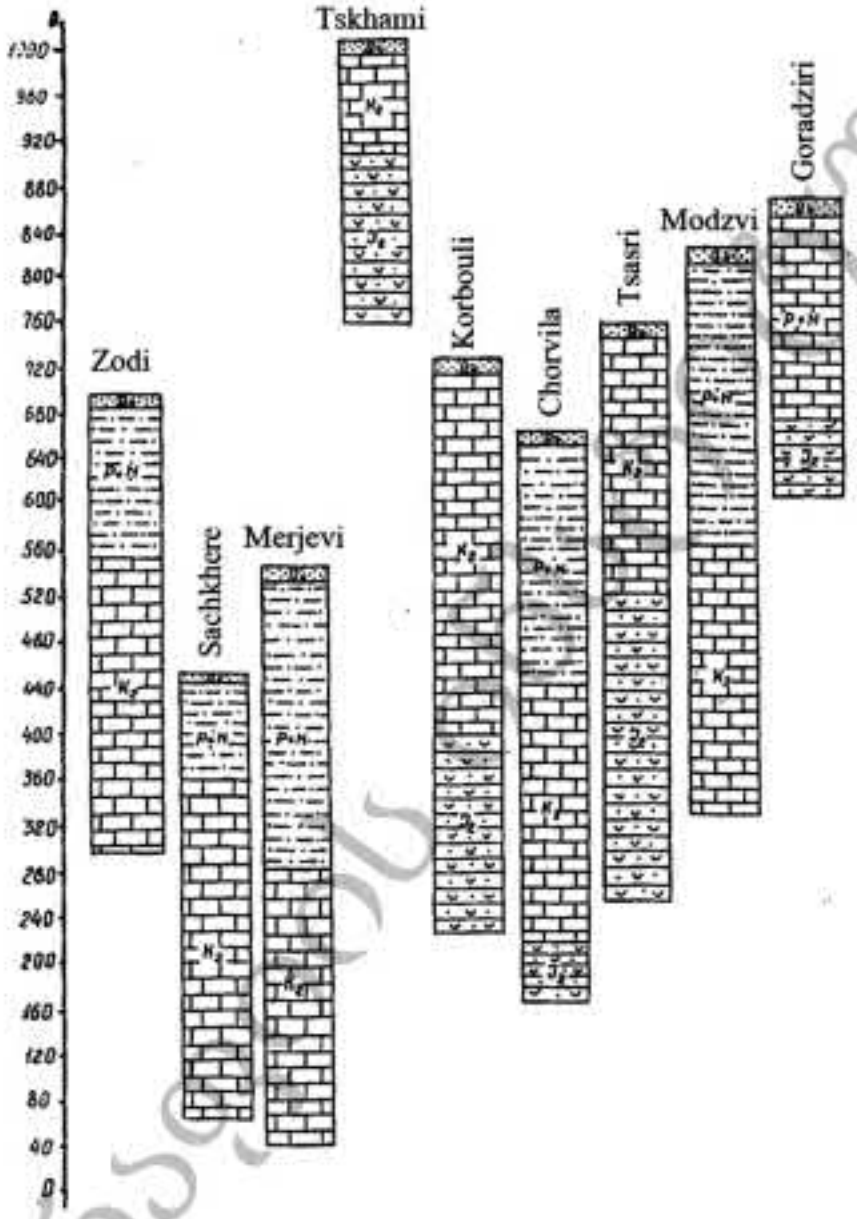

Figure 7. Geological section of the drilling wells in the Zemo Imereti (Chiatura) structural plateau

Based on the above mentioned materials we conducted the paleomorphostructural zoning of the Chiatura structural plateau and separated the two hydrogeological basins, into which the karst water concentration zones were recorded (prospective areas of drinking water supply); in particular, under the Jruchula River bed and in the vicinity of Sachkhere, from which it is possible to obtain clean waters by means of the wells for the water supply of the Chiatura town and its surroundings (Figure 8).

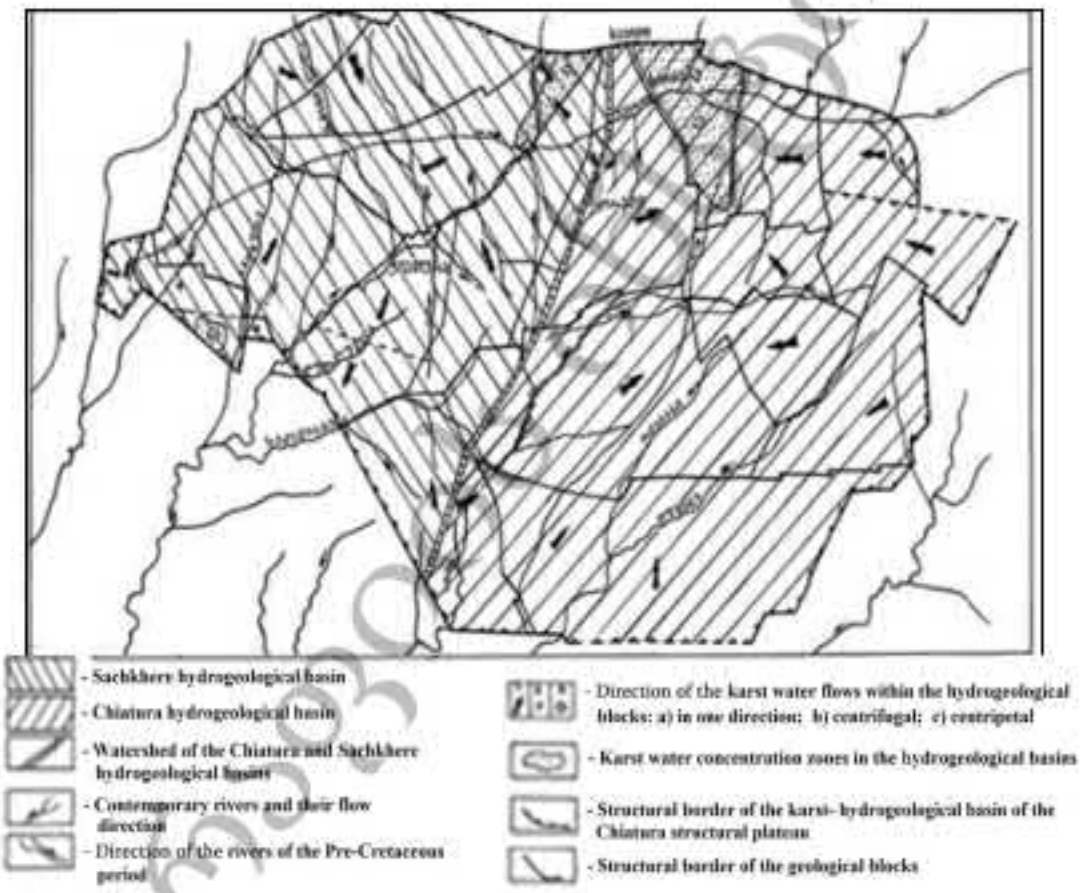

Figure 8. Paleomorphostructural zoning of the submerged block of the Chiatura structural plateau (According to the General Scheme of the hydrogeological situation)

During the separation of individual blocks with the fault lines, it was taken into consideration that the crystalline foundamention within the Chiatura structural plateau has been raised on different heights, and the section of sedimentary cover and capacity is also different. The direction of the underground karst waters movement inside the individual blocks separated by faults seems to be different, but it is not excluded that there is a water shift among the blocks as well. Inside separate blocks and at the same time, the underground karst waters traffic trends have been practically confirmed within the Chiatura hydrological basin on the basis of the indicator experiments conducted by us (Figure 27).

Thus, the block-fault disorders, along with intense depth fragmentation, play an essential role in the karsto- and speleogenesis of the Chiatura structural Plateau, identifying their morphological characteristics, hydrological-hydrogeological features of underground streams, and control the absorbtion centers of the underground streams and their movement routes.

Besides, considering the geological structure of the neighboring territories and fault dislocations, it may be possible "foreign" waters to enter from the northern slope of the Racha limestone range in the common underground basin of the Zemo Imereti (Chiatura) structural plateau; this is possible due to their connecting narrow (1.5–2km) neck (Figure 9) composed of Hauterivian limestones. The above-mentioned circumstances give the Chiatura municipality water supply system the prospect of complete water protection from pollution. Therefore, in the future, it is necessary to carry out large-scale indicator experiments in the above-mentioned area.

1.2 Geological structure

Geological peculiarities of the region was studied. Chiatura plateau's platform cover, which is the main object of our study, is represented by the two subhorizontal stages: Cretaceous-carbonate rocks and Neogene-terrigenous deposits (Gamkrelidze, 1969). Cretaceous limestones are wide-spread in the Chiatura structural plateau and reach the significant widths, the capacity of which changes within 50-320 m and eaqual to 230- 240 m in averidge (Kakhadze, 1941).

Tertiary sediments are also widespread in the region, which lie on the top of the Upper Cretaceous limestones transgressively. At the same time, the Tertiary sediments, as well as the upper Cretaceous ones, are characterized with the horizontal layout within the structural plateau (Figure 9).

Tertiary sediments section begins with the Oligocene-Miocene sediments is mainly comprised of non-carbon clays and quartz sandstones. In the Chiatura structural plateau (c. Chiatura vicinities) the Chiatura manganese deposits are associated with the mentioned sediments. In the vicinity of the mentioned deposits the suites are divided into the three parts lithologically: the lower part, so called underore horizon, is comprised of gravellites and quartz sandstones; the underore horizon is being substituted by the so called productive suites, which is presented by the alternation of thin layers containing manganese and bad rocks (sands and clays).

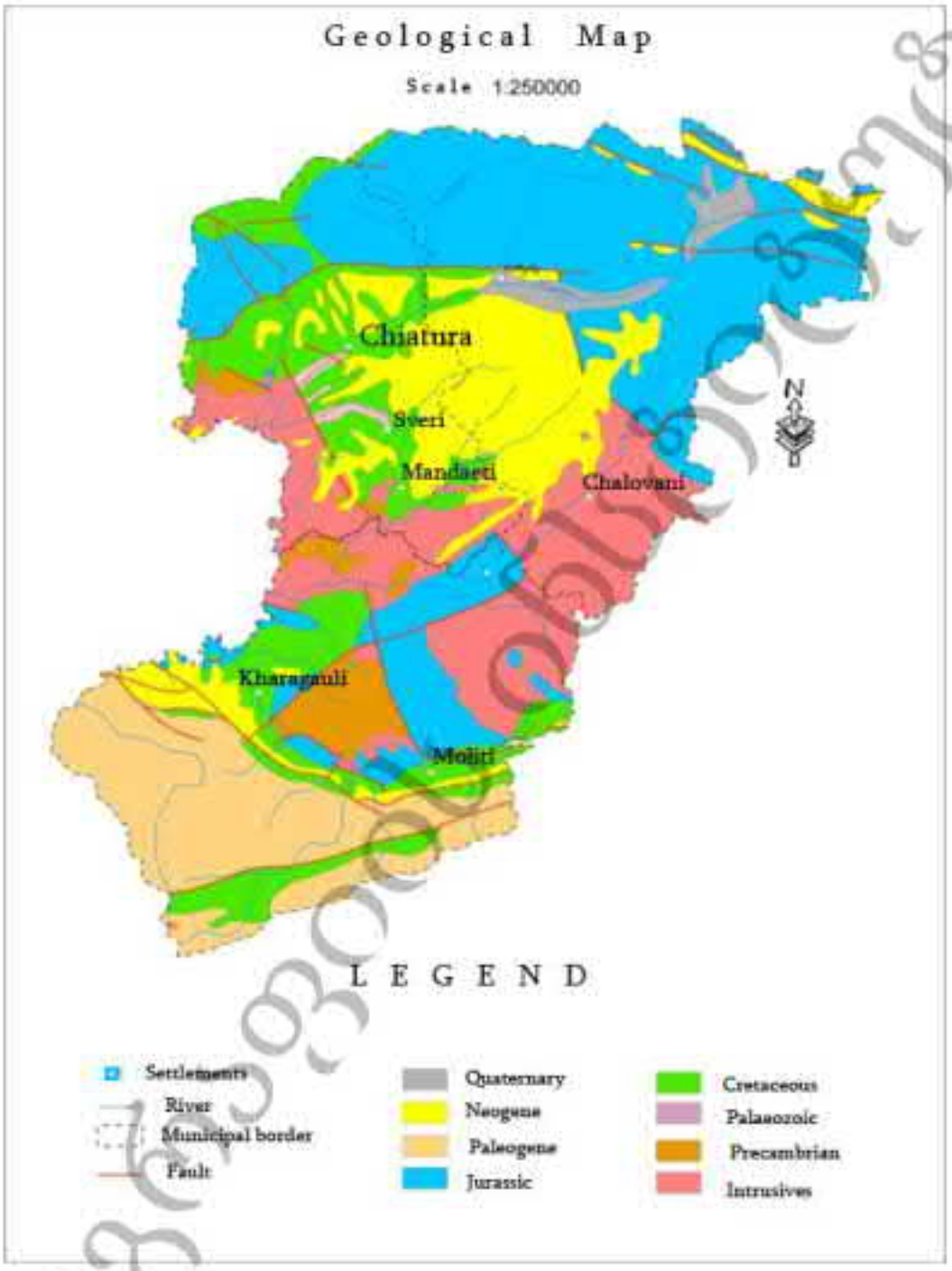

Figure 9. Geological map of the Zemo Imereti Plateau

Capacity of the productive suites varies from several meters to 12-15 meters. The productive suites in the Chiatura mining zone are covered by the spongolithic thin layered sandstones and clay sandstones from the top, which are followed from the top by the gray thin layered limestones. The thickness of the mentioned mentiones seried ranges within 10-90 m in the mining zone (Figure 10).

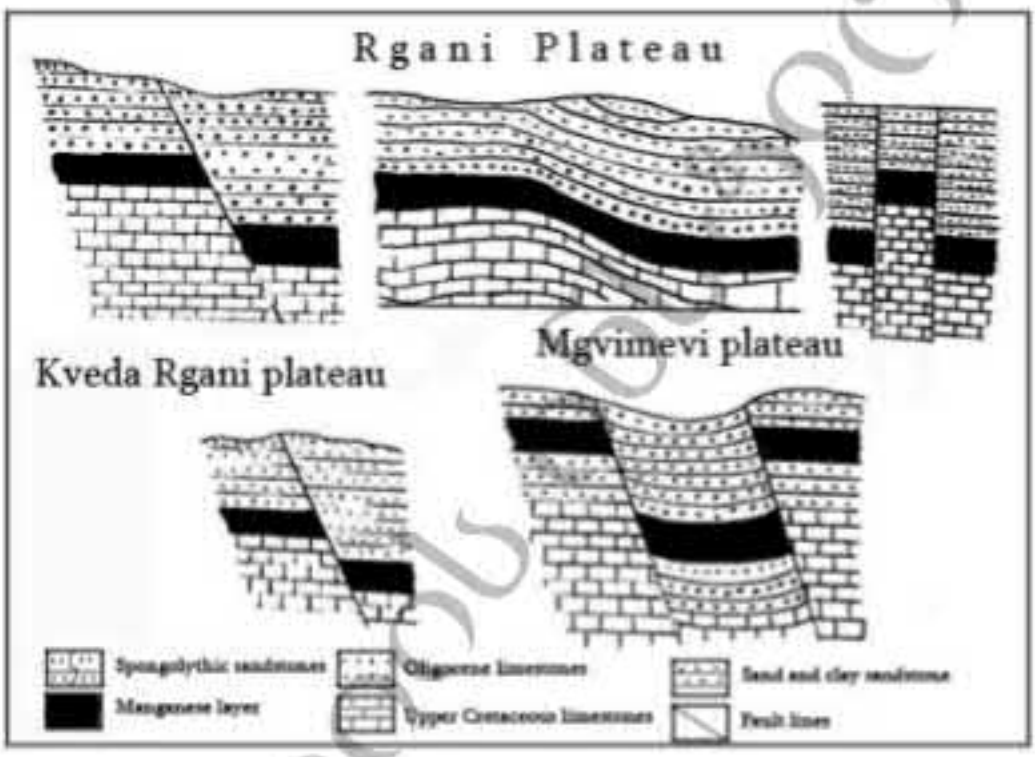

Figure 10. Layout of fault dislocations and manganese layers in the Chiatura structural plateau

A significant distribution has the middle Miocene (Chokrak, Karagan, Konka, Sarmatian) deposits, which cover the older formations transgressively.

Thus, based on the desk and field surveys, it can be said that the situation in the study area is as follows: in the significant area of the Chiatura structural

plateau, the Upper Cretaceous limestones are covered by the Oligocene - Miocene sandy - clay layers, due to which the water circulation in the depth is somewhat complicated and therefore, the karst process speed should be slowed down. In addition, the atmospheric precipitations are filtered through the sandy-clay layers before leaking into the karst fissures and in this form they get in limestone rocks.

Such natural conditions are often violated in Chiatura region due to industrial and agricultural activities, and an intense destruction of upper cover of limestones is underway. In the areas, where the sheet cover destruction takes place, the karst processes take place intensively and the uinderground streems, in the form of turbulent and contaminated water, through the complicated ground flow into the cracks and ponors developed in limestones, from which they get in the karst springs used for drinking water. As evidence we compiled the blokdiagrams (Figure 11) to show the geological and hydrogeological situation of one of the plateaus.

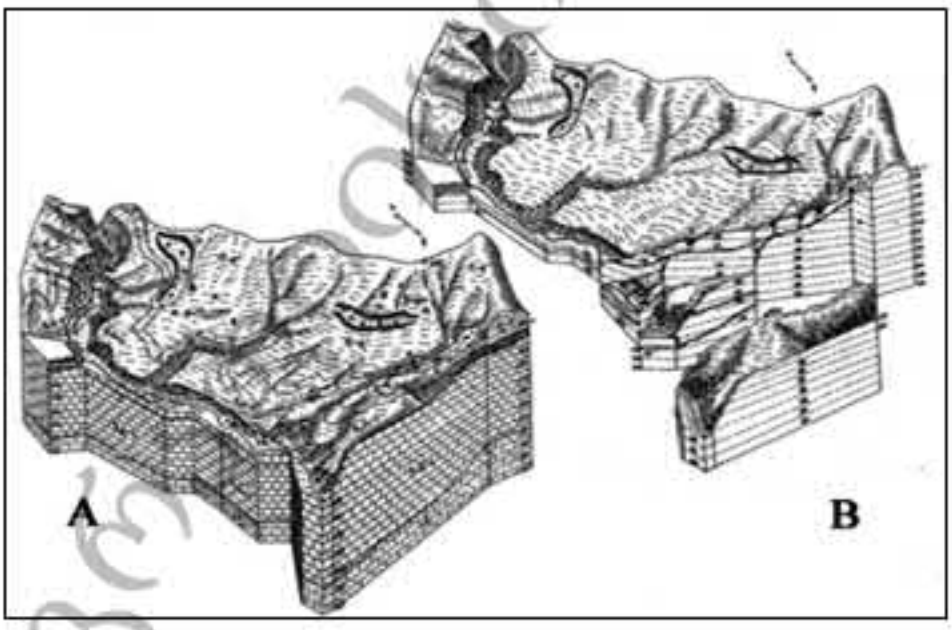

Figure 11. The Geological Conditions of Karst Phenomena Development (A) and Hydrogeological Situation (B) in the Darkveti-Zodi Plateau (Block-Diagrams)

CHAPTER 2
The main causes and factors of turbidity-pollution of the karst waters

There are areas, where the manganese extraction-related activities are particularly vulnerable to the sheet cover devastation and destruction (Figure 12).

In Chiatura region the exploitation of manganese mine has over 120 years history. Here, at present, the total length of artificial tunnels exceeded 400 km at 150 km^2 area. Frequent and powerful explosions conducted in mines significantly contribute to the expansion or formation of new cracks in the limestones formation and activation karst processes.

Figure 12. Distribution of Chiatura municipality manganese open quarries (white spots) according to the aerial image

In addition, due to the mounting poles rotting in the abandoned mines, a frequent arch wide collapses take place, causing cracking and destruction of the massif built by Oligocene-Miocene age suites located in the Cretaceous limestones, as well as relief's heavy deformations, development of landslide and erosion processes, drying of water-bearing horizons (especially of Chokrak) and in general, sharp change in the hydrodynamic situation of the region.

Karaga-Konka, Chokrak and Oligocene-Lower Miocene aquifers separated by the waterproof layers from each other through vertical cracks formed as a result of collapse, were connected hydrodinamically to each other and all above mentioned horizons were, in their turn, connected hydrodinamically to the Upper Cretaceous limestones located beneeth them (this is stipulated by the fact that there is no distinct one common waterproof horizon in the region).

Due to above mentioned, in such areas the atmospheric precipitations get directly into the limestones and the karst activation processes takes place. This process is particularly intense in Perevisa, Mghvimevi, Kveda Rgani and Rgani and plateaus, where the manganese suites are located on the uneven surface of the Upper Cretaceous limestones (Figure 13).

Figure 13. Manganese layers located on the surface of the Upper Cretaceous limestones

Development of in-depth cracks stipulated ceiling collapse-filling and destruction of some caves developed in the plateau (Pirana abyss, Kvatia Cave, etc.). The wells, which were made in the Oligocene-Miocene deposits by the population, were massively dryed up; springs were massively dryed up as well as.

Since 1950 in the Chiatura plateau, has begun ore processing in the open pit, which destroyed the important area (2640 hectares) not only of the soil cover, forest massifs and pastures, but also it changed the relief. Predatory extraction of ore requires removing of about 5 million m^3 of rocks annually (Gongadze, 1982). The area occupied by the bad rocks is 10-15% of the study area at present (volume of the bad rocks is 3.5 million m^3 in the Nikrisa River gorge).

Horisontal and shallow allocation (at a depth of 10-45 m from the surface) of a very powerful ore comprising layers contribute to manganese mining in the open pits. Such a form of manganese extraction is followed by the activation of karst processes, which is expressed by the leakage of aggressive shallow waters in the newly opened fissures. Frequent and powerful explosions significantly contribute to the idenning of the old and creation of new cracks. In the south-western and eastern parts of Darkveti plateau, the Oligocene-Lower Miocene suites located above the limestones are almost totally removed due to manganese mining in the open pits. Many sinkholes were formed in the messed bad rocks, from the bottom of which the water leaks into the limestones (Figure 14).

Figure 14. Messed bad rocks after the open pit manganese processing

Similar situation is in the Mgvimevi, Itkhvisi, Perevisa, Rgani and other plateaus. Manganese suites in the Perevisa and Rgani plateaus are often located directly in the cracked Upper Cretaceous limestones due to which the waterconsumption process is more intensified. In addition, during the heavy rains an intensive erosion of loose rocks takes place and the polluted waters directly get into the karst springs through the cracks, which often leads to turbidity and pollution of Chiatura drinking waters (Figure 15).

Figure 15. Badland relief remaining after the manganese processing

Frequent explosions in the quarries contribute not only the relief deformation and cracks origin, but also the air pollution. Due to explosions the 3-4 tons of dust and manganese are emissed in the air daily. In the 180000 m^3 of waste poluted waters, flowing into the Kvirila River from the manganese washing plants annually, contain 5000 tons of floating particles.

The actual concentration (which is equal to 3995 m.gr/l and 24 m.gr/l respectively) of floating particles and oil products in the purified water, is several times higher than the limit value norms (accordingly: 6.0 m.gr/l and 0.3 m.gr/l) (Davitaia, 1988). Highly contaminated is the tributaries of the Kvirila River, in the beds of which the manganese is washed after they are withdrawn from the mines (Figure 16).

Often karst sinkholes and wells are used as open landfills by the local population; we have registered many of the landfills in the Rgani, Mgvimevi, Bunikauris, Darkveti, Sveri and other plateaus, villages and their surrounding areas (Figure 17). Their connection with the Ghrudo, Monastristskali, Kldekari, Tiri and other springs involved in the Chiatura town's water supply system actually has been proven on the basis of the indicator experiments.

Figure 16. The Rganisghele River polluted by the washed manganese wastes

Figure17. Karst sinkholes and wells turned into the landfills by population

In poor conditions are head buildings and water catchment basins of single springs involved in the Chiatura town water supply, most of which are outdated and need to be updated. In some of them the sanitary rules are not observed at all. Especially our indignation and surprise was aroused by the condition od Lezhubani head building in the Rganisghele River bed (in its downstreams) and espacially of water catchment basin, where no sanitation and safety measures are observed. Anyone can freely enter the territory (even the domestic animals); we found open water tank covers everywhere, where we went down by stairs and saw the insanitariness – there were leaves in the water, as well as plastic bags; water color had changed and oily spots were observed (Figure 18).

Figure 18. Contaminated head buildings and water catchment basins in the Rganisghele River bed

We thought that this head building was not functioning, but as we identified later, a significant part of the Chiatura population is supplied with a water collected in this water catchment basin that creates organic and bacteriological contamination risks of drinking water.

CHAPTER 3
Hydro-chemical features of karst waters

To solve a number of karstogenesis issues (substances migration, formation of underground karst water composition and etc.) in Chiatura structural plateau and karst water chemical composition (namely, surface streams, karst springs and cave streams macro and micro elements), and in order to identify the chemical regime, our expeditionary team conducted the series of hydrochemical studies. For this purpose, about dozen samples were processed in the laboratory (chemical analysis were performed in the Analytical Chemistry Laboratory of Ivane Javakhishvili Tbilisi State University. Figure 19).

Figure 19. Contaminated water in the tap observed during heavy rains (Chiatura; photo downloaded from the internet source) and water samples control in the Analytical Chemistry Laboratory of Tbilisi State University

Research results have revealed that in the investigated region the underground karst water mineralization is 1.5-3 times higher than the corresponding figures of other karst regions of Georgia (Supatashvili, et al., 1990). The reason is not only the region's complex lithological-stratigraphic structure, but also a wide distribution of manganese ore pits. In the open pit

areas intensive wash of substances from loose rocks takes place (especially during heavy rains). Due to the mentioned reason, in the left side of the Kvirila River, where the quarries are relatively less represented, karst springs are about twice less mineralized than in the right side (Σ_i 422 and 712 $mg.l^{-1}$ respectively).

On the example of underground waters of Zemo Imereti plateau, close relation between the regions' base rocks and karst waters' chemical composition can be observed (Table 1).

Table 1. Correlation between the underground karst waters' chemical composition and the region's base rocks

Rocks	pH	$Mg.l^{-1}$						
		Cl^-	SO_4^{2-}	HCO_3^-	Na^+	Mg^{2+}	Ca^{2+}	Σ_i
Pure limestone	8,03	0,4	1,1	183	3,3	5,0	51,4	244
Sandy and marl Limestone	7,83	1,2	6,6	242	4,9	9,4	64,1	328
Dolomite Limestone, gypsum	7,62	8,9	165	261	15,6	34,0	91,0	575

The least mineralized are the waters, which wash pure limestones. By maximum values are distinguished the main ions (Σ_i) of the waters, which wash dolomite, magnesites, gypsums and other rocks. High mineralization of sulfate - magnesium waters is stipulated by good gypsum and magnetize soluble ability compared to due limestones.

Mineralization increases regularly in the water samples we studied in the following order: surface stream –karst spring – cave stream. However, the deviations are found as well. In particular, abnormally high mineralization (Σ_i - 960 $mg.l^{-1}$) is characteristic to the Nekrisa River, which is fed also by karst springs of high mineralization and cave streams (Σ_i 1052-2290 $mg.l^{-1}$ respectively). Such high rates of mineralization in this case, mainly is due to

wide distribution of manganese quarries in the feeding basins of underground karst waters. Often inflow of influential waters is one of the main reasons for the decrease in cave streams mineralization (Table. 2).

Table 2. Change in mineralization (Σ_i) value in the different sections of the cave

Caves	Number of samples	Σ_i, mg.l^{-1}			
		Entrance	Exit	Tributary	From stalactites
Khvedelidzeebisklde	7	371	385	-	401
Shvilobisa	7	347	302	312	275
The pits	8	1800	1959	1892 (lake)	-

Content of manganese and boron in the karst waters that we have investigated is increased comparing to surface waters of other regions of Georgia (Table. 3).

Table 3. Microelements (mkg.l^{-1}) and acidity (mg.l^{-1}) content in the karst underground waters of Zemo Imereti plateau

Acidity element	Karst springs		Cave streams		Surface waters of Georgia	
	Min., Max.	Average	Min., Max.	Average	Min., Max.	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	-

This fact can be explained by the wide distribution of manganese ore in the investigated region and a direct relationship between boron content and mineralization values in natural waters (correlation coefficient is +0.84).

On the basis of prior conducted identification of permanganic acidity in the cave stream and karst spring, the existence of hydrogen sulfide was recorded only in two cases (Tuzi Cave; springs in the vicinity of the Tuzi village). But in this direction a deep and qualified researches should be carried out in the future, as the mentioned fact and a number of contaminated water absorbtion centers detected during our field studies and in addition, their direct connections to the karst springs (which is indicative of our experiments was determined by a) do not exclude the threat organic and bacteriological pollution of drinking water.

CHAPTER 4
Outputs of underground karst waters tracing (indicator tests)

To strengthen our views and assumptions on the basis of the conducted studies (in order to the proof it practically), also to identify the direct relation between the polluted water loss centers detected by us and karst springs used as drinking water, our expedition team conducted the indicator experiments (dyed waters tracing) in the different parts of the Chiatur structural plato.

For the experiments conducted by us, a water marking method was used. For this purpose, we selected pure fluorescein that can be discovered in the stream even in case of very large dilution. We launched the dyed solution both in the previously detected surface streams and in the sinkholes and holes as well. In order to record a dye, launched in the waterabsorbtion center, we placed the activated coal bags in the expected discharged centers. Such coal has an fluorestcein adsorption or containment ability. It contains even the minor amount of fluorescein in the water and maintains for a long time. Activated coal can be separated from fluorestcein any time by KOH's alcohol solution of 5%.

We were identifying the existence of the traced substance in the filtered solution by means of the improvised fluoroskope (we use it successfully for years), which is equipped with ultra-violet impulse two bulbs and purple lightfilter (Figure 20). The use of activated coal bags enabled us to systematically control over all springs. In this case it is not necessary daily shifts at the checkpoints. In addition, at some checkpoints it was possible to determine the stream speed by periodically changes of the coal bags.

Figure 20. 1) Laboratory control of the solution diluted by fluoroscein in the water through fluoroscope; 2) During the desk works

The first experiment was conducted in the water loss center of the Rganisghele River (Kvirila River's right tributary) in the area of limestone active quarry, at 1.5 km beyond Lezhubani drawned-out springs. 3 kg of fluoroscein solution was launched in the mentioned waterabsorbton center (Figure 21).

Figure 21. Experiment conducted in the Rganisghele River bed and the dyed stream observed in the Monastery spring

In the meantime, at all suspicious springs, where the apparance of the water dyed with fluorescein was expected, the checkpoints were arranged with the activated coal bags. After 4 hours of launching the dye in the water, the Monastery spring water, involved in the Chiatura water supply, was clearly dyed and the outcome of dyed water lasted for several hours. In other springs the dyed stream was not observed visually, but the laboratory examination of activated coal showed a positive sign of passing fluorescein through the Ghrudo and Chikauri springs.

Thus, experimentally was proven that the springs absorbed in the Rganisghele River bed flow along the tectonic fault line, pass the bottom of the Bogiristskali River from below and discharge in the Monastery spring, which is involved in the Chiatura water supply system. Part of the stream reaches the Ghrudo spring (Figure 22, Table. 4).

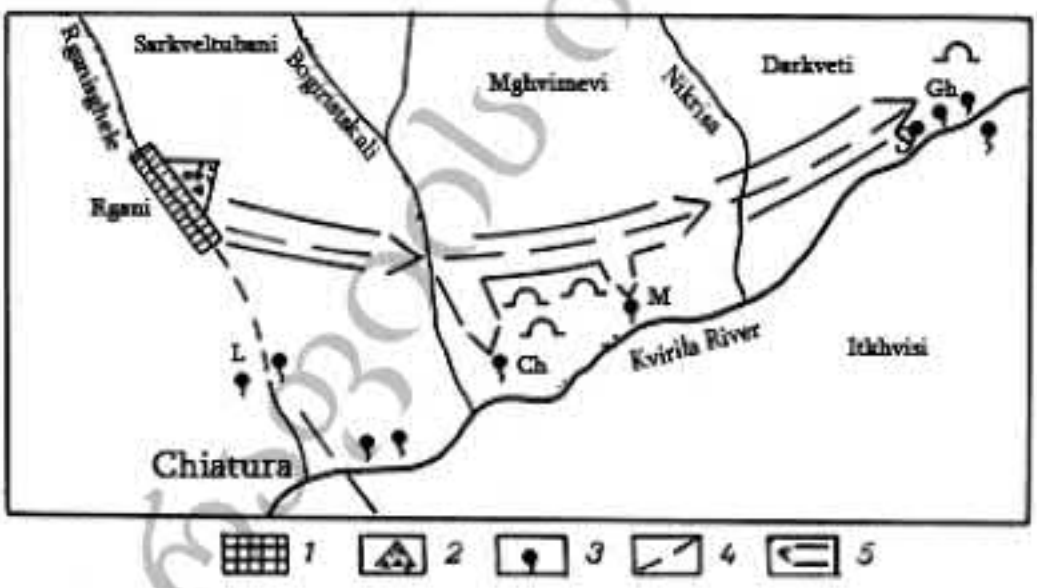

Figure 22. Groundwater flow movement scheme obtained by indicator experiments conducted in the Rganisghele River bed

1 – Water absorbtion center (paint dropping place); 2 - Limestone quarry; 3 - Karst springs: Ghr - Ghrudo, S – Spring near Ghrudo, Ch -chikauri, M- Monastery, L- Lezhubani; 4 - Fault lines; 5 - Groundwater movement direction

Table 4. The results of the indicator experiments in the Rganisghele River bed

Checkpoint name	Absolute height, m	The distance among the water loss and exits, km	The dye passage time, h	Groundwater flow movement speed, m / h / km / day
Monastery spring	355	3	4	750 / 18
Bogiristskali River	375	2,5	3	833 / 20
Ghrudo	370	6	9	667 / 16
A spring near Ghrudo	368	5,8	8	725 / 17.4
Chikauri tskaro	363	3,5	72	48 / 1.2

The next indicator experiment was conducted in one of the old sinkholes (720 m a.s.l.) occured in the top of the manganese wastes' horizon in the Rgani plateau (Figure 23), where, in the rainy period the temporary streams flow into and through the cracks flow in the depth. At this time the fluorescein of 3.5 kg was launched into the water.

18 hours later from launching dye the labeled water was detected in the Monastery spring by checking it with a bag with coal. Flow of the dyed stream was not visually detected in the other checkpoints. Laboratory testing of activated coal confirmed the weak sign of the fluorescein passage only in the Tskhrili and Tiri springs after long time (Figure 24 and Table. 5).

Figure 23. Experiment conducted in one of the sinkholes of the Rgani plateau

Figure 24. Groundwater flow movement scheme obtained by indicator experiments conducted in the Rgani plateau

1 – Dye launching place; 2 - Limestone quarry; 3 - Karst springs: M - Monastery, L - lezhubani; Ts - Tskhrili, Ghr - Ghrudo, T - Tiri, 4 - Fault line; 5 - Groundwater movement direction

Table 5. The results of the indicator experiments in the Rgani plateau

Checkpoint name	Absolute height, m	The distance among the water loss and exits, km	The dye passage time, h	Groundwater flow movement speed, m / h km / day
Monastery	355	5,7	18	316 7.5
Tiri	420	5,5	240	23 0.5
Tskhrili	610	1,5	192	8 0.2

In the past years, our expedition team conducted similar indicator experiments in the north-eastern and eastern parts of the study area: in one case, the dye was loanched in the karst water absorbtion ponor located in Darkveti plateau, and in the second case – in the water absorbtion ponor located in the Sachkhere cotton spinning area (Lezhava, et al., 1990; Jashi, et al., 1997).

The loanched fluoroscein trace was discovered in all karst springs of large or small debit which flow out at the bottom of side precipice of the Chiatura plateau. Therefore, we did not consider it necessary to repeat the experiment in this part of the region.

The indicator experiments were conducted in the left bank of the Kvirila River too. For this purpose, many karst sinkholes, wells and caves were studied in the Sveri plateau. The local population use the part of the karst sinkholes as landfills. Most of them are ended by ponors or transfer into the well, and in some sinkholes temporary lakes are emerged. The latters are often swamped and much polluted.

In the mentioned three areas of the Chiatura plateau, the three indicator tests were carried out – in one of the garbage polluted karst sinkhole in the Sveri plateau, Kotiasklde and Zakariasklde Cave. In all three cases the water dyed with fluorescein was observed in the springs involved in the watersupply

system of Chiatura town and flown in the territory of the villages. Results of experiments are given in the iages, schemes and tables (Figure 25 and 26; Tables 6 and 7).

Figure 25. Results of indicator experiments

Figure 26. The underground streams flow scheme obtained by indicator t experiments conducted in the Sveri plateau

1 – Dye launching place: S. w. –Sveri well, K. C.– Kotiasklde Cave;

2 - Karst springs: K - Kldekari, Ghr.- Ghrudo, B - Bondi, K- Kvabisi, T- Tvalueti, Ts - Tsereteli; 3 – Direction of groundwater movement

Table 6. Results of the indicator tests in the Sveri Plateau

Checkpoint name	Absolute height, m	The distance among the water loss and exits, km	The dye passage time, h	Groundwater flow movement speed, m / h / km / day
Kldekari	560	1,8	60	30 / 0,7
Tsereteli	570	2,2	62	35,5 / 0,85
A spring on the left slope of the Sadzalekhevi River	580	1	24	41,6 / 1,0
Rekevisa River	550	3	64	47 / 1,1

Table 7. The results of the indicator tests in the Sveri Plateau

Checkpoint name	Absolute height, m	The distance among the water loss and exits, km	The dye passage time, h	Groundwater flow movement speed, m / h / km / day
Kvabisi	660	1,5	130	11,5 / 0,27
Ghrudo	370	11,5	240	48 / 1,1
Kldekari	560	4,5	172	23,3 / 0,55
Tsereteli	570	4,5	176	25,5 / 0.6

Thus, the indicator experiments (colored waters tracing method), carried out by us, basically confirmed the direct contact of underground springs flowing into involved in the watersupply of the town of Chiatura and the surrounding villages. At the same time the karst springs feeding basin boundaries were identified, from which the polluted waters is expected to get into the water supply system (Figure 27).

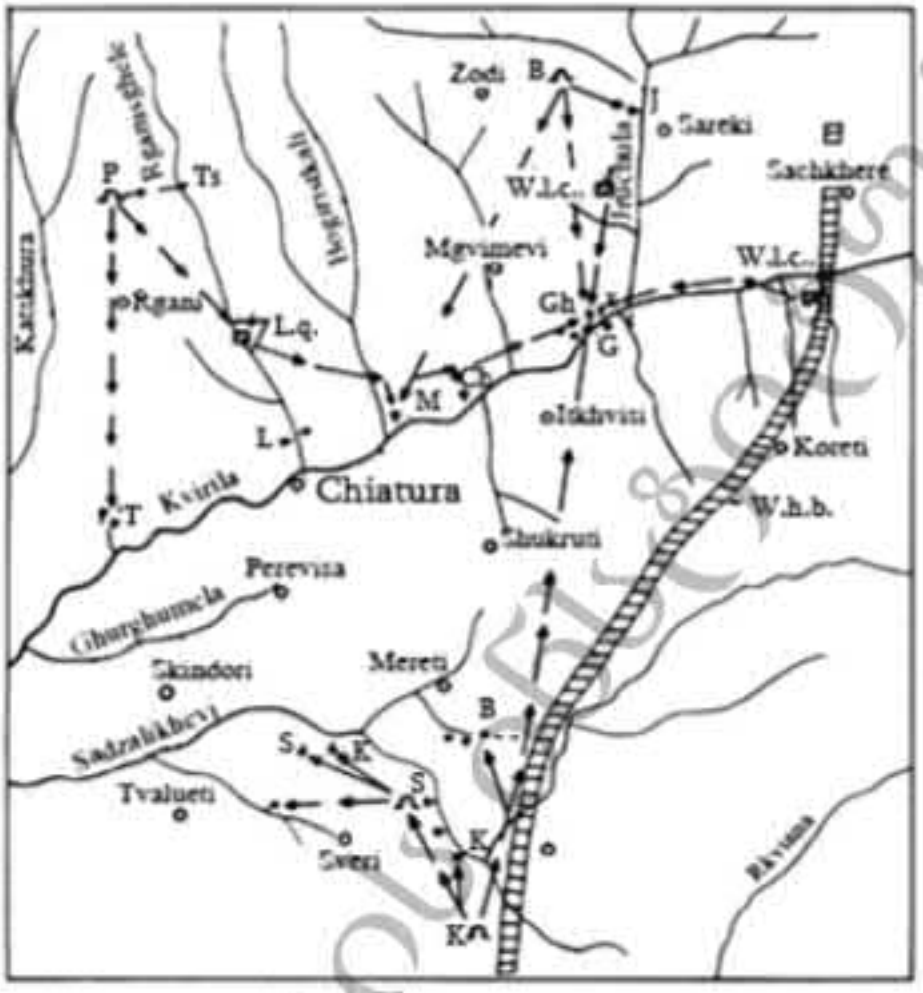

Figure 27. The Groundwater Stream Movement Scheme Obtained by the Indicator Experiments Carried out in the Chiatura Structural Plateau

→ → *– Direction of the colored waters movement*

***Karst hollows**: P– Pirana abyss, B– Barataslvilis shaft, S–Sveri well, K–Kotiasklde;*
***The main karst springs**: Gh– Ghrudo, M– Monastery, P– Pardulisklde, J– Jruchula griphon, G– Gaghma; Ch– Chikauri, L–Lezhubani; T–Tiri, Ts–Tskhrili, S– Spring near Ghrudo, B– Bondi, K– Kvabisi, T–Tvalueti, Ts–Tsereteli, K–Kldekari, W.l.c.– Water loss center, L.q.– Limestone quarry, W.h.b.–Watershed of hydrogeological basins.*

Conclusions

Laboratory, field and experimental studies have revealed man-made (anthropogenic) factors important role in karstformation and turbidity-pollution of springs. As it turns out, wrong economic activities, the geological and underestimation of the role of karst-hydrological peculiarities and the ignorance of geo-ecological forecasting caused the activation of karst processes together with the other negative consequences; a heavy geo-ecological situation was created in the karst springs' feeding basins, many springs were dried, turbidity-pollution of the waters involved in the water supply system became frequent.

Proceeding from the project objectives, on the basis of the carried out researches, the main causes, factors and centers of turbidity-pollution of the karst waters used for drinking and involved in the water supply system of Chiatura town and surrounding villages were revealed:

1. Mmanganese mining underground and open-pit extractions are expanded almost over the area of 170 km^2 in the Chiatura plateau, which led to the relief, soil-vegetation cover, surface and groundwater hydrologic regime change. Collapsing of arches of the abandoned mines and exploitation of quarries were followed by cracking and strong deformations of surfaces built by loose Oligocene-Miocene sediments, as well as the landslides and erosion processes, also the drying up of aquifers, and in general, sharp change in the hydrogeological situation of the region.

Karaga-Konka, Chokrak and Oligocene-Lower Miocene, separated from each other by the waterproof layers as a result of collapse, and Upper Cretaceous limestones aquifers were connected hydrodinamically to each other, which intensified the influation of atmospheric precipitations, activated the karst processes and contributed to turbidity-pollution of underground karst streams.

Extracting of manganese ore in the open-pit in Chiatura region is performed by wrong, it can be said, by a predatory manner, due to which limestone-

based ore containing suites are being removed, and the waste bad rocks remain there in the form of uneven embankments after finishing the opening works, so that they are not grading and recultivated.

During the heavy rains the intensive washing of substances from loose and messed bad rocks takes place and through the fractures, ponors and sinkholes exposed as a result of mining works the turbid and polluted waters directly get into the karst springs that intails the Chiatura drinking waturbidity-pollution of Chiatura drinking waters. Such connections were identified on the basis of indicator tests.

2. Washing of manganese, excavated in the Chiatura plateau, takes place in the river beds of the Kvirila River tributaries that also contains the additional threat in terms of turbidity-pollution of karst waters involved in the Chiatura water supply system. In this case the Rganisghele River (the right tributary of the Kvirila River.) is particularly noteworthy, in the bed of which the intense process of manganese ore washing and water pollution is underway that is unacceptable and risky, because here along the river bed the fault line passes, and in the bed the water loss centers are observed; on the basis of indicative experiments we practically confirmed the relation of manganese seturated polluted waters leaked from the above mentioned water loss centers with the Monastery spring involved in the Chiatura water supply system. This process is also contributed by the open limestone quarry on the left slope of the riverbed, where the produced explosions further increases the risk of water leakage under the riverbed.

3. In the Chiatura plateau, near the villages, the problem of landfills is unregulated. They massively use the sinkholes, wells andshafts as lkandfills, which is absolutely unacceptable, because the mentioned karst forms have direct contact with the underground karst streams. The waters leacked there during the rains and snow melting, flow out in the day lightin the form of karst springs, majority of which are used as the drinking waters (eg., Tuzi well and Cave, Sveri sinkholes, Mandaeti sinkholes, wells and etc.) This fact

stipulates the creation of a big danger not only of turbidity, but the organic and bacteriological pollution of drinking water as well.

4. Head buildings and water catchment basins protection and control mechanismis completely collapsed. To get there and go to the water catchment basins is possible freely. There is no sanitation supervision there; the entrance into the basins are open or left without locks. In the basins the water is discolored and contaminated, where a lot of leaves and dusts are there. There is no water filtration and chlorination.

- On te basis of structural decoding of the erial images of Chiatura structural plateau, also on the basis of the analyses of geological sections and boreholes, a topography of the bed of upper tectonic stage (Mesozoic-Cenozoic) of the plateau was restored and we made the paleomorphostructural zoning of Chiatura structural plateau, where we distingushed the two hydrogeological basins, and in each hydrogeological basin the underground basins (drinking water supply prospective sites) of karst water concentrations related to the depth circulation zone was recorded under the Jruchula River bed and in the vicinity of Sachkhere, from which it is expected to obtain clean waters through the boreholes for water supply of Chiatura town and its surroundings.

- Directions of the underground karst streams within the Chiatura structural plateau are determined by the total submergence of karst rocks from the periphery toward the center, as well as the fault dislocations, which largely controll the absorbtion of the underground streams and their movement traffics. This assumption was practically confirmed on the basis of the indicator experiments carried out by us.

- Feeding basins of the Lezhubani, Monastery, Tiri and other springs, involved in Chiatura water supply system, was specified. Their feeding is performed from the Sareki, Darkveti-Zodi, Mgvimevi, Bunikauri, Tabagrebi and Zeda Rgani plateaus located between the Katskhura River

and Sachkhere, as well as from the underground streams formed within the plateaus of the Kvirila River's left side and the waters leaked from the riverbeds of some of the tributaries of the Kvirila River (eg., Rganisghele). It seems that within these borders a united karst hydrogeological system is formed with the dynamic water resources, most part of which discharches in the karst waters involved in the Chiatura town's and surrounding villages water suply system. This fact, together with the scientific meaning is of great practical importance, as far as within the mentioned borders it is possible the polluted waters to get in to the chiatura water supply system from any karst places without any problem.

- Hydrochemical studies identified that the karst waters mineralization (400 - 700 mg/l) of investigated area 1.5 - 3 times higher than the same data of other karst regions of Georgia. The reason for this is not so complex lithological-stratigraphic structure of the region, but the open-pit processing, which facilitates the processes of removal and washing down the demolition products under the ground. In the left side of the Kvirila River, where the quarries are relatively less represented, the karst springs are almost twice less mineralized compared to the ones in the right side (423 - 712 mg/l respectively).

The karst springs of anomalous high mineralization (960 - 2290 mg / l) are found as well that is associated with a wide distribution of manganese quarries. In the karst waters of investigated area the content of manganese (in Chiatura structural plateau in average by 0.15 mg/l, while in the surface waters of Georgia by 0, 02 mg/l) and boron (also accordingly: 0,22-0,29 mg/l and 0, 04 mg/l) is increased compared with other karst regions of Georgia. In some of the streams (eg., Tuzi Cave) the hydrogen sulphide was recorded as well. The existence of landfills, recorded by us around the settlements, and the results of water chemical analysis does not exclude the danger of organic and bacteriological pollution of karst waters.

- The official statistic on drinking water, air and soil pollution-related diseases and deaths (high performance) is not available in Chiatura municipality. According to information obtained by us on research results of individual organizations and agencies, the contaminated drinking water, air and soil-related illnesses and diseases are increased. As far as the main pollutant factor is still manganese, the related prevalent diseases are – manganese coniosis, manganizm, dermatitis, bronchial asthma and etc.

Labor, Medicine and Ecology Research Institute's (Director: Rusudan Javakhadze) Preventive Toxicology Department (headed by Dr. Inga Gvineria) found by years of researches in Chiatura municipality that manganese certain concentrations and quantities affect people's reproductive health and causes reduction in women and men's birth fertilization ability and menstrual disorders.

In the foreground are diseases of the nervous system, cancer and diseases of children as well as.

Recommendations

In order to reduce karst springs turbidity and protect the drinking water from pollution, it necessary to carry out the following measures:

- ✓ Agricultural works must be prohibited in the significantly inclined slopes of the karst sinkholes in the surroundings of Chiatura. Exploited mines must be filled by inert materials. Limited and civilized methods must be used for an open-pit manganese processing, and recultivation must be carried out rapidly in the abandoned quarries areas. In particular, the messed ground consisting of bad rocks must be flattened and the natural vegetation and soil cover must be timely recovered. Recommended measures will significantly reduce the washing process of slopes and messed ground, increase the solid runoff in the surface and underground streams, and therefore reduce the karst springs turbidity-pollution;
- ✓ Restoration works should be carried out at a rapid pace in the first place in south of Darkveti plateau, in the at the south-westof Mghvimevi and Rgani plateaus and south-eastern parts of Rgani plateau, from where the periodical water durbidity of the Monastery, Lezhubani and Ghrudo springs mainly occurs;
- ✓ To cancel the manganese washing plant in the Rganisghele River bed. To suspend the explosions in the limestone quarry in the river bed, as the mentioned river bed it crossed by the tectonic fault line and even a little push can lead to unexpected and unwanted results (sudden openning of the cracks and leakage of polluted waters in a big amount). To clean the river bed from the talus materials and industrial rubbish and restore its natural state. To declare the Rganisghele riverbed as drinking water sanitary protection zone. After clearing the riverbed, the filling-cementing of water absorbing centers revealed by us. It is better to isolate the flow in the section of the quarry and tectonic fault with the concrete channel, as the intensive draining in the fissures takes place in the very mentioned section.
- ✓ To suspend the extraction of manganese in the open pits in the vicinity of Pirana abyss (Rgani plateau), because in the mentioned are the tectonic fault passes and from this place the Monastery and other vaucluse springs,

involved in the Chiatura water supply system, are supplied that is proved by the indicator experiments as well;

