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Geophysics

Assessment of Water Karstic Resource in the Alazani Basin, Georgia

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(Presented by Academy Member Tamaz Chelidze)

The impact of climate change has caused significant precipitation decreases in Alazani valley (East Georgia) region, leading to the depletion of local water resources in the water-scarce areas of the lowland part of the region. Alazani basin is located between the Southern Slope of the Greater Caucasus and Kakheti Ridge and represents a classical thrust-top basin. Karstic waters, flowing from the Southern Slopes of the Greater Caucasus and sinking under the Neogene-Quaternary sediments play an important role as the alternative and sometimes the main source of water supply in the lowland. Isotope methods were used as a useful tool in classification of groundwater genesis and circulation assessment along the karstic aquifer. In order to understand and estimate karstic groundwater resources, several steps of investigation were performed. Seismic profiles and structural cross-sections were applied in order to recognize the geometry of Late Jurassic – Early Cretaceous reservoir strata within the Alazani basin. A subsequent assessment of groundwater fluxes between individual aquifers and their mutual interaction was performed by hydrodynamic modelling in the next step. It was determined, that groundwater horizons have high hydraulic conductivity and good vertical interaction between them. The Cretaceous and Jurassic karst sediments located below the Quaternary layers are recharged by groundwater circulating in the superimposed Quaternary sediments. At the same time, the deep karst artesian layers are feeding Quaternary layers from the lower horizons in some areas of Alazani basin. Thus, the waters of the upper karst aquifers represent an alternative source of drinking water. *© 2023 Bull. Georg. Natl. Acad. Sci.*

Greater Caucasus, Alazani basin, karst, groundwater resources, structural cross-sections, hydrodynamic modelling

Alazani basin, located between Greater Caucasus (GC) and Kakheti Ridge (KR) is filled by late Miocene-Pleistocene continental sediments (Alazani series) and is represented by a classical thrust-top basin [1] (Fig. 1). Their maximum thickness is 2 km and the dominant components of the sedimentary filling are gravels, conglomerates, and sands. Gravels are typically formed by large size boulders of sandstone and limestone material. Imbricate thrust sheets and duplexes beneath the Alazani basin are composed of the Jurassic, Cretaceous, and Paleogene rocks [1].

Due to its semiarid climate, a big deficit of surface water for irrigation and domestic use is deeply precepted around all East Georgian Alazani basin. Growing population and industrial and agricultural activities therefore require new insights into assessment the groundwater resources of the karstic aquifers of Cretaceous and Jurassic formations and further development of these resources.

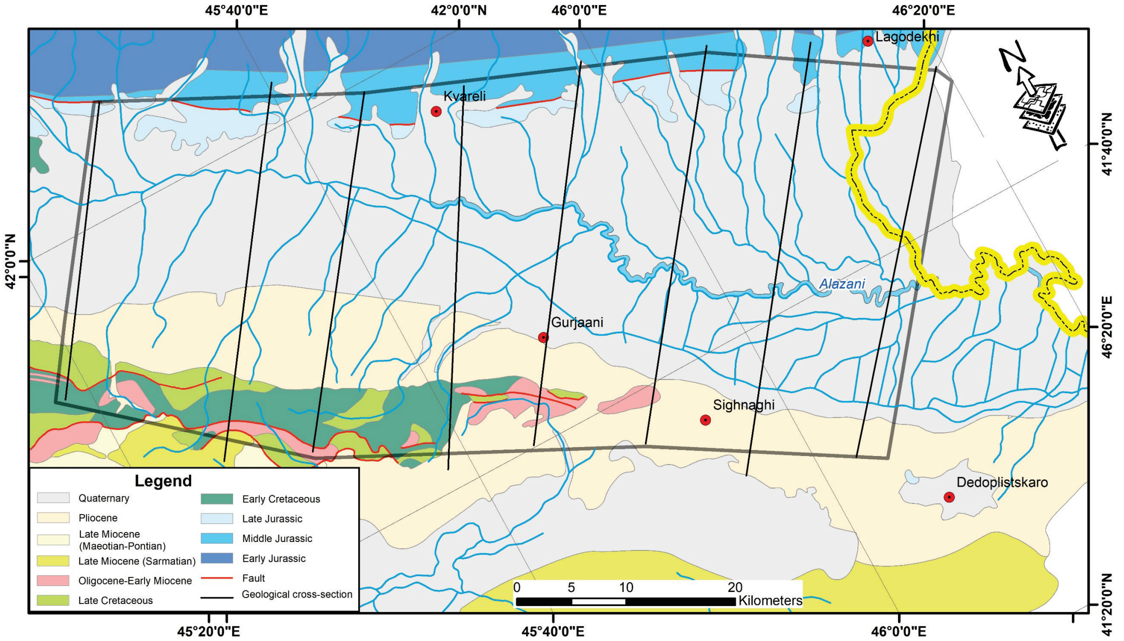

Fig. 1. Geological map of the Alazani basin and surrounding area.

