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Geophysics

Using Stable and Radioactive Isotopes for Assessment of Origin and Sustainable Management of Groundwater Resources

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(Presented by Academy Member Tamaz Chelidze)

ABSTRACT. The paper reports on drinking water storage situation in the Eastern Georgia and recent study of underground water resources in Alazani-Iori catchment with using a hydro-geochemical and environmental isotope application. More than hundred groundwater and surface water samples were analyzed to study composition of major ions and isotopes ^{18}O, ^{2}H and ^{3}H. During the field work, physical and chemical parameters of waters (temperature, pH, DO, EC) were obtained. Three groups of groundwater were identified, revealing the dominant evolution of mineralization from Northwest to Southeast, with major increase in the Shiraki area. The geochemical patterns among the groups change from Ca(Mg)/HCO_3 type in the Kvareli aquifer to Na/SO_4(Cl) type in the Shiraki syncline. Variation indicated the evolution of groundwater isotopic composition on the path from the recharge area in the mountains and then through the river valley to exfiltration areas, from the $\delta^{18}O$ values more, than -8.5 ‰ V - SMOW and $\delta^{2}H$ values less than -55 ‰ V - SMOW, till $\delta^{18}O$ values between -11 and -13‰ V - SMOW and $\delta^{2}H$ less than 75 ‰ V - SMOW. Tritium concentration is decreasing from the West to the East on the territory and the smallest concentration is observed on the Shiraki plain. Almost all aquifers in the study area contain admixture of older waters with no Tritium and low $\delta^{18}O$ values. Whereas the ground waters in the Alazani valley artesian aquifers are concluded to be of a good quality they are recommended for drinking. *© 2017 Bull. Georg. Natl. Acad. Sci.*

Key words: stable isotopes, GMWL, water origin

More than 70% of Georgian water supply comes from the groundwater (GRW). One of the biggest zones of groundwater is the Eastern Georgia [1]. These groundwaters belong to the least surveyed and exploited aquifers in Georgia. It is expected that global warming will have negative effect on natural conditions of Georgia. These negative effects could be the most serious in the Eastern Georgia, especially in the hydrogeological basin area of the Iori river, which is known to have clearly depicted characteristics of arid-zone and semi-desert. Preliminary meteorological data show that precipitation has significantly decreased in this region, which caused depletion of underground water and natural springs. Hence, there is a distinct tendency of processes actively leading to desert formation. All these negative ecological events led to deterioration of population's social-economic conditions. As the negative ecological processes become stronger, desert formation can easily turn into an irreversible form. Understanding the GRW regime, its interactions with surface waters, which influence groundwater quantity and quality is therefore of the utmost importance to secure water supply for the economy and population.

Besides the traditional methods of hydrogeological survey, mapping of the environmental and radioactive (tritium) isotopes concentration as water tracers provide useful complementary information on water origin, history and contamination, thus contributing to the assessment of groundwater vulnerability and sustainability in terms of both water quantity and quality [2, 3].

Regular sampling and analyses of oxygen and hydrogen isotopes in natural waters (18O, 2H, 3H) are permanently held by International Atomic Energy Agency. Therefore, it becomes common practice in many countries as a part of national meteorological, geological and hydrological observation systems. In contrast, the topic is new in the Caucasian region.

Material and Methods

Study area is represented by a valley surrounded by the Greater Caucasus Mountains (altitudes up to 3500 m a.s.l.) in the north and lower Gombori Range (altitudes up to 2000 m a.s.l.) in the South. From the geological point of view, composition of the study region is complex and contains Jurassic, Cretaceous, Paleogene, Neogene and Quaternary rocks [4]. The Northeastern and Northwestern slopes of the Kakheti ridge are formed by Alazani series of Neogene and Pleistocene continental sediments. Their maximum thickness is 2 km and the dominant components are gravels, conglomerates and sands. Gravels are typically formed by large size boulders of sandstone and limestone material.

The Alazani valley between the Greater Caucasus and the Kakheti ridge is filled with Quaternary sediments and sediments of the river Alazani. It consists of sandy-gravel and clay-loam sediments, forming several water-bearing horizons down to approximately 500 m in three principal aquifers – Kvareli, Gurjaani and Telavi. The total thickness of sediments of the Alazani valley, lying on the surface of crystalline rocks, is between 2 and 4 km.

The Garekakheti Plateau is formed by tertiary sediments with outcrops of Upper Jurassic rocks (Dedoplitskaro Hill). The synclines on the Shiraki Plain are filled by Quaternary sediments of the Krasnokolodski suite. They consist of argillaceous sands, conglomerates and gravels. The sands are partly gypsiferous. The largest Shiraki syncline is of considerable extension up to 50 km, and the sediments are approximately 1000 m thick.

From the hydrogeological point of view, the Alazani and Iori basins have the area of approximately 8000 sq.km. It includes the Alazani and Iori artesian aquifers, the adjacent aquifers of the Shiraki Plain synclinal and the Kakheti-range in the West-North-west. This range and the entire Greater Shiraki Plain are climatic boundaries between the water-abundant Alazani basin and the water-scarce Iori basin. The valley is drained by the Alazani and Iori rivers. Another important source of water is the groundwater from numerous boreholes and wells [5]. The origin of the groundwater remains unknown.

In the frame of the mentioned project more than one hundred water points (springs, boreholes, dug wells, rivers and lakes) were sampled during six campaigns from April 2012 until October 2013. Isotopes ^{18}O, ^{2}H and ^{3}H were measured at each site. During field work, physico-chemical parameters of waters (Temperature, pH, DO, EC) were obtained by the WTW Multi 340i set. Samples were also taken for stable isotopes' and Tritium analyses.

Isotopic composition of precipitation was studied on the basis of monthly composite samples from Global Network Isotope in Precipitation (GNIP) and Global Network Isotope in Rivers (GNIR) stations,

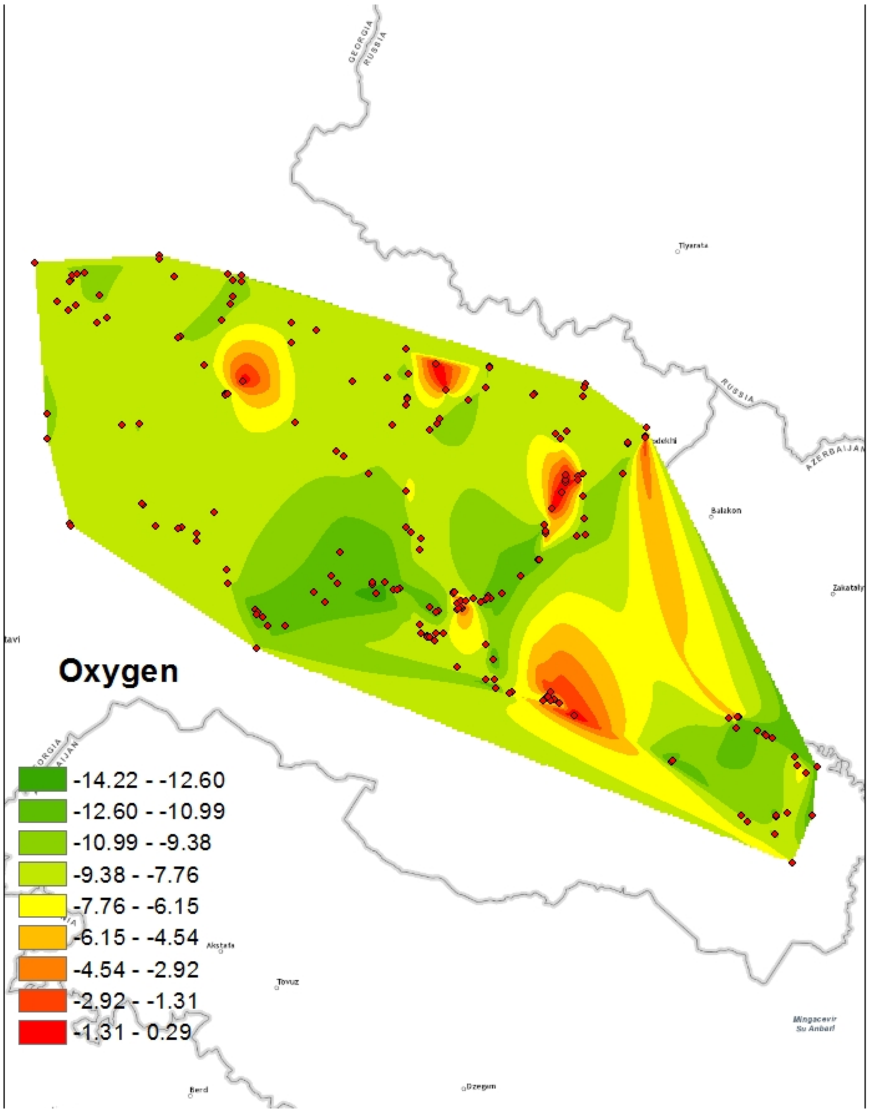

Fig. 1. Distribution of ^{18}O isotopes between different sites on the topo- map.

located in Tianeti, Telavi, Lagodekhi, DedoplisTskaro [6, 7].

The isotopic and hydochemical analyses were performed in the Laboratory of Institute of Geophysics by laser analizator Picarro L2110-I; chemical composition was measured by Flame-photometer PFP7 and DREL2800; Tritium analysis was performed in the Hacettepe University, Turkey.

Theory/Calculation

Groundwater sampling was generally conducted in the NW-SE transects, i.e. from the Southern slopes of the Greater Caucasus across the Alazani valley stable isotopes (^{18}O, ^{2}H) were analysed in all water samples from different hydrogeological groups (Fig. 1). Fig. 1 reveals that modern recharge water with $\delta^{18}O$ values more than -8.5 ‰ V-SMOW (Vienna Standard Mean Ocean Water - is a water standard defining the isotope composition of the fresh water) is fixed in the spring, river and boreholes in the left bank of river Alazani. These values are related with groundwaters of the Alazani series and Kvareli aquifer. Similar values of $\delta^{18}O$ were fixed in the spring and boreholes in limestone's aquifers located on the DedoplisTskaro "Hill". Telavi and Gurjaani artesian structures contain groundwater with heavier ^{18}O value