- ✓ To establish strict control and prohibit using the sinkholes, wells and shafts for landfills. In particular, to identify the area and the number of such spontanous landfills; to clean the contaminated sites and arrange banners with special inscriptions, while in the rural areas or in the vicinity, to place special garbage bins for the population. Otherwise, if the population is not protected, this will lead to the not only the contamination of springs, but also organic and bacteriological pollution;
- ✓ In the head buildings of karst waters used for drinking and the areas of deposition basins, it is necessary to restore control and monitoring service (it is now canceled). It is necessary to change the damped pipes, to arrange deposition basins (some of the water pumps is operating without deposition basin) and filters, which allow us to avoid the unexpected flowing of heavily turbid and polluted waters into the supply system;
- ✓ As it turns out, the Chiatura municipality drinking water is managed by three companies: 1. Georgian Manganese, 2. United Water Supply Company, and 3. The local municipality. In case of water pollution they avoid responsibility, and the population has been suffering contaminated drinking water using.
- ✓ According to current legislation, the drinking waters are registered in the local municipality balance and as a rule, the control procedure should be entrusted to him as well. Early in 2000, the wrong, it can be said the criminal agreement was concluded with the investor, in this case, with the "Georgian Manganese", according to which the water supply system - pipelines, reservoirs, basins and etc. belongs to the "Georgian manganese", which states that it is not engaged in the water distribution (supply) and therefore, on the bases of the agreement the law does not make theis company responsible for conduction the drinking water filter-clearing works, since it requires only these reservoirs and water pipes only for washing manganese and for its ows technical consumption, and if manganese or other pollutants get into the pipes, it bears no responsibility at all.
- ✓ It turns out that a major polluter of the drinking water is the "Georgian Manganese"; it possesses the water supply system, mines the manganese by

predatory methods, washes the ore, where and as it please, makes population to dring the polluted water and is frees itself from any responsibility. In its turn the "United Water Supply Company" is also guilty, as the company's water quality management department that is in charge for laboratory examination of water, believes that everything is all right, and water quality is in line with the standards, while our research and the materials obtained from independent organizations show, that not everything is in order. Even in the early 2016, in Pasknara drinking water pipe the coli bacterias or the enteric bacilli have been revealed and recorded together with the other hard substances, which later on has been aired by local television (by Mr. Malkhaz Tsereteli, the Parliament member), but the United Water Supply Company kept the silence and made the population to drink the polluted water for certain period.

- ✓ According to the above-mentioned facts, we consider it necessary to review the agreement with the "Georgian Manganese"; to make organized centralization of Chiatura region water supply (in the possesion of one structure) and through the central body supervision, control and permission to carry out any economic and construction activities in the munitsipality, as far as our studies have confirmed that the following feedingbasin of karst springs involved in water supply totally covers the Chiatura structural plateaus and polluted waters can get into the Chiatura water supply system from any karst sites.
- ✓ Chiatura structural plateau complicated geological and ecological situation dictates the nessessity of further extension of karst-hydrological and speleological works and permanent moritoring of the drinking water, as far as it comes to a very important problem of water supply of population of our country's most important industrial center - the town of Chiatura.

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Authors short biographical information

Lezhava Zaza – Academic Doctor of Geography, Research fellow, karstologist, speleologist. Since 1980 he works at TSU Vakhushti Bagrationi Institute of Geography. He participated in complex studies of the speleo-objects of Gumishka-Psirtskha, Migaria, Racha, Zemo Imereti, Ertso-Kudaro, Sataplia-Tskaltubo and Odishi limestone massifs. Detailed research of Prometheus (Tskaltubo) and other cave systems was performed with his direct participation, as well as the projects related to contamination of karst waters used as a drinking water and for water supply to numbers of settlements (Chiatura and others).

On the example of Zemo Imereti structural plateau, he revealed the isolated systems of fissural-karst flows, which are conditioned by disjunctive dislocations together with the tendency of generation common level of underground karst waters in the conditions of the platform karst. He deals with the problems of karsto- and speleogenesis. He has published two monographs, about 60 research and scientific-popular works, including 20 – in the foreign publications.

Tsikarishvili Kukuri – Academic Doctor of Geography, Senior Rsearch fellow, Speleoclimatologist. He has been working for many years at TSU Vakhushti Bagrationi Institute of Geography; he is the chairman of the Speleo Club of Georgia. He is a direct participant of about 200 cave surveys. Tsikarishvili Kukuri is the author of more than 100 scientific articles and 8 monographs; he elaborated the practical recommendations for using caves for the spillotherapy and spelloturist purposes, as well as fr solving the water supply problems of populated areas, etc.

Bolashvili Nana – Academic Doctor of Geography; Director of the Vakhushti Bagrationi Institute of Geography of Ivane Javakhishvili Tbilisi State University; President of Georgian Geographical Society. The main directions of her research are the investigations of karst waters formation, sustainable management of water resources, flooding, etc.

Asanidze Lasha – Academic Doctor of Geography. Speleologist; Research fellow at TSU Institute of Geography. He is interested in research of karst processes. He studies the terms of formation (genesis) of caves, its geomorphology and karst hydrogeology. By his direct leadership a complex study of Racha limestone massive was conducted. Using modern technologies he works on the deriving of three-dimensional models of karst caves, which is a novelty in Georgian speleology. His research area also includes karst waters. The recommendations have been elaborated by him on granting the status of the monument of nature to the karst caves.

In 2007-2017 he participated in the international and local scientific conferences. He is the author of about 20 scientific works, many of which are published in foreign highly rated journals. In the years of 2014-2016, he stayed for scientific-research internships at various universities in the United States, where there is a great experience in karst research. He gained several scientific projects (financed by the Shota Rustaveli National Science Foundation), related to study of karst processes.

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Chikhradze Nino – Geographer; since 2006 she is a Research fellow at the Department of Geomorphology and Geoecology at TSU Vakhushti Bagrationi Institute of Geography. Since 2010 she is a PhD student at Ilia State University and also the PhD Alumni of the 2013-2014 Doctoral exchange program in the School of Earth Sciences, University of Minho, Portugal. The area of her interests is multi-spectral. She has participated in local and international conferences, as well as in various educational and scientific research projects within Georgia and outside its borders, funded both by the National (Shota Rustaveli National Science Foundation, etc.) and international organizations' programs (European Commission Tempus-Tassis , Erasmus-Mundus-Electra, and others).

Chikhradze Nino has more than 50 publications, including articles in local and foreign peer reviewed journals, curriculum and textbooks for students, as well as editorial and translation publications. In addition, she is a member of various scientific-research organizations, including the Speleo Club of Georgia and the official Vice-Delegate at the European Spéleological Federation.

Chartolani George is a student of Bachelor's IV course at Ivane Javakhishvili Tbilisi State University. Since 2015 he is an employee at TSU Vakhushti of Bagrationi Institute of Geography. In 2016-2017 he participated in the international exchange programs and interdisciplinary seasonal school. He participated in complex study of Zemo Imereti, Racha, Migaria, southern Imereti (Bzvani) and Okhajkue limestone massifs. Detailed research surveys of Muradi, Mandaeti (Zakariasklde), Ushalta and other caves were conducted by his direct participation. He has published 5 scientific papers, including 2 – in the foreign journals.

The photo of Chiatura view on the
cover of the monograph by: **Lado Mumladze**