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Austrian Journal of Earth Sciences | Vienna | 2019 | Volume 112/1 | 42 - 49 | DOI: 10.17738/ajes.2019.0003

Recharge and dynamics of a karst groundwater system in Kakheti (Eastern Georgia)

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KEYWORDS groundwater; karst; isotopes; Kakheti region; Georgia

Abstract
Monitoring temporal variations of ^{18}O and ^{2}H isotopes in precipitation, groundwater and surface water was performed in the region of Kakheti (East Georgia). Data were collected from three meteorological stations at altitudes between 400 – 1,100 m a.s.l., from two shallow and one deep hydrogeological boreholes, and from two surface water monitoring stations (Alazani River and Patmasuri karstic stream). ^{18}O values in precipitation show an annual variation between -22 ‰ and +1 ‰ and a distinct altitude effect. A clear correlation exists between the seasonal isotope composition of precipitation, shallow groundwater and surface water. A five-fold amplitude dampening and a delay of 10-15 days was observed. The data show that precipitation in the Caucasus Mountains to the North infiltrates into the Upper Jurassic – Lower Cretaceous karstic aquifer and travels to the Alazani valley towards south-east. The isotopic signature of winter precipitation is reflected in stream water as well as in shallow groundwater isotope data of groundwater in a 2,000-m-deep hydrogeological borehole at Heretiskari show a distinctly different character with $\delta^{18}O$ ranging between -2.8 ‰ to -2.2 ‰ and a deuterium excess of -25 ‰.

1. Introduction

The impact of climate change has caused a significant decrease of precipitation in the region of Kakheti (East Georgia), leading to the depletion of local deep and shallow groundwater resources in the water-scarce areas of the lowlands (Elizbarashvili, 2007). Groundwater resources of the Tianeti, Akhmeta, Kvareli and Lagodekhi confined groundwater systems, recharged on the southern slopes of the Greater Caucasus Mountains, may be considered as an alternative water supply for the communities in the Alazani basin and the adjacent foothills. Numerous karst features are found here, especially in the southern part. Karstic springs such as e.g. Apenis Tskali, Patmasuri, Tsivi Tskali and Kuistskali with discharge varying from 2.3 up to 250 L/sec are present at lower altitudes Zviadadze (1995) describes that a part of the water infiltrating along the southern slope of the Greater Caucasus Mountains reappears in the form of springs feeding the streams in valleys, while another part moves deeper, feeds artesian aquifers and discharges along the Alazani valley. In addition to precipitation, surface waters also play an important role as the source of regional groundwater recharge (Marques et al., 2012).

All-natural groundwater and surface water outlets were identified and documented on the hydrogeological map of Alazani valley by Melikadze et al. (2014a). Hydrochemical and isotope investigations were carried out by Melikadze (2014b) and numerical modelling of groundwater resources in the Shiraki catchment was performed by Melikadze et al. (2014b). Mechanisms and proportions of different recharge types (De Vries and Simmers., 2002) in the heterogeneous karstic-fractured recharge zone remain largely unknown. For the purposes of groundwater protection, pathways between recharge zones and artesian aquifers in lowlands need to be addressed (Singhal et al., 2016; Herczeg et al., 1997) and possible risks of groundwater contamination along these pathways should be evaluated. The main goal of this study is the assessment of water mass exchange between surface waters and groundwater, as well as the identification of possible links between the recharge and discharge zones.

1.1 Geological Setting

The study area covers the valley of the Alazani River, where numerous water supply sources, boreholes and wells are located, and the Greater Caucasus Mountains (with altitudes up to 3,500 m a.s.l.) to the north (Fig.1).

2. Materials and Methods

As part of our study, a monitoring network of precipitation, surface water and groundwater isotopic composition was established along the Alazani River (Kakheti region), in the area of outcropping karstified rocks (Király, 2003) as well as in confined karstic aquifers in the lowlands.

Meteorological data were acquired at Tianeti (1,099 m a.s.l.), Telavi (568 m a.s.l.) and Lagodekhi (432 m a.s.l.) stations which are operated by the Georgian Hydrometeorological Department of the National Environmental Agency of the Ministry of Environment Protection and participate in the IAEA GNIP network (IAEA/WMO, 2006).

Figure 1: Geological overview and location of the study area (Eastern Georgia) in Caucasus region, with position of boreholes, meteorological and hydrological stations sampled during hydrological mapping.

At these stations, air temperature and humidity, as well as daily precipitation totals, were measured at hourly intervals using a HOBO sensor. Discharge of the Alazani river was monitored at the IAEA GNIR station Shakriani (Melikadze et al., 2015) with a classical river gauge (Bartl et al., 2009) measuring water table and water temperature at hourly intervals. A new water level gauge was installed near the city of Kvareli in the karstic stream Patmasuri, which is fed by karstic springs nearby. In total, three meteorological and two hydrologic stations were monitored in the area (Fig. 1).

Samples for the determination of water isotopic composition were collected from all the aforementioned stations on a monthly basis, except for the Patmasuri karstic stream which was sampled two times per month. All analyses were carried out at the chemical laboratory of the Research Centre of Hydrogeophysics and Geothermy, M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University. Determination of $\delta^{18}O_{VSMOW}$ and $\delta^{2}H_{VSMOW}$ in water samples performed using a Picarro L2110-i analyser (Precision (per sample) δ18O < 0.05 ‰, δ^2H < 0.3 ‰).

3. Results

Measurements of precipitation and air temperature at all three meteorological stations show that periods of negative temperatures were short and snow fall reduced during the winters of 2013/2014, 2014/2015 and 2016/2017 (3 months at Lagodekhi, 2 months at Telavi, and 4 months at Tianeti), while the winter of 2015/2016 was long (Lagodekhi – 3 months, Telavi – 3 months, Tianeti – 6 months), with abundant snow cover and a significant snow melting period.

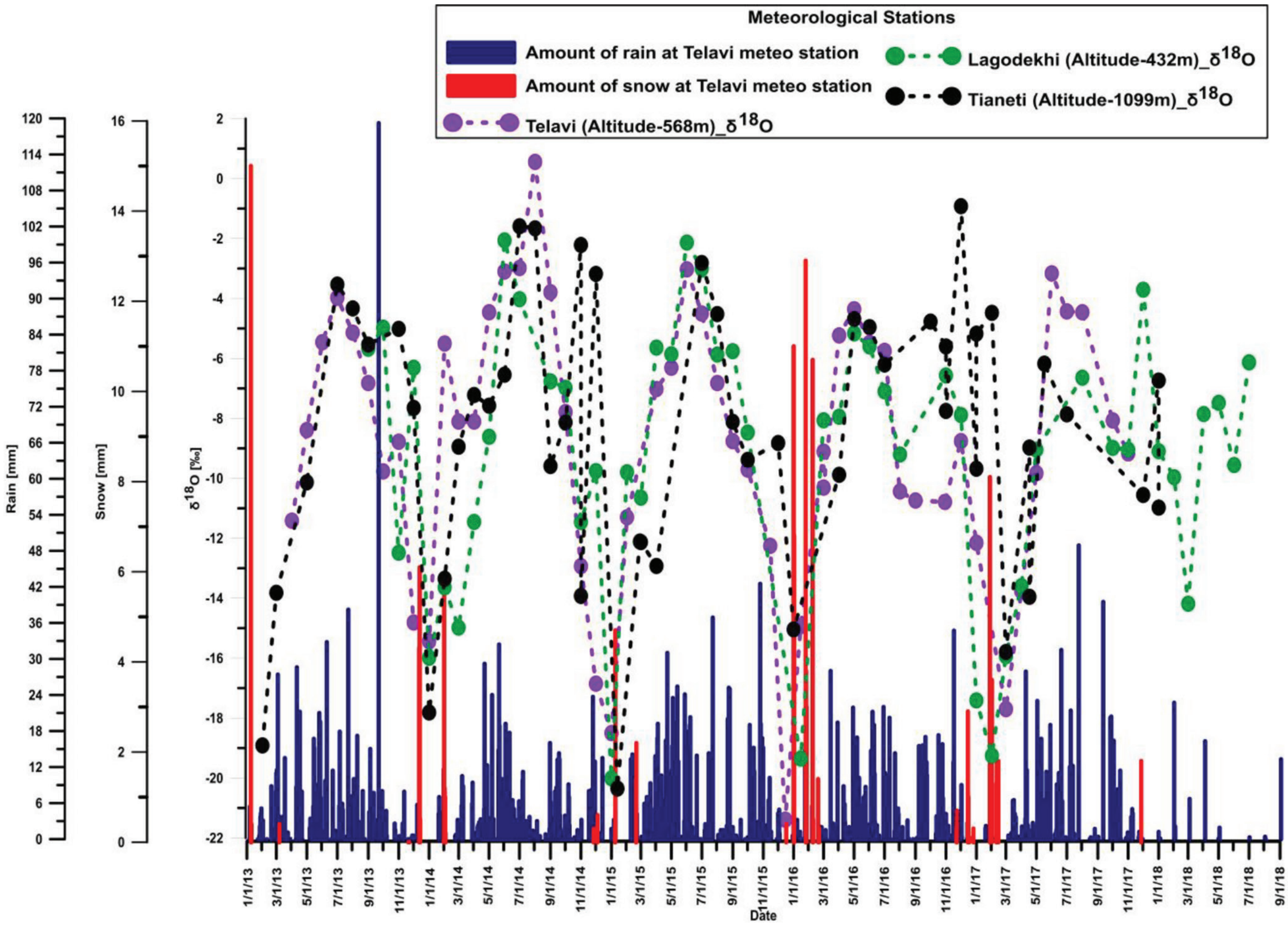

Figure 2: Precipitation amount of Telavi station and values of $\delta^{18}O$ in precipitation at 3 meteorological stations during 2013 – 2017.

$\delta^{18}O$ values in precipitation (Araguás-Araguás et al., 2000) range from -22 ‰ up to +1 ‰ (Fig. 2). According to sinus curve, the amplitude of the time series is approximately 5 ‰ (from -5 ‰ to -15 ‰). Isotopically, the lightest precipitation was measured at Tianeti station, located at the highest elevation, while the values of $\delta^{18}O$ at the remaining stations were higher, corresponding to their lower altitude.

$\delta^{18}O$ values in surface water of the Alazani river at Shakriani range from -11 ‰ up to -7 ‰ (Fig. 3). Compared to $\delta^{18}O$ values in precipitation at Telavi, the amplitude of seasonal variation is far less pronounced (4 ‰) and the signal is delayed by 10 to 15 days.

Monitoring at the Patmasuri karstic stream started at the beginning of 2016. Isotopic compositions are very stable, with $\delta^{18}O$ ranging between -8.9 ‰ and -8.1 ‰ and $\delta^{2}H$ - between -47‰ and -60 ‰ (Fig. 4).

For the period of 2016–2017, Telavi meteorological station, the Alazani river waters at Shakriani station and the Patmasuri karstic stream waters show similar isotopic behaviour (Fig. 5). It seems that after feeding Patmasuri karstic stream, the recharging rain water almost simultaneously discharges into Alazani River, while snowmelt water primarily discharges into Patmasuri karstic stream and afterwards feeding the Alazani river.

Isotopic data (^{18}O, ^{2}H) are available for several hydrogeological boreholes in the region of Kakheti reaching shallow groundwater such as Gurjaani and Sagarejo boreholes (100–150 m depth, which are opening Quaternary age alluvial-proluvial sediments,) as well as deep aquifers of Heretiskari borehole which is opening at depth of 2050-2100 m main aquifer of upper Cretaceous age carbonate rocks. Isotopic composition of groundwater in shallow boreholes ($\delta^{18}O$ -8.5‰ to -7.9 ‰) is similar to isotopic values of surface waters (Sophocleous,2002), especially those of the Patmasuri karstic stream.

Compared to the shallow groundwaters, a notable difference can be observed in the isotope composition of deep groundwater sampled in the Heretiskari borehole, where $\delta^{18}O$ ranges from -2.8 ‰ to -2.2 ‰ and $\delta^{2}H$ from -49 ‰ to -42 ‰ (Fig. 6).

Distribution of the mentioned values along the Global Meteoric Water Line (Craig, 1961; Fig. 7) marks the difference.

4. Discussion

Time series of rain and snow falls and of $\delta^{18}O$ values obtained at all three meteorological stations (Tianeti, Lagogekhi and Telavi) demonstrate the nature of seasonal changes (Fig. 2). Although the stations are located at lower altitudes (maximum 1099 m a.s.l.), the measured data can

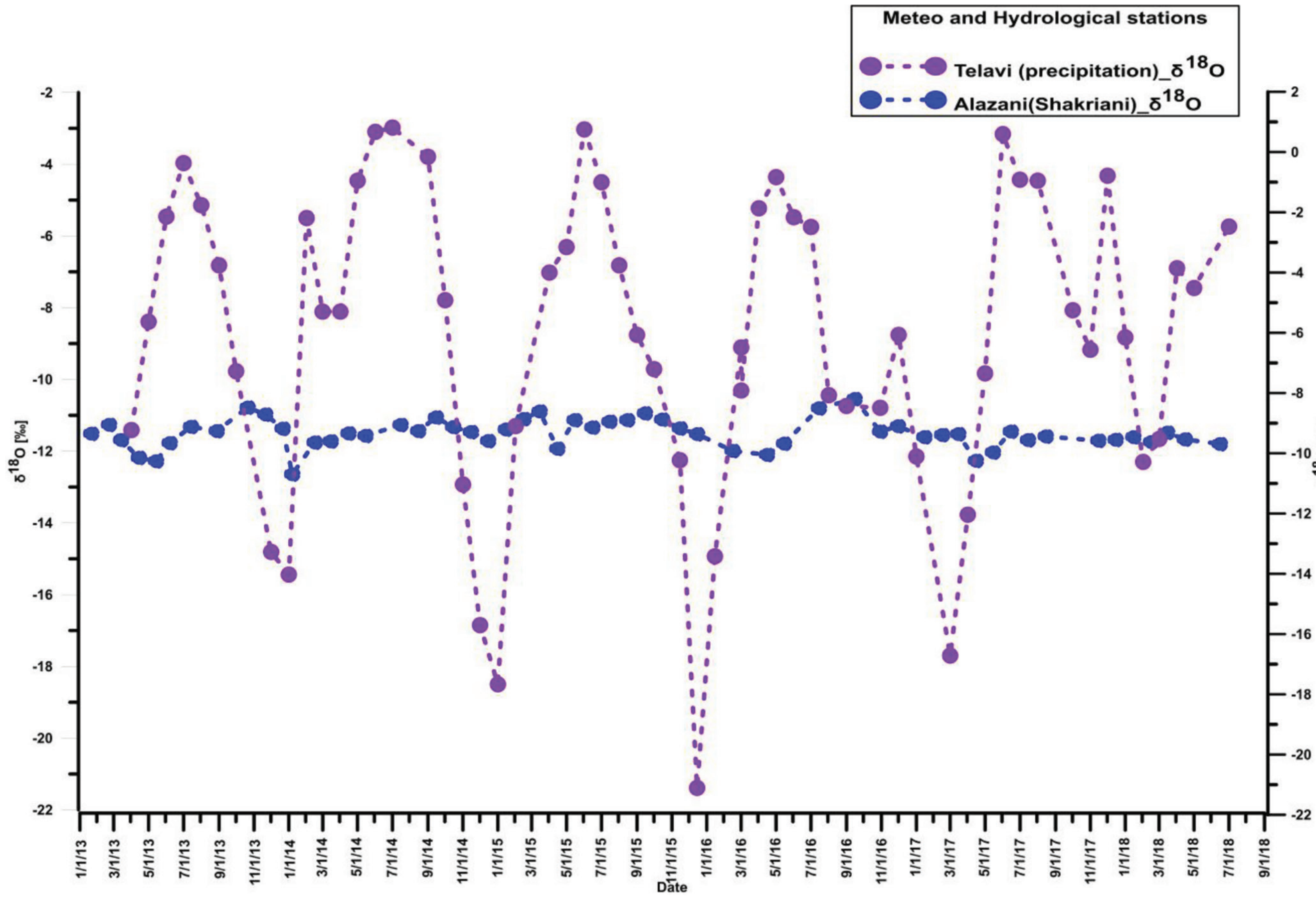

Figure 3: Values of $\delta^{18}O$ in Alazani river water (Shakriani) and in precipitation (Telavi) during 2013 – 2017.

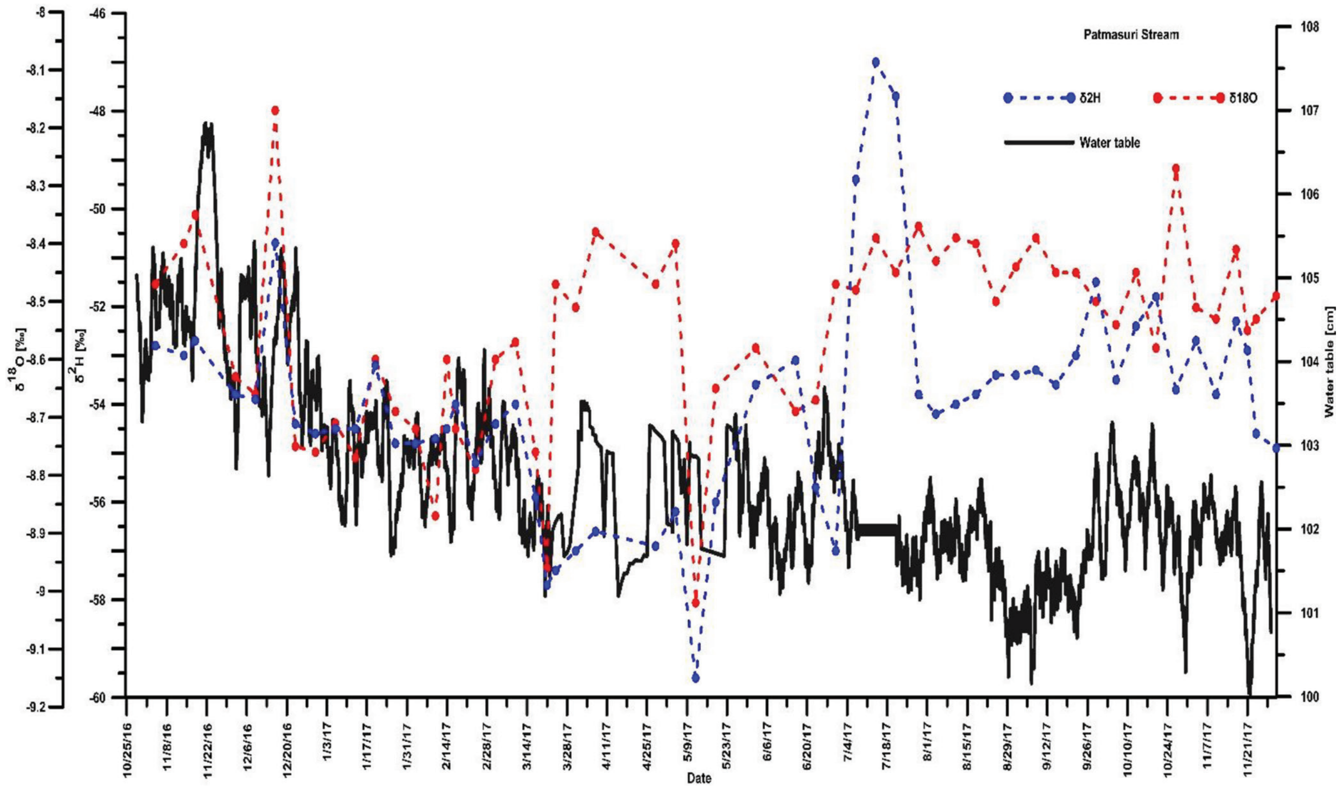

Figure 4: Values of $\delta^{18}O$ and $\delta^{2}H$ in Patmasuri karstic stream water and water table measurements during 2016–2017.

