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Numerical modelling of groundwater system in the East Georgia's lowland

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Abstract

In order to assessment water pathway and origin, a numerical model of groundwater was elaborated for East Georgia's lowland - Alazani and Shiraki catchments. The model was calibrated in transient transport mode to tritium concentration measured in boreholes and springs located in East Georgia areas. Tritium was assigned as a single mobile species, not reacting with chemical elements and concentrated in water, what allowed determining the residence time of groundwater flow. The model estimated groundwater flow directions and velocities between recharge and discharge areas, as well as groundwater age for Alazani and Shiraki catchments.

Introduction

Eastern Georgia is the most important the agricultural area of Georgia. This territory, with semiarid climate and a big deficit of drinking water resource are crossing two large rivers Alazani and Iori. In order to reassessment water resource of this two catchments, a numerical model of groundwater layers was elaborated based on the obtain data. Modelling has been processed by special software VisualModflow Package.

Geological and Hydrogeological settings

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 Transcaucasia Intermountain Area (1).

The folded system of the northern slope of the Greater Caucasus is formed by sediments of the Upper Lias up to Upper Cretaceous age. The folded system of the Kakheti Ridge, representing the southeastern branch of the folded system of the southern slope of the Greater Caucasus, is composed of sediments from Jurassic to Pliocene age (1). In turn, the northeastern and northwestern slopes of the Kakheti ridge are formed by Alazani series of Neogenic 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 tertary 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 (1).

The aquifers of the Alazani basin are generally abundant in artesian groundwaters 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. The dynamics of the ground waters are greatly affected with the peculiar composition of Shiraki Massif, which is the component of the Iori Plateau dividing the basins of the rivers Iori and Alazani in the lower current. To the north the Shiraki Massif is distinctly divided from the Alazani valley with the eroded tectonic batter of 400m of height. Within the plain the modern relief is characterized with considerable sloping towards the axial part. Besides, bending can be observed along the axis of the syncline as well, thus, in spite of the general regional sloping in the south- east direction, the plain is contoured as a locked depression (2-3).

In conditions of the entire lack of the hydrographic network in the area the ground water supply takes place at the expense of atmospheric precipitation, which is proved by the given regime observations. Besides we suppose the possibility of some injection of the ground waters from below by the downstream waters. The horizon of the ground waters is dated for the fourth sediments and is mapped quite sharply by the given measurements of the boreholes. On the map hydroisogyps the picture of water movement from the relatively raised peripheral parts of depression towards the lower and locked central part where ground waters are closer to the ground surface is quite distinctly depicted (6m at the middle sedimentary depth of 25m) and on the whole are spent on evapotranspiration. A great width of the crumby continental layers krasnokolodski suite (Akchagil- afsheron), lain in a large syncline, is a main aquifer, and contains pressure ground waters (4-5).

Field work

More than one hundred water points (springs, boreholes, dug wells) were sampled during expedition (6). Major ions, ^{18}O, ^{2}H and ^{3}H were measured at each site. Physico-chemical parameters (Temperature, pH, DO, EC) were obtained directly in the field, by the WTW Multi 340i set. Hydrