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Evaluation of recharge origin of groundwater in the Alazani-Iori basins, using hydrochemical and isotope approaches

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Abstract

85 groundwater, stream water and lake water samples were analysed in 2013 for composition of major ions and isotopes ^{18}O, ^{2}H and ^{3}H in the Alazani-Iori area, eastern Georgia. Three groups of groundwaters were identified, revealing the dominant evolution in mineralization from Northwest to Southeast, with major increase in the Shiraki syncline area. The geochemical patterns among these groups evolve from $Ca(Mg)/HCO_3$ type in the Kvareli aquifer to $Na/SO_4(Cl)$ type in the Shiraki syncline. Almost all aquifers in the study area contain admixture of older waters recharged prior to the 1950's or paleowaters with no Tritium and low $\delta^{18}O$ values between -11 and -13 per mil SMOW. Although most of the artesian boreholes are up to 500m deep, their groundwaters belong to different hydrochemical and isotopic groups and must be considered with respect to local stratigraphy. Whereas the groundwaters in the Alazani valley artesian aquifers are concluded to be of a good quality for drinking, it is recommended to enhance the use of waters from the karstic formations such as the Dedoplitskaro Plain for alternative drinking water sources in the Shiraki –Iori basin.

Introduction

Eastern Georgia encounters, due to its semiarid climate, a big deficit of water for irrigation and domestic use. The aquifers of the Alazani basin are generally abundant in artesian groundwater due to recharge from Cretaceous and Jurassic formations of the southern slope of the Greater Caucasus and the northern slope of the Kakhetian ridge, the growing population and industrial and agricultural activities require new insights into the monitoring, assessment and development of these resources, partly abandoned after the collapse of the Soviet Union. Historically, the Alazani area was not prone to droughts and was not characterized by water shortages. However, runoff predictions for a temperature increase of 1.3 ^{o}C and precipitation decrease by 12% in 2011-2040 compared to 1961-1990 data result in average decrease in annual water flow by 12% (1). This may lead to lower groundwater recharge and cause water shortage for crops. Particularly the Shiraki plain encounters serious water quality problems due to limited regional recharge, elevated evapotranspiration-induced salinity and high content of organic sulphates. The communities on the Shiraki plain therefore need a better assessment of their groundwater supply facilities for drinking water purposes.

The groundwater resources of Eastern Georgia were systematically assessed since the 1940's. First boreholes were drilled in the northwestern part of the Alazani basin (Kvareli aquifer). Geophysical and hydrochemical studies were conducted until the 1990´s, but their publication has been very sparse. Some geochemical data from the 1950's and 1960's mostly based on the work of Buachidze and Zedginidze (2) were published in the USAID report "Groundwater Resources of the Alazani Basin"(3). Data from the 1970's and 1980's were partly elaborated in Beselia (4), Bagoshvili

(5) and in particular Buachidze and Zedginidze (2). They have revealed the hydrogeological and hydrochemical characteristics of the principal aquifers (Kvareli, Telavi, Gurjaani) of the Alazani basin, demonstrating the main groundwater flow gradient and hydrochemical evolution from Northwest to Southeast. Geochemical evolution from Ca/HCO_3 type to Na/Cl (SO_4) type appears in the Telavi and Gurjaani artesian aquifers, the Lower Alazani series and the Cretaceous-Jurassic formations, whereas the Kvareli artesian aquifer is concentrated around Ca/HCO_3 type. Groundwater in the Quaternary synclines around the Shiraki Plain shows Na/Cl (SO_4) characteristics and in particular remains poorly understood. No tangible publications exist on the water resources on the Shiraki Plain and its surroundings. Because groundwater and surface water resources have been assessed separately from the institutional point of view, little is known on the interactions between streams and aquifers and on the groundwater recharge travel times.

Until the beginning of 1990, about 2000 hydrological and geological boreholes were drilled in the study area, including about 20 % observation wells and the rest production wells (7). Most of them are in a very poor condition and without any documentation or records. A large proportion of these wells are overflow wells, and their construction does not allow them to be sealed and there is therefore a huge loss of groundwater and significant disruption to the piezometric conditions of the hydrogeological structure. Non-artesian wells or wells which have lost their artesian overflow over time have in most cases been destroyed because their wellheads have been stolen and such wells are currently overgrown or buried. This may have a negative impact groundwater flow and cause hydraulic short circuit, unnatural overflowing between watershed layers,decrease of water levels and deterioration of the entire hydrogeological structure (7).

Besides the traditional methods of hydrogeological survey such as geochemistry and groundwater flow modelling, environmental isotopes as water tracers provide useful complementary information on water origin (where does the water come from) and history (which pathways did the water move until it arrived to an aquifer). These methods have been applied in Georgia since the first decade of this century through projects under the auspices of the International Atomic Energy Agency (IAEA). While the first project of this nature has focused on the identification of recharge areas drinking water resources in the Borjomi-Bakuriani region (8 and 9), recent activities cover various parts of Georgia, incl. eastern Georgia.

The Rustaveli National Science Foundation Grant was awarded for assessment of recharge conditions in the principal hydrogeological units of the Alazani-Iori catchment basins including the semi-desert areas, using environmental isotope and hydrochemical approaches. This paper has therefore the following objectives:

a) Evaluation of recharge conditions in the principal hydrogeological units of the Alazani-Iori area

b) Evaluation of groundwater travel times and hydrochemical evolution along flowpaths

c) Identification of zones of increased groundwater vulnerability and possible alternative sources of drinking water.

Geological and hydrogeological settings

The area of the Alazani and Iori basins is located in eastern Georgia. It has an area of approximately 8000 sqkm. It includes the Alazani and Iori artesian aquifers, the adjacent aquifers of the Shiraki Plain synclinale and the Kakheti-range in the West-Northwest. This range and the entire Greater Shiraki Plain are a climatic boundary between the water-abundant Alazani basin and the water-scarce Iori basin.

The geological composition of the study region is complex and contains Jurassic, Cretaceous, Palaeogene, Neogene and Quaternary rocks. Most of the area belongs to the folded system of the Greater Caucasus, and a smaller part on the southeast (Garekakheti Plateau) belongs to the Transcaucasian Intermountain Area (10).

The major units of the Alazani-Iori water-bearing complex are the Telavi and Gurdjaani water-bearing horizons. The Telavi water-bearing horizon is located from village Kogoto to the village of Sabatlo over 150 km. It contains about six water-bearing layers with the total capacity up to 50 m. The horizon is formed from coarse-grained sand and fine pebbles with the sandy filler. The horizon is deposited at the depth from 90 to 360 m, gradually submerging towards north-east and south-east directions, to the central part of Alazani valley. The Gurdjaani water-bearing horizon belongs to the upper part of the middle section of the Alazani. It submerges at the depth of 125-500 meters and is observed from the Velistsikhe station to the Gumbati village over 140 km. The Gurdjaani horizon is formed by porous gravely sediments with sandy fillers, in about nine water-bearing layers. The maximum number of these layers is observed in Gurdjaani-Kardanakhi region. Almost the whole horizon is covered by the Telavi water-bearing horizon. Eastwards of the Lagodekhi meridian the groundwaters from this water-bearing horizon border with Azerbaijan.

In contrast, the water-bearing horizons of the Iori-Shiraki artesian basin are developed locally within the boundaries of monoclinal and synclinal structures such as Sartichala, Sagaredjo, Mtsvanemindori, Shiraki, Olei and Djeiran-Choli basins.

Methodology

Fieldwork

85 water points (two examples on Fig.1) were sampled during six campaigns from April 2013 until October 2014. They include 5 points on surface waters (rivers and lakes) and 76 on groundwaters (springs, boreholes, dug wells). Major ions, ^{18}O, ^{2}H and ^{3}H were measured at each site. Physico-chemical parameters in the field (Temperature, pH, DO, EC) were obtained by the WTW Multi 340i set.

Depth and position of screen in the boreholes were taken from local archives and registers (2),

Additional monthly monitoring of isotopes ^{18}O, ^{2}H and ^{3}H in rainwaters and streamwaters was established in the study area in the framework of the Global Network of Isotopes in Precipitation (GNIP) and Global Network of Precipitation in Rivers (GNIR) operated by the IAEA (11). New GNIP (^{18}O, ^{2}H) stations in the study area include the recharge area in Tianeti (since January 2013), the central area in Telavi (since May 2012), and the discharge area in Dedoplitskaro (since January 2013) and Lagodekhi (since July 2013). While the information on temperature, rainfall amount and air humidity at Telavi is supplied by the adjacent meteorological station, the rain samplers at Tianeti, Dedoplitskaro and Lagodekhi were complemented by air temperature and humidity sensors HOBO. New GNIR (^{18}O, ^{2}H) stations include Alazani/Shakriani (since May 2012) and Iori/Tianeti (since January 2013), both equipped with HOBO water level sensors. Available meteorological datasets and discharge data from official meteorological and hydrological stations were obtained from the office of Hydro-Meteological service of Ministry of Environment and Natural Resources Protection in Tbilisi.

Fig. 1 "Tetri-Tsklebi" –Borehole (left) and "Telavi" -Borehole №1 (right)

Laboratory

Stable isotope (^{18}O, ^{2}H) analyses of water sampleswere performed in the Laboratory of the Ivane Javakhishvili Tbilisi State University, M. Nodia Institute of Geophysics, by the Picarro Laser Water Isotope Analyzer L2110-I equipment purchased in the framework of the IAEA projects. Major ions were obtained by Flame photometer PFP7 and spectrophotometer DREL2800. Tritium was measured in the radioisotope laboratory Hydrosys, Inc. in Budapest, Hungary. Additional stable isotope and hydrochemical analyses were also carried out in other external laboratories in Hungary, Czech Republic and Morocco.

Fig. 2 laboratory equipment "Picarro" and "Flame photometer"

Interpretation

According on the regional knowledge, obtained field data and information on the geology and existing boreholes, the sampling points were assembled into following groups for further interpretation:

1. AK Kvareli artesian aquifer
2. AT Telavi artesian aquifer
3. AG Gurjaani artesian aquifer
4. AN Lower Alazani series artesian aquifer
5. SCJ Springs in Jurassic and Cretaceous formations
6. CJ Jurassic and Cretaceous formations - boreholes
7. SQS Quaternary formations of the Shiraki syncline –springs
8. QS Quaternary formations of the Shiraki syncline - boreholes
9. R Streamwaters (and lake)

The distribution of the water points according to these categories is given in Fig. 3.

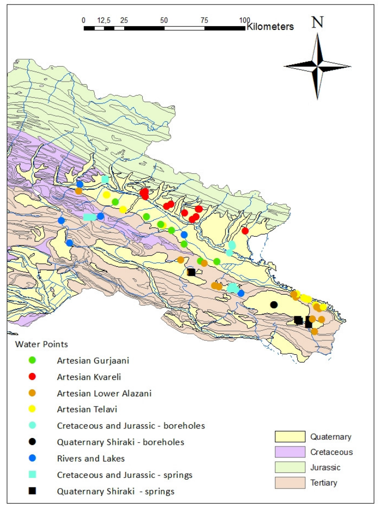


Fig. 3 – Distribution of water points according to hydrogeological groups.

Following techniques were used to visualize and interpret the hydrochemical and isotopic data

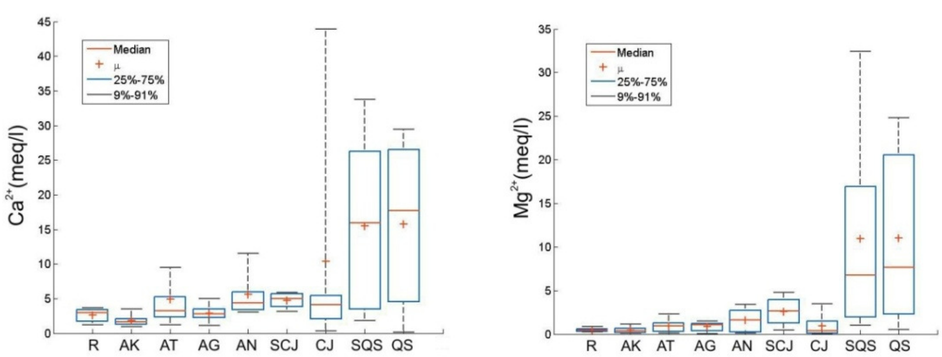
a) Bivariate plots and Box-Whisker plots
b) Aquachem 5.0 with trivariate plots (Piper-diagrams)

Results

Hydrochemistry

Hydrochemical composition of water samples from different aquifer units was assessed. Patterns of formation of the chemical composition of groundwater were refined with new data and the hydrochemical zonation of groundwater "Alazani-Iori"Artesian Basin was created.

Fig. 4 displays the hydrochemical characteristics of the different hydrogeological groups of water points.



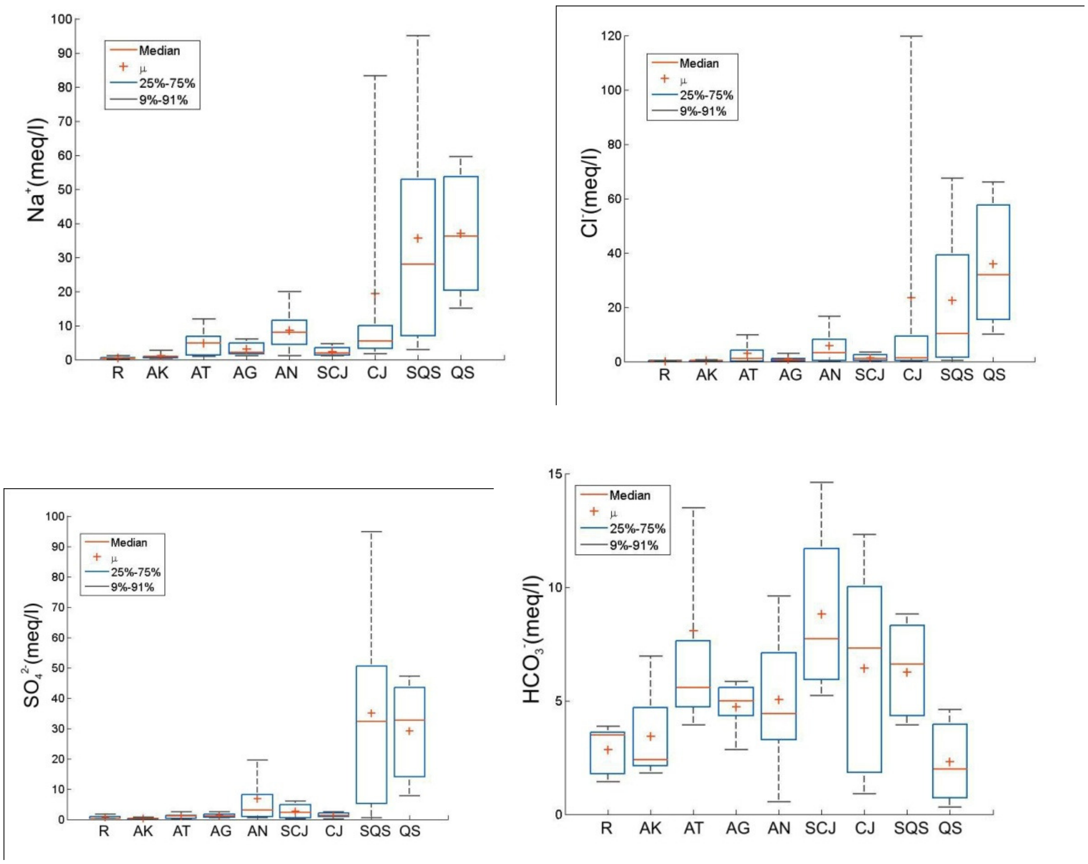


Fig. 4 – Content of major ions in groundwater from the “Alazani-Iori” area according to the main water point groups

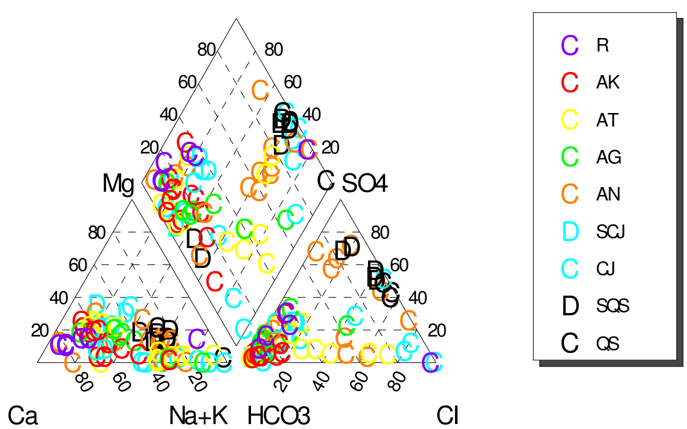


Fig. 5 - Hydrochemical evolution of the groups of water points.

Three types of groundwater were derived from the hydrochemical paterns.

The most mineralized groundwater type covers the territory of the waters of which have total mineralization of more than 2 g/l, temperature 14-19 ° C. By the chemical composition these water are sodium chloride. This type of water are generally located in the Shiraki Plain area (springs QS and boreholes SQS, see Fig. 3). The increased mineralization can be explained by saline sediments of Quaternary age as a result of intense evaporation, with a minimum amount of precipitation.

The upper groundwater layer is more mineralized, while the bottom layer which is assessed by the wells, is less mineralized. This can be explained by the fact that the top layer does not have discharge area, being located within a closed syncline under the influence of intense evaporation. There lower-layer pressure horizons dischargeas springs, located on the slope north of the Shiraki on the right bank of the Alazani river. They are characterized by a more rapid discharge and relatively good conductivity of the aquifer. These patterns are reflected on the general map of groundwater conductivity (Fig. 6) An upward trend of conductivity is observed along the river Alazani from the North-west to the South-east direction, and on the Shiraki valley from the South-west to the North-east.

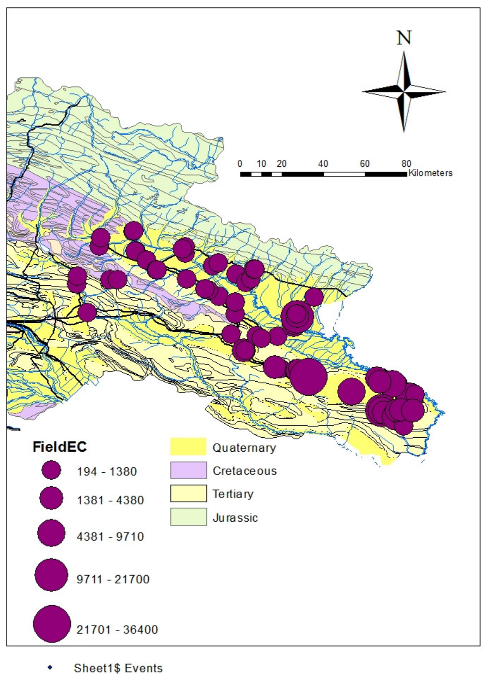


Fig. 6 Spatial distribution of electrical conductivity in the Alazani-Iori area.

Groundwater on the Kakheti ridge (between the Alazani and Iori valleys) has a local distribution due to their confinement to the zones of tectonic faults (Gamardzhveba, Bodbe) in the Lower Alazani series artesian aquifer (AN).

The second type of groundwater has a total mineralization between 1.0 to 2.0 g / l. By chemical composition this water is represented by various compositions of (Na,Mg)/ (Cl,$SO4_2^-$) and temperature between 14 and 19^0C. These types of waters are distributed in parts of the Telavi and Kvareli aquifers and in the entire Gurjaani aquifer (AT, AK, AG, see Fig. 3).

The third type of groundwater has a total mineralization up to 1.0 g / l. Water chemistry is represented by various proportions of Ca(Na,Mg)/ HCO_3^- ($SO4_2^-$) and temperature between 12 and16^0C. This type of groundwater is distributed in the rest of the basin, covering most of the area of distribution Kvareli aquifers and Neogene, Cretaceous and Jurassic sediments.

Pronounced changes in the total mineralization of the artesian water of Telavi, Gurjaani and "methane" aquifers of the Alazani series are observed in the vertical cross section of the boreholes.

Isotopes

Stable isotopes (^{18}O, ^{2}H)and Tritium (^{3}H)were analysed in all water samples from the different hydrogeological groups. Fig. 7 reveals that modern recharge with $\delta^{18}O$ values between -8.5 and -9.9 ‰ V-SMOW is dominant in groundwaters of the Alazani series (AN), Kvareli aquifer (AK), springs (SQS and SCJ) and in the rivers. Aquifers of Telavi (AT) and Gurjaani (AG) artesian structures as well as the Cretaceous and Jurassic formations (CJ) and the Shiraki syncline (QS) contain paleowaters with $\delta^{18}O$ values between -11 and -13‰ V-SMOW. Similarly, the Tritium concentrations (Fig. 7) show a presence of older (recharged prior to 1950's) waters in samples from all groups except for the Quaternary Shiraki springs (SQS) and the rivers (R). The isotopic composition of samples confirms the groundwater hydrochemical patterns explained in 4.1. The first highly mineralized groundwater type has relatively low concentrations of tritium (0.1-1.8 TU), which characterizes old groundwaters recharged prior to the 1950´s, including paleowaters. Tritium concentrations increase for the second (3-6 TU) and third group of waters, respectively (7-11 TU). These values indicate waters with modern recharge (after 1950), partly with admixture of old components.

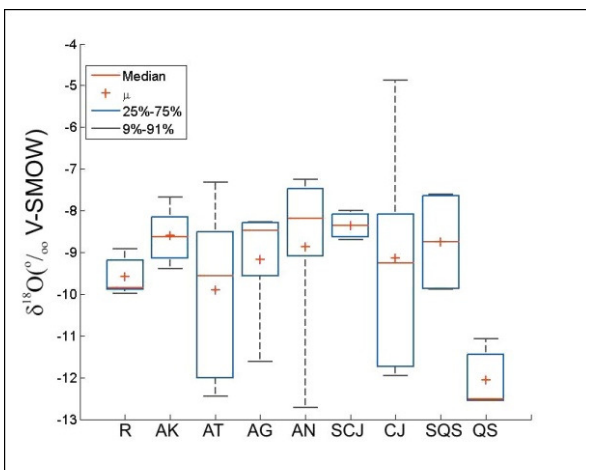


Fig.7– Isotopic characteristics of waters in the Alazani-Iori area. Left: content of ^{18}O; right : content of ^{3}H.

Tritium concentration is decreasing from the West direction to East on the territory and smallest is observed on the Shiraki plain (Fig. 8).

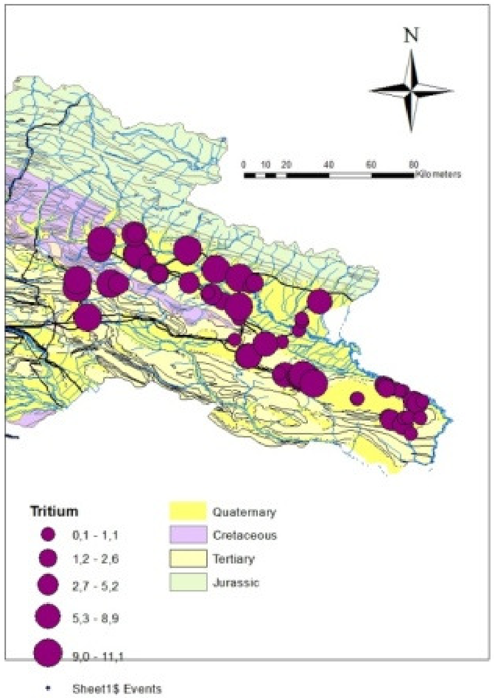


Fig. 8- Spatial distribution of Tritium in the Alazani-Iori area.

Fig. 10 displays the ^{18}O-^{2}H relationship. It reveals that waters in almost all samples are located along the global meteoric water line. Values of two samples deviate from the global meteoric water line – the Lake Kechabi on the Shiraki Plain, and the geothermal karst spring Heretitshkali. These deviations are related to evaporation under semiarid climate conditions and to water-rock interactions in geothermal environment.

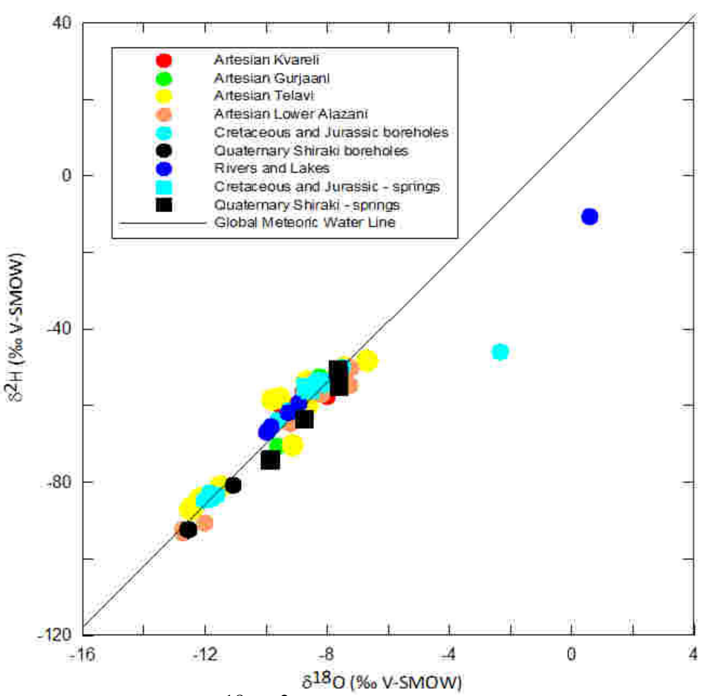


Fig. 10.Plot of ^{18}O-^{2}H of waters in the study area.

Conclusions

Complex geological, hydrogeological, hydrogeochemical and isotope investigations were carried out in the Alazani-Iori area. They have confirmed the evolution in mineralization from Northwest to Southeast, with major increase in the Shiraki syncline area. Isotope investigations have confirmed the entirely modern groundwater origin of the Kvareli aquifer and admixture of pre-1950 waters (or paleorecharge in case of $\delta^{18}O$ values between -11 and -13 per mil SMOW) in all other aquifers. Although most of the artesian boreholes are up to 500m deep, their groundwaters belong to different hydrochemical and isotopic groups and must be considered with respect to local stratigraphy. Waters on the Shiraki plain area are characterized by high content of SO_4 and Cl and therefore lower quality for drinking. It is recommended to enhance the use of waters from the karstic formations such as the Dedoplitskaro Plain for alternative drinking water sources in the Shiraki region. The conjunctive use of hydrochemical and isotopic approaches demonstrates a high potential for future water resources studies in Georgia.

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Оценка происхождение и миграции подэемной воды в Алазани –Иорском бассейнах с использованием гидрохимических и изотопных методов

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РЕЗЮМЕ

2013 году были проанализированы 85 образцов из подземных, речных и озерных вод для изучения состава основных ионов и изотопов ^{18}O, ^{2}H и ^{3}H в районе Алазани-Иори в Восточной Грузии. Были определены три группы подземных вод, которые показали доминирующую эволюцию в минерализации с северо-запада на юго-восток, со значительным увеличением в синклинальной области Шираки. Геохимические модели среди этих групп эволюционируют от $Ca(Mg)/HCO_3$ -типа в Кварельском водоносном горизонте к $Na/SO_4(Cl)$ -типу в синклинали Шираки. Почти все водоносные горизонты в области исследования содержат примесь старые предварительно до-1950 воды или палеоводы без трития и низкие значения δ^{18}O между -11 и -13 промилле SMOW. Хотя большинство артезианских скважин имеют глубину до 500м, их подземные воды принадлежат к разным гидрохимическим и изотопным группам и должны рассматриваться по отношению к местной стратиграфии. Хотя, как выяснено, в долине Алазани артезианские водоносные горизонты имеют хорошее качество и пригодны для питья, рекомендуется расширить использование вод карстовых образований, таких как вДедоплисцкаро-равнине для поиска альтернативных источников питьевой воды в бассейне Шираки-Иори.

ჰიდროქიმიური და იზოტოპური მეთოდების გამოყენებით მიწისქვეშა წყლების წარმოშობის და მოძრაობის შესწავლა ალაზანი-იორი აუზებში

გიორგი მელიქაძე, ნატალია ჟუკოვა, მარიამ თოდაძე, სოფიო ვეფხვაძე, ნინო კაპანაძე, ალექსანდრე ჭანკვეტაძე, თამარ ჯიმშელაძე

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რეზიუმე

2013 წელს გაანალიზებული იქნა ძირითადი იონური შემადგენლობა და სტაბილური იზოტოპების (18O, 2H და 3H) შემცველობა ალაზანი-იორის აუზის ზედაპირულ და წვიმის წყლებში. დადგენილი იქნა მიწისქვესა წყლების ძირითადი სამი ჯგუფი, ასევე მინერალიზაციის ზრდა ჩრდილოეთიდან სამხრეთი მიმართულებით, მისი უმაღლესი მნიშვნელობბების დაფიქსირებით შირაქის ველზე. გეოქიმიურად აღნიშნულ ჯგუფებში ფიქსირდება ჩა(Mგ)/HჩO3 ტიპის წყლების ცვლილება Nა/შO4(ჩლ) ტიპით. შირაქის ველზე თითქმის ყველა წყალშემცველი ჰორიზონტი შეიცავს ძველი (1950 წლამდე), განამარხებული ტიპის პალეო-წყლებს, რომლებშიც არ ფიქსირდება ტრიტიუმის შემცველობა, ხოლო ჟანგბადის იზოტოპების (18O) შემცველობა იცვლება -11 დან -13 მდე (პერ მილ შMOჭ). თითქმის ყველა არტეზიული ჭაბურღილის სიღრმე აწარბებს 500 მ. მათ მიერ გახსნილი წყალშემცველი ჰორიზონტები თავისი ქიმიური და იზოტოპური შემადგენლობით მიეკუთვნებიან სხვადასხვა ჯგუფებს და განპირობებული არიან ადგილობრივი სტრატიგრაფიით. იმის გათვალისწინებით , რომ ალაზნის ველის მიწისქვეშა წყლები მიეკუთვნებიან სასმელად კარგი წყლების კატეგორიებს, დამატებით რეკომენდირებულია დედოფლისწყაროს კარსტული წყლების გამოყენება სასმელი წყლის ალტერნატიულ რესურსად .