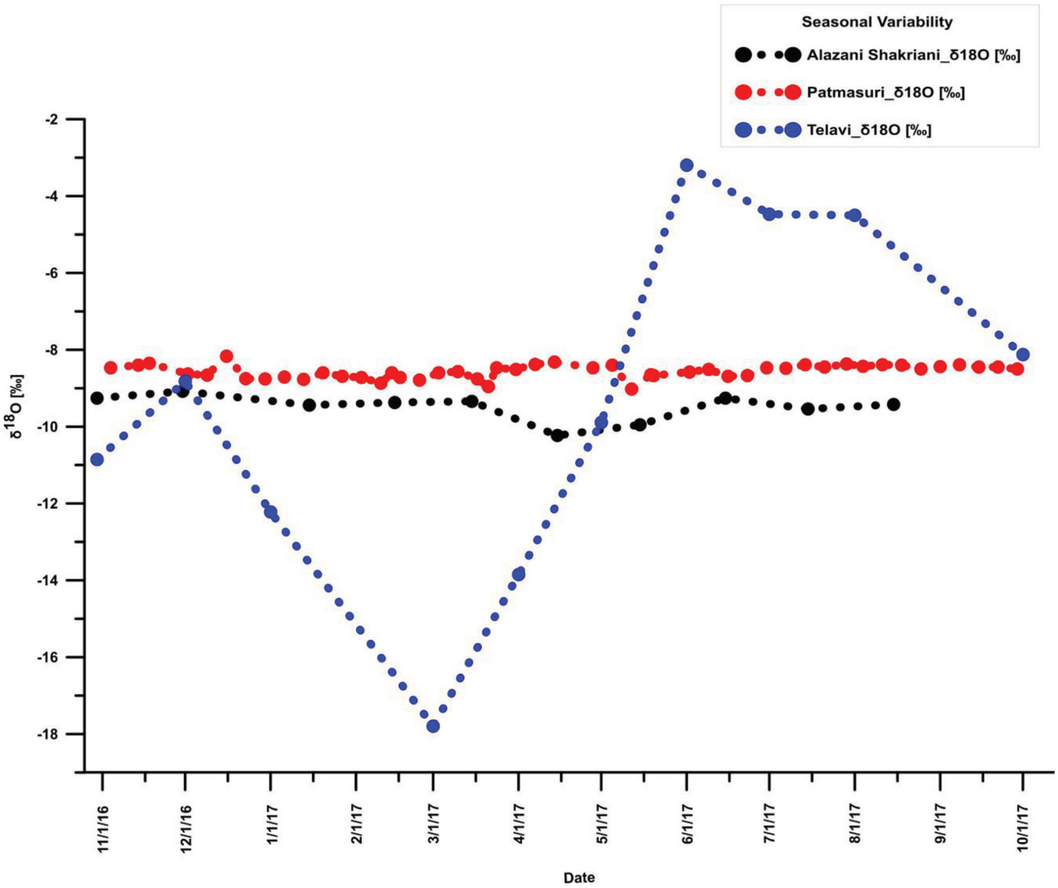

Figure 5: $\delta^{18}O$ in precipitation (Telavi station), Alazani river water (Shakriani) and Patmasuri karstic stream water during 2016–2017.

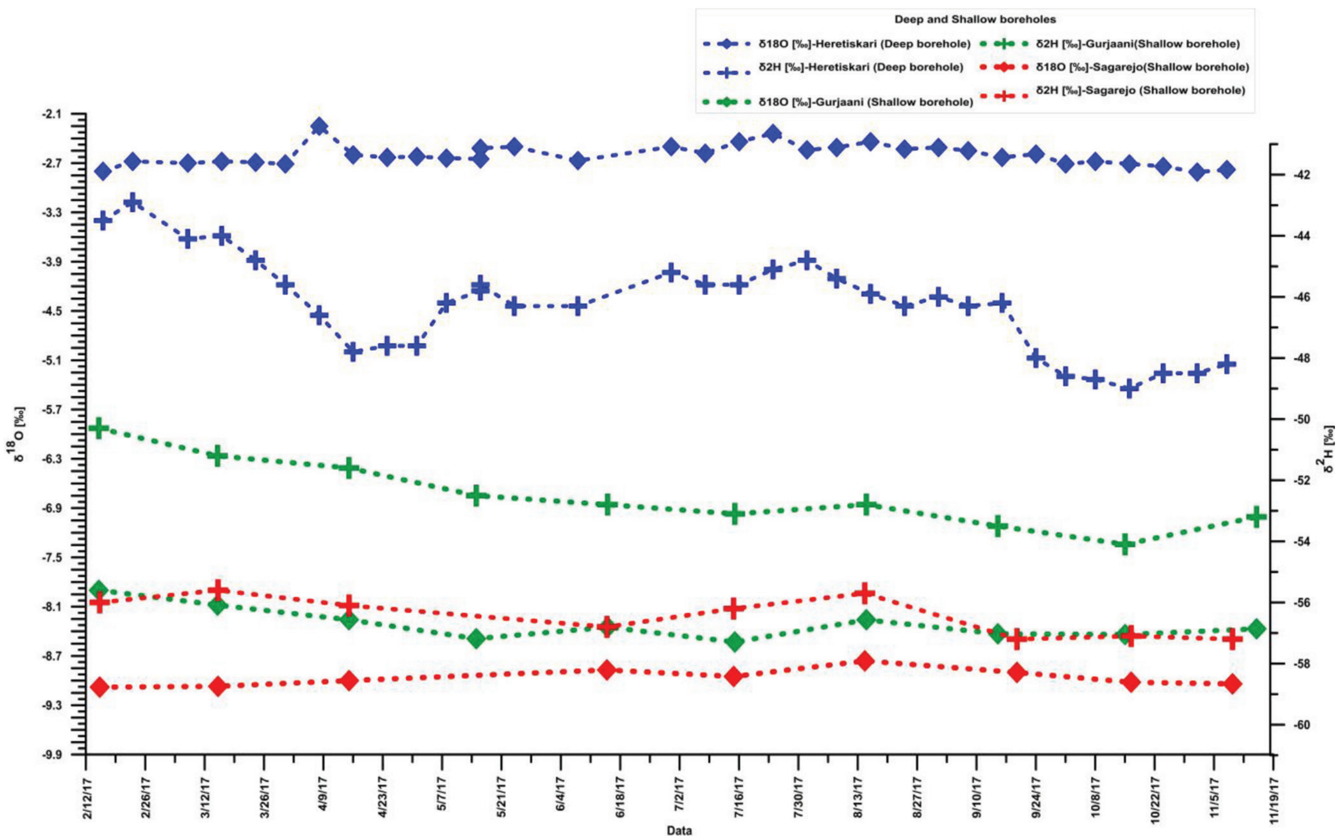

Figure 6: Variation of $\delta^{18}O$ and $\delta^{2}H$ values in the deep groundwater of the Heretiskari borehole and shallow boreholes 2017.

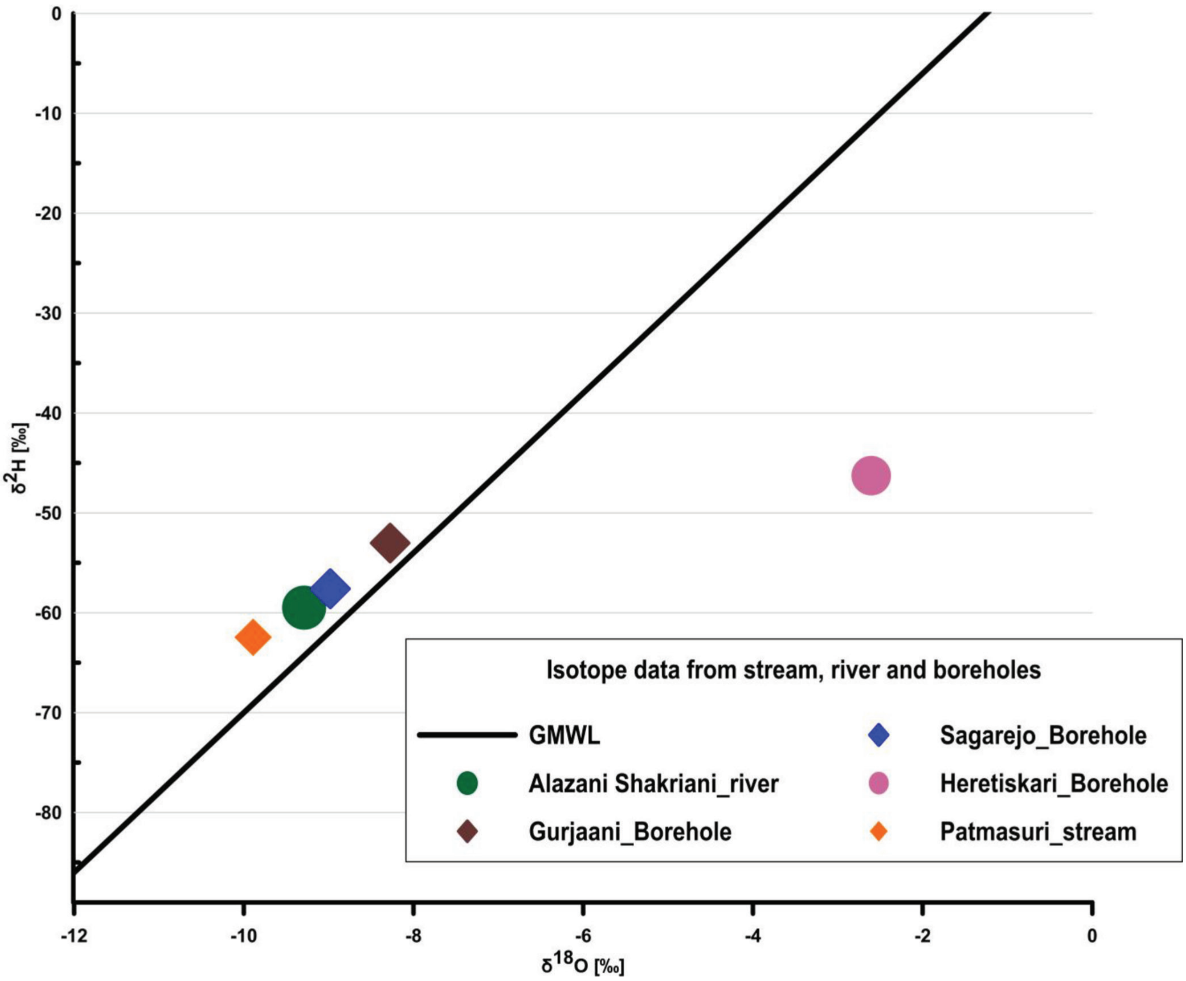

Figure 7: Values of $\delta^{18}O$ and $\delta^{2}H$ of surface water, shallow and deep groundwater samples plotted along the Global Meteoric Water Line (GMWL).

serve as a good proxy to estimate isotope composition in precipitation and especially the temporal distribution for the entire region. Seasonal variability of $\delta^{18}O$ and $\delta^{2}H$ indicates the influence of snowmelt on recharge during spring periods.

Precipitation data demonstrate that altitude is the dominant factor influencing snowfall formation and that the regional distribution (Elizbarashvili, 2007) of precipitation depends on ground surface morphology.

At all surface water and shallow groundwater monitoring stations, isotopic values indicate periodic surpluses of lighter water, which can be attributed to snowmelt contribution. The reduced amplitude (5-fold reduction) and the delay (time-shift of 10 to 15 days) in the $\delta^{18}O$ signal at Alazani River (Shakriani station) compared to the isotopic composition of precipitation (Telavi station) can be explained by the residence time of shallow groundwater flowing from the recharge area to the river.

Comparison of the Patmasuri karstic stream and the Alazani river oxygen isotope composition (Fig. 5) indicates that the Alazani river is mainly supplied by isotopically lighter water from higher altitudes. $\delta^{2}H$ values range from -40 ‰ to -55 ‰ which is typical for mountain precipitation in other mountain ranges, like the Carpathians (Froehlich et al., 2002).

Time series of $\delta^{18}O$ in the Alazani River water at Shakriani station and the Patmasuri karstic stream demonstrate similar isotopic behaviour during spring seasons (Fig. 5), characterised by the decrease of isotopic values, caused by snowmelt. This decrease is preceded by a decrease of isotopic values in precipitation, caused by snowfall at Telavi station.

Precipitation from the slope of the Caucasus Mountains feeding Patmasuri karstic stream and almost simultaneously discharges into Alazani river. This territory is considered as groundwater recharge area. Afterwards, groundwater flows from North-West to South-East direction and infiltrates into deep alluvial-prolluvial horizons (Gurjaani, Sagarejo etc). This process of deep infiltration is accompanied by increasing mineralization, rising temperatures and an increase of heavy isotope fraction. Finally, water flow reaches deep thermal aquifer, such as Heretiskari borehole (Fig.7).

Calculation of the mean transit time (MTT) was based on changes in $\delta^{18}O$ (McGuire and McDonnell, 2006). Estimation of transit time using the lumped parameter model by computationally simple sine wave method showed the mean transit time of 15-17 months.

Isotope data displayed in Fig. 7 show that waters of the Patmasuri karstic stream and the Alazani River are of modern meteoric origin, predominantly fed by precipitation. The ^{18}O and ^{2}H isotopic composition of shallow groundwater (Gurjaani and Sagarejo boreholes) is similar to surface waters. In Sagarejo, the groundwater is isotopically slightly lighter than in Gurjaani due to the groundwater flow direction from north-west to south-east within the Alazani valley.

^{18}O and ^{2}H values of deep groundwater at Heretsikari plot on the right side of the GMWL in Fig. 7. The observed oxygen shift amounts to 4 ‰ - 5 ‰, deuterium excess amounts to -25 ‰. This can be explained by the depth of the aquifer (2000 m below ground) and by the thermal character (temperature-37°C, Na-1773 mg/L, K-16.97 mg/L, Mg-2571 mg/L, Ca-23.046 mg/L, Cl-4329 mg/L, SO_4 -4802 mg/L) of the water.

5. Conclusions

Due to the impact of climate change, precipitation has significantly decreased in the region of Kakheti (East Georgia), leading to a significant decrease in surface water flows and to a depletion of groundwater bodies. The groundwaters recharging at the southern slopes of the Greater Caucasus may be considered as alternative drinking water resources for the communities in the Alazani basin and adjacent foothills.

This study demonstrates that groundwater, flowing through the Upper Jurassic – Lower Cretaceous karstic aquifer towards the South-East, feeds into surface waters and shallow groundwater in the Alazani Valley. Isotope data of deep groundwater in the valley show a distinctly different character. Identification of the origin of these waters and of possible links to the karst aquifer requires further hydrogeological and hydrochemical investigation.

Acknowledgements

The authors gratefully acknowledge the financial support of Shota Rustaveli National Science Foundation of Georgia (SRNSF), through the project *Using of Environmental Isotopes and Hydro-chemical Application for Assessment of Water Resources of Karstic Aquifer of the Greater Caucasus for an Improved Drinking Water Supply of Kakheti Region* (PhDF2016_95). We would like to thank Sebastian Pfleiderer and an anonymous reviewer who strongly helped to improve this manuscript. Furthermore, we express our deepest appreciation to the Georgian National Environmental Agency for data support.

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Received: 22 05 2018
Accepted: 28 12 2018

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