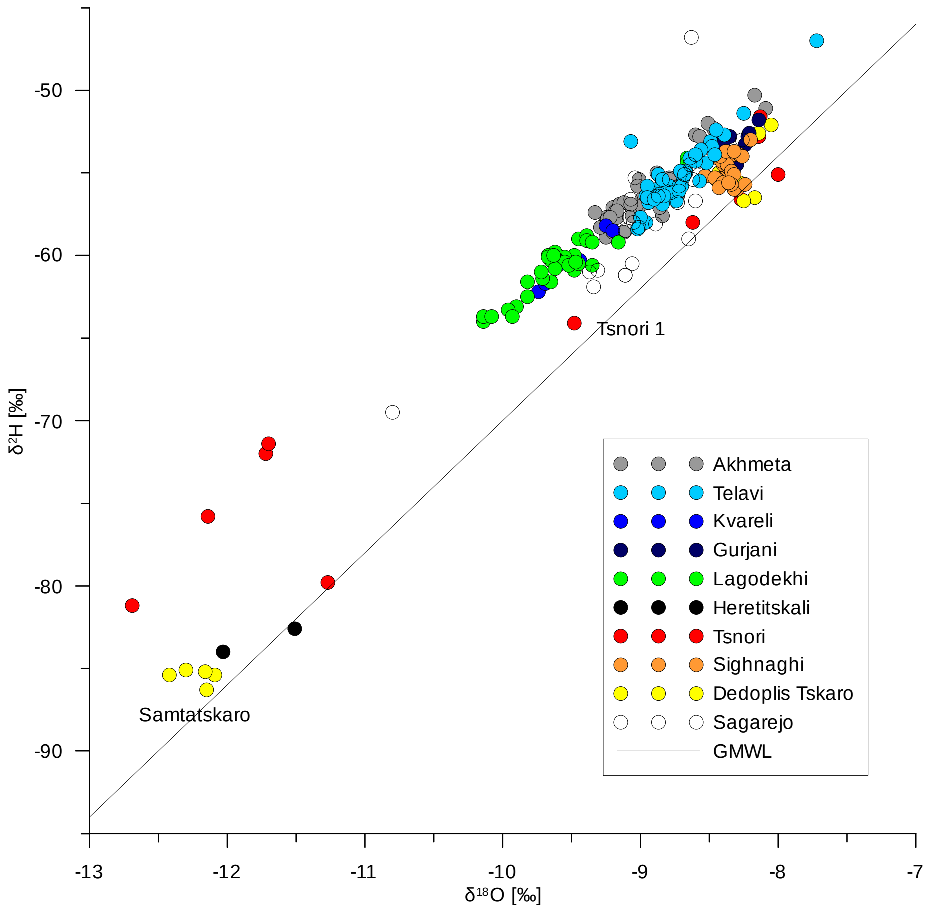

Fig. 2. Isotopic composition of different groundwater samples is compared with the Global Meteoric Water Line (GMWL).

between -7.5 and -8.5 ‰ V-SMOW, in the 200-500 m deep layer. Samples from deep boreholes in the open thermal water layer (Heretitshkali, Tsnori, etc), contain paleo-waters with d^{18}O values between -11 and -13‰ V-SMOW. Similar value of δ^{18}O has the groundwater of the Shiraki syncline and of the middle part of river Iori.

Exactly the similar picture of distribution was fixed for δ^{2}H. Modern recharge water has δ^{2}H values less than -55 ‰ V - SMOW; Telavi and Gurjaani aquifers - between-55-65 ‰ V - SMOW; Thermal water spring and the Shiraki groundwater - less than 75 ‰ V-SMOW.

The above values are characteristic for the regional scale, but there are more variations between water sources in local areas. For example, Dedoplis-Tskaro form two groups of springs. Part of them, from the "Samtatskaro" borehole, probably represents older waters. The rest of samples are modern water, which partially underwent evaporation. The Sagarejo waters do not form one group. Tsnori field is characterised with changeable values of samples. The data presented point to the evolution of groundwater isotopic composition on its travel from the recharge area in the mountains and through river valley to the exfiltration areas. The concept, which is in agreement with hydrogeological data of the area, is presented also in Table 1. Fig. 2 displays the ^{18}O ❑ ^{2}H relationship. It reveals that waters of almost all samples are located along the global meteoric water line (GMWL). This is relationship between deuterium and oxygen-18 concentrations in natural meteoric waters and indicated isotopic enrichments, relative to ocean water, which display a linear correlation over the entire