Hydrogeological Settings

From the hydrogeological point of view, the Alazani basins have the area includes several artesian aquifers and assembled into following groups (Table 1) for further interpretation. Alazani basin is drained by the Alazani river as the main surface stream in the area. Some geochemical data come from the work of Buachidze and Zedginidze [2], Beselia [3], Bagoshvili [4]. Apart from surface water in the streams, another important source of water in the area is the groundwater from numerous boreholes and wells.

Based on the previous research in Alazani basin indicates the increase of mineralization from 1 up to 3 in g/l, from the northwest to the south-eastern part of the basin and the gradual replacement of hydrocarbonate-calcium-type water by sodium chloride-type water from the northwest to the southeast of the area. Changes in the overall mineralization in the artesian aquifers reaching as well 3 g/l in the groundwater of Quaternary layers, in the vertical section were also described by previous studies [5, 6]. The evaluation of groundwater chemical and isotope composition and their distribution over the area, in terms of groundwater genesis, revealed the prevailing direction of groundwater flow from northwest to southeast [7].

Materials and Methods

The surface geological information is obtained from a 1:100,000 geological map and shallow and deep well data from the oil prospection of the study area (Fig. 1). For the construction of 3D structural modelling, the Move software was used.

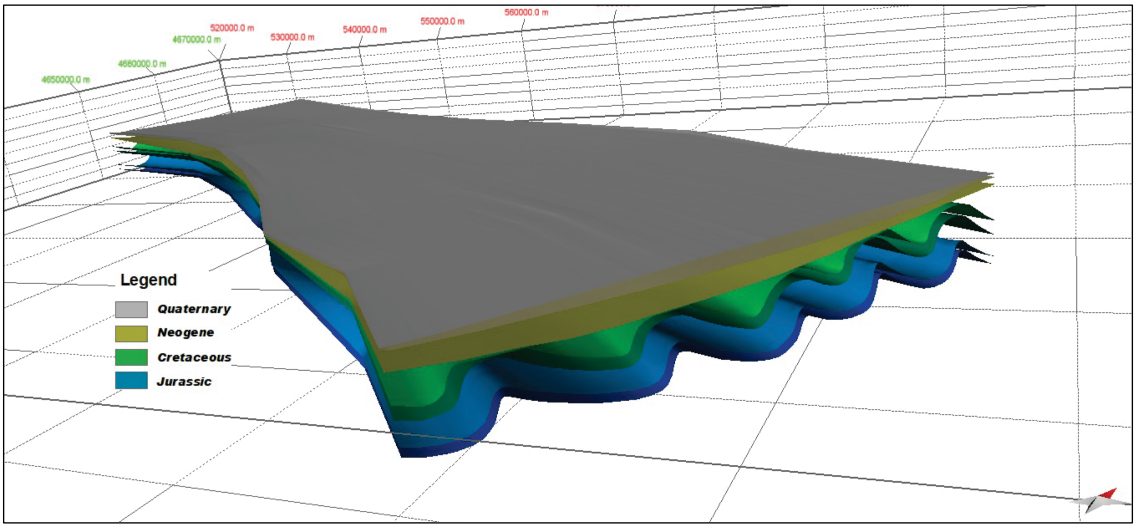

Fig. 2. 3D structural model of the Alazani basin.

According to geological map data and detailed analysis of deep and shallow oil-well data, including own personal field data, 8 structural cross-sections across the Alazani basin were constructed (Fig. 1).

Structural cross-sections were gradually crossing from south to north KR, Alazani basin, and Southern Slope of the GC. The surface geological information is obtained from the existing 1:100,000 scale geological map (Fig. 1). The 3D modelling (Fig. 2) was performed in the following order: (1) construction of 2D structural cross-sections, and (2) interpolation of identified horizons, thrusts, and their connection.

In order to calculate groundwater resources, the three-dimensional hydrodynamic digital modelling on the base geological model geometry was performed for main central part of Alazani river basin. Based on these data, the 3D model was created in the “Feflow” software tool. The northern border of the model runs along the Caucasus ridge and belongs to the recharge area, the eastern border is separated from the Mingechauri reservoir and has the function of discharge. The west passes through the Akhmeta region and the south along the Kakheti range-recharge area. Size of model is 71.5 x 25.53 x 5.3 km. Its surface area covers The total volume of the 3D model is then $4.85*10^{12}$ m^3. The model covers intervals of depth from -4685 m to 714 m. Model contains all seven aforementioned hydrogeological layers represents a porous medium with different properties, summarised in Table 1.

According to long-term meteorological observations in the Telavi station, precipitation falling on the model area was estimated to be 2.4 mm/day using the simple calculation form of:

Table 1. Hydrodynamic parameters of different layers

Layer	Lithology	Thickness, m	Transmissivity m^2/sec	Conductivity m/sec
Soil	Layer thickness 10m for soil	10	65	$7.5*10^{-5}$
Q	Gravel, clays, sands, clastic rocks	150	972	$7.5*10^{-5}$
Q4-Alazani suite	Alazani suite. Sandstones, gravel and conglomerates	500	3240	$7.5*10^{-5}$
pl-ol	Sandstones, claystone, marls	900	10-20	from $1.29*10^{-7}$ to $3.34*10^{-6}$
Cr_2	Limestones, sandstones, marls, clays	450	130	$3.34*10^{-6}$
Cr1	Sandstones, shales, claystone	420	150	$2.17*10^{-6}$
J_3	Limestones with intersect of limy siltstones	380	160	$2.17*10^{-6}$

700-900mm/year or $19.17*10^{-4}$-$24.65*10^{-4}$ m/day

With a model area of 1437.2 km^2 and precipitation of 900 mm/year, the total annual precipitation gives $3.544*10^6$ m^3/day. In the model, after calibrations, the following distribution of precipitation is established:

900mm/year or $24.65*10^{-4}$ m/day.

However, the value of unevaporated precipitation, i.e. the water column that has a potential of actual recharge is according to expert estimates using Blaney-Criddle method of potential evapotranspiration calculation [8], monthly precipitation cycles at Telavi met station and soil field capacity of 80 mm was of about 265 mm in average for the lowland Telavi station and of about 500 mm for the whole mountainous watershed. The actual recharge values should therefore be from the interval of 0.72 to 1.37 mm/day, 30 to 55% of the precipitation totals. Including of the Alazani River into the hydraulic model was carried out using the transfer mechanism (flow boundary of the 3rd type), which allows simulating rivers (black dots). The river lines (and coordinates of dots later) were obtained using Google Earth. The transfer mechanism has an additional parameter for the water exchange at the bottoms of the rivers (transfer in equal to 1 m/day, as well as transfer out equal to 4 m/day). Near the rivers in the upper (first) layer of the model, an increased value of conductivity $Kx=13*10^{-4}$ m/sec was applied. On the south-east part of the model constant hydraulic head (flow boundary of the 1st type), as 83 m above sea level (blue points) was set on all layers.

Results

In order to calibrate the model, the pressures of the wells located in the area were imported into the model as boundary conditions. The following table

Table 2. Boreholes data – position of boreholes and mean groundwater level in the boreholes

location	longitude	Latitude	Water level m a.s.l.
	WGS 1984 UTM zona 38N		
Sanavardo	568205E	4637862**N**	306.6
Pichkhis Bogiri	588515E	4632032**N**	278.2
Shakriani	549190E	4650211**N**	350.8
Gremi	548774E	4649438**N**	353.8
Kindzmarauli	564120E	4641296**N**	331.0
Kuchatani	569473E	4637754**N**	300.9
Afeni	586092E	4629488N	247.2
Vardisubani	594702E	4625156N	243.0

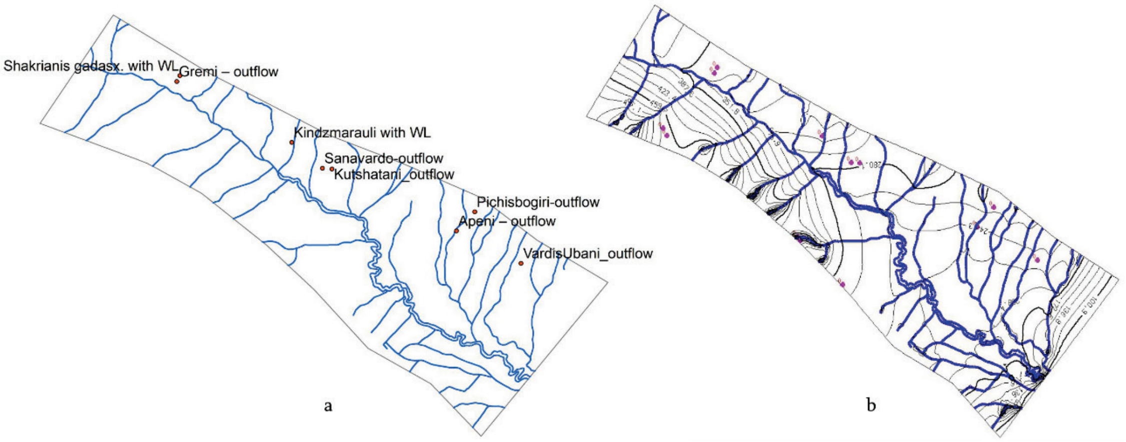

Fig. 3. a – Location of the observation boreholes in area; b – water head – piezometric lines of the uppermost model slice.

Table 3. Fluxes through slices into the vertical direction

Up slice of layer order number (from the top)	Flux Up, m^3/day	Flux Down, m^3/day	vertical exchange m^3/day
1	$0.74*10^6$	$5.20*10^6$	$-4.46*10^6$
2	$2.61*10^6$	$7.13*10^6$	$-4.52*10^6$
3	$3.71*10^6$	$5.58*10^6$	$-1.86*10^6$
4	$1.36*10^6$	$1.52*10^6$	$-0.16*10^6$
5	$0.80*10^6$	$0.10*10^6$	$0.69*10^6$
6	$0.71*10^6$	$0.19*10^6$	$0.52*10^6$
7	$0.45*10^6$	$0.23*10^6$	$0.22*10^6$

Table 4. Fluxes through layers into horizontal direction

Layer order number (from the top)	Integral flux inside m^3/day	Integral flux outside m^3/day	Flux inside-outside m^3/day
1-Soil	$1.42*10^5$	$9.41*10^5$	$-7.99*10^5$
2- Quaternal	$1.02*10^5$	$31.23*10^5$	$-30.21*10^5$
3-Old Quaternal	$3.07*10^5$	$32.68*10^5$	$-29.61*10^5$
4-Paeogen-Oligocen	$1.85*10^5$	$5.62*10^5$	$-3.76*10^5$
5-Up Gretareus	$1.10*10^5$	$0.59*10^5$	$0.51*10^5$
6- Law- Gretareus	$4.57*10^5$	$1.37*10^5$	$3.20*10^5$
7-Up Jurasic	$1.60*10^5$	$0.42*10^5$	$1.1*10^5$
Sum 1-3 Quaternal layers	$5. 51*10^5$	$73.3*10^5$	$-67.8*10^5$
Sum 5-7 Karstic layers	$7.27*10^5$	$2.38*10^5$	$4.81*10^5$

Table 5. Steady-state balance

Name	**Into model, m^3/day**	**Out of model, m^3/day**
Fluxes due to surface water infiltration, and precipitation recharge	$3.53*10^6$	0
Fluxes through outer and inner boundaries	$9.92*10^6$	$1.34*10^7$

Name of boundary	**Into model, m^3/day**	**Out of model, m^3/day**
Fluxes through Dirichlet boundary (1st type)	$2.84*10^3$	$6.39*10^6$
Fluxes through Neumann boundary (2nd type)	$9.46*10^5$	0
Fluxes through Cauchy boundary (3nd type)	$8.97*10^6$	$7.06*10^6$

lists the parameters used. The discharge of wells depends on the location of the screen in the well.

Pressure data of observation boreholes were compared to the modelled ones to create a calibration line. All boreholes' pressure value located nearby the calibration line (Fig. 3 a). Next step, the groundwater piezometric levels in all layer for the Alazani basin were calculated (Fig. 3 b).

After formulating of the conceptual model, the simulation was carried out, when the intensity of vertical and lateral water flow was calculated (m^3/day), for individual layers and for all layers simultaneously. This actually allows us to calculate the groundwater resources.

By definition of the steady state of the model, the incoming water volume is equal to the outgoing volume of water, and the balance change is 0.

Conclusion

On the basis of the new obtained seismic material and the Move software it was possible a three-dimensional geological conceptual model of Alazani was created. Next step, a hydrogeological conceptual model was developed and its digital modelling was carried out, which allowed us to determine the direction of groundwater movement in the model. It was determined, that totally model recharged about $9.92*10^6$ m^3/day from the different sources (river and runoff) and precipitation about $3.53*10^6$ m^3/day, at the same time discharged from the model about $13.4*10^6$ m^3/day of water. This means that the role of rivers in feeding the aquifers is approximately three times more important than the role of recharge by precipitation, and the water quality in rivers should be adequately protected.

The Quaternary layers located in the upper part of the model are characterized by high hydraulic conductivity ($7.5*10^{-5}$ m/sec) and the Cretaceous and Jurassic karst sediments located below are recharged by groundwater circulating in the superimposed Quaternary sediments. The vertical flux through the Quaternary sediments is approximately $11*10^6$ m^3/day and the horizontal flux passing out from the model is about $7.166*10^6$ m^3/day.

The large volume of water supplied to the deep karst layers creates artesian-dynamic conditions for these layers, as a result, the upper Quaternary aquifers are feeding from the lower horizons on the left bank of the Alazani River and in some areas of the right bank. The upward flow is approximately $1.226*10^6$ m^3/day. Thus, the waters of the upper karst aquifers (Cr_2-Cr_1) represent an alternative source of drinking water.

Due to the decrease in conductivity of the karst alluvial layers towards the depth (J_3 $-1.29*10^{-7}$ m/sec), the flowpace decreases observed, which is followed by the increase of groundwater mineralization from 1 g/l up to 3 g/l, reported from the northwest to the southeastern part of the study area and also towards the depth. The gradual replacement of hydrocarbonate-calcium-type water by sodium chloride-type water from the northwest to the southeast of the area was also reported.

The application of environmental isotope analyses reported in the previous studies [5- 7] also confirms this regulation. Stable isotope values of $\delta^{18}O$ (-8.5) -(-9.9)% and tritium values are of about 7-11 TU are typical for the recharge areas. The fresh groundwater dominates in the Alazani series, as well as in the upper part of Cretaceous and Jurassic formations, located in the north-western part of the Alazani basin. Highly mineralized groundwater, which is located on the south-east of the study area, contains oxygen stable isotope values of about $\delta^{18}O$ -11 and -13% and tritium concentration is relatively low (0.1-1.8 TU), which characterizes the old groundwater components.

The hydraulic model described in the paper allows determination of the groundwater amounts available for water consumption for the desired cross section of the horizon. In addition, vertical and horizontal movement of groundwater flux paths are identifiable at every point within the model area of the bordered polygon of Alazani catchment. The overall water balance within the model underlines the importance of surface water / groundwater interaction in the region and imposes the need of adequate stream water protection especially in the upper part of the area.

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გეოფიზიკა

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(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

კლიმატურმა ცვლილებებმა გამოიწვია ნალექების მნიშვნელოვანი შემცირება კახეთის (აღმოსავლეთ საქართველო) რეგიონში, შედეგად კი მოხდა ღრმა და არაღრმა მიწისქვეშა წყლების რესურსების ამოწურვა რეგიონის დაბლობ რაიონებში. ალაზნის აუზი მდებარეობს დიდი კავკასიონის სამხრეთ ფერდსა და კახეთის ქედს შორის და წარმოადგენს კლასიკურ ტექტონიკური ნაოჭების თავზე მდებარე სედიმენტაციურ აუზს. კარსტული წყლები, რომლებიც ჩამოედინება დიდი კავკასიონის სამხრეთ კალთებიდან და იძირება ნეოგენურ-მეოთხეული ნალექების ქვეშ, მნიშვნელოვან როლს ასრულებს, როგორც დაბლობში მიწისქვეშა წყლების შევსების ალტერნატიული და, ზოგჯერ, ძირითადი წყარო. ამ კვლევებში იზოტოპური მეთოდები გამოიყენებოდა, როგორც სასარგებლო ინსტრუმენტი მიწისქვეშა წყლების წარმოშობისა და კარსტული წყლების ცირკულაციის შეფასებისას. კარსტული წყლის რესურსის დასადგენად ჩატარდა კვლევის რამდენიმე ეტაპი. სეისმური პროფილები და კონსტრუქციული განივი კვეთები გამოყენებულ იქნა ალაზნის აუზში გვიან იურულ-ადრე ცარცული წყალსაცავის ფენების გეომეტრიის ამოცნობის მიზნით. მომდევნო ეტაპზე, ცალკეული წყალშემცველი ფენების წყლის რესურსების შეფასებისა და მათი ურთიერთგავლენის დადგენის მიზნით განხორციელდა ჰიდროდინამიკური მოდელირება.

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