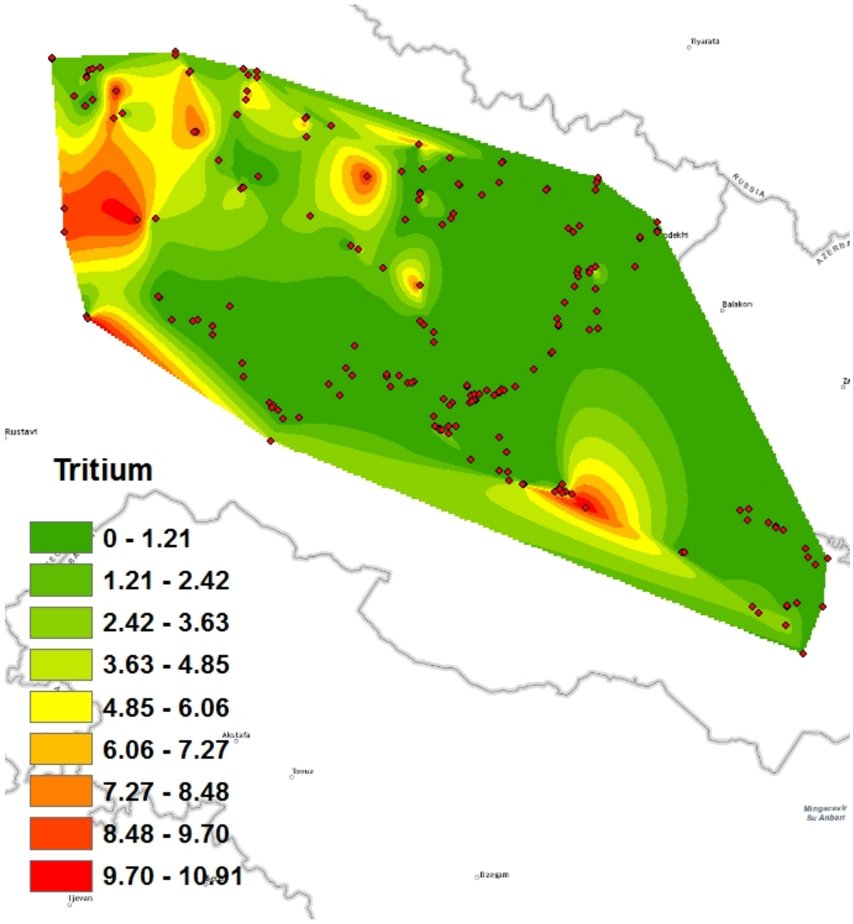

Fig. 3. Spatial distribution of Tritium in the Alazani-Iori area on the topo- map

range for waters, which have not undergone excessive evaporation.

Values of two samples, collected from the Lake Kechabi on the Shiraki Plain and the geothermal karst spring Heretitshkali deviate from the global meteoric water line. These deviations are related to evaporation under semiarid climate conditions and to water-rock interactions in geothermal environment.

Tritium concentration in the area is presented in Fig. 3: it decreases from the North-West direction to South-East. The Tritium concentrations (TU units) show a presence of older (recharged prior to nuclear tests' ban in 1950's) waters in samples from thermal water and Shiraki groundwater group type has relatively low concentrations of tritium (0.1-1.8 TU), which characterizes old groundwaters, recharged prior to the 1950rs, including paleo-waters. Tritium concentrations increase for the Telavi and Gurjaani aquifer (3-6 TU), which correspond to admixture of modern recharge waters (after 1950) with old-age waters and for Alazani and Kvareli groundwater group, respectively (7-11 TU), which are of modern origin.

Results and Discussion

Complex geological, hydrogeological, hydrogeochemical and isotope investigations were carried out in the Alazan-Iori Artesian Basin and three types of hydraulic zones were revealed.

The first type of groundwater has a total mineralization up to 1.0 g/l. This corresponds to the modern recharge pattern with $\delta^{18}O$ values between -8.5 and -9.9 ‰ V - SMOW and respectively with Tritium content of 7-11 TU. This type is dominant in groundwaters of the Alazani series, Kvareli aquifer, springs and in the rivers.

The second type of groundwater has a total min-

Table 1. Average values of isotopic composition in precipitation, river and GRW samples and perceptual model of groundwater movement (column groundwater zone).

Groundwater zone	Site, source	^{18}O average [‰]	^{2}H average [‰]	Deuterium excess average [‰]
	Precipitation, Telavi	-7.9	-50	12.9
	Precipitation, Lagodekhi	-9.3	-61	14.1
	River, Alazani (Shakriani)	-9.4	-60	15.3
Recharge area	GRW, Kvareli	-9.5	-60	15.6
	GRW, Lagodekhi	-9.6	-61	16.1
River valley	GRW, Akhmeta	-8.9	-56	15.4
	GRW, Telavi	-8.7	-55	14.6
Exfiltration	GRW, Gurjani	-8.3	-53	13.3
	GRW, Sighnaghi	-8.4	-55	12.1
	GRW, DedoplisTskaro	-8.3	-55	11.7
Evaporate	GRW, Shiraki	11	75 ‰	11.5
Mixed water	GRW, Sagarejo	-8.9	-58	13.6

eralization between 1.0 to 2.0 g/l. Tritium concentrations increase for the second type of GRW to 3 - 6 TU. These types of waters are fixed in some parts of the Telavi and Kvareli aquifers and in the entire Gurjaani aquifer.

Third group is the most mineralized sodium chloride type groundwater - covers the territory of the Shiraki Plain area, contains paleo-waters with $\delta^{18}O$ values between -11 and -13‰ V - SMOW and relatively low concentrations of tritium: 0.1 - 1.8 TU. This pattern characterizes the old type of GRW, recharged prior to the1950rs. The increased mineralization can be explained by saline sediments of the Quaternary age, as a result of intense evaporation with a minimum amount of precipitation.

Although most of the artesian boreholes are up to 500 m deep, their groundwaters belong to different hydraulic and isotopic groups, what should be related to the local stratigraphy. Groundwater analyses confirmed the evolution of mineralization pattern from North-West to South-East, with a major value in the Shiraki syncline area. Tritium concentration is decreasing from the West to East on the territory and the smallest is observed on the Shiraki plain.

Finally, the wwaters of the Shiraki plain area are characterized by high mineralisation and therefore are of lower quality for drinking. It is recommended to enhance the production of drinking waters from the karstic formations, such as the Dedoplitskaro Plain for alternative drinking water sources in the Shiraki region.

Conclusions

Isotopic composition of river water in the Alazani valley evolves according to the global meteoric water line. Available isotopic data indicate several groups of groundwater. Some of them probably represents older waters. The most of variables indicate the evolution of groundwater isotopic composition on the path from the recharge area in the mountains and then through river valley to exfiltration areas. The isotopic composition of river Alazani near Telavi indicate that the river is contributed mainly by isotopically light water from higher altitudes. Deuterium excess has higher value, which is typical for mountain precipitation and snow in other mountain ranges. If the seasonal snow cover at the foothills of the Greater Caucasus does not last for a longer period, spring rainfalls might be crucial for groundwater replenishment. The conjunctive use of isotopic approaches demonstrates its high potential for future water resource studies in Georgia.

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გეოფიზიკა

სტაბილური და რადიაქტიური იზოტოპების გამოყენება მიწისქვეშა წყლების წარმოშობის დადგენისა და მდგრადი განვითარებისათვის

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(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

ნაშრომში განხილულია აღმოსავლეთ საქართველოში არსებული ვითარება, კერძოდ, სასმელი წყლის დეფიციტი. ალაზანი-იორის აუზის მიწისქვეშა წყლის სისტემის შესწავლის მიზნით პირველად განხორციელდა კვლევები ჰიდროგეოქიმიური და ეკოლოგიური ტრასერების გამოყენებით. ასზე მეტი მიწისქვეშა და ზედაპირული წყლის სინჯი იქნა გაანალიზებული ძირითადი იონების შემადგენლობისა და ^{18}O, ^{2}H, ^{3}H იზოტოპების შესწავლის მიზნით. საველე კვლევებისას დადგინდა წყლის ფიზიკურ-ქიმიური პარამეტრები (ტემპერატურა, pH, გახსნილი ჟანგბადი, ელექტრო-გამტარობა). დადგენილ იქნა მიწისქვეშა წყლის სამი ჯგუფი, გამოვლინდა მინერალიზაციის ზრდა ჩრდილოეთიდან სამხრეთის მიმართულებით, შირაქის სინკლინში უმეტესი მნიშვნელობებით. ამ ჯგუფებს შორის ყვარელის წყალშემკრები აუზისათვის გამოვლენილია $Ca(Mg)/HCO_3$ ტიპის წყლები, ხოლო შირაქის წყალშემკრები აუზისათვის კი $Na/SO_4(Cl)$ ტიპი. დაფიქსირებული ცვლი-ლებები მიუთითებს მიწისქვეშა წყლების იზოტოპური შემადგენლობის ევოლუციაზე, მთებში განლაგებული კვების არეალიდან მდინარის ხეობების გავლით განტვირთვის არეალებისაკენ; შესაბამისად $\delta^{18}O$ მნიშვნელობით -8.5 ‰ V-SMOW-დან $\delta^{2}H$ მნიშვნელობით -55 ‰ V-SMOW-მდე, $\delta^{18}O$ მნიშვნელობით -13‰ V-SMOW-დან $\delta^{2}H$ მნიშვნელობით 75 ‰ V-SMOW-მდე. ტრი-ტიუმის მნიშვნელობა მცირდება დასავლეთიდან აღმოსავლეთის მიმართულებით და უმცირესი მნიშვნელობები ფიქსირდება შირაქის ველზე. წყალშემცველი ჰორიზონტების უმეტესობა მოიცავს შერეული ტიპის წყლებს, ტრიტიუმის ნულოვანი შემცველობით და ჟანგბადის იზოტოპის მცირე რაოდენობით. ალაზნის ხეობა შეიცავს მაღალი ხარისხის მიწისქვეშა წყლებს და რეკომენდებულ იქნა სასმელად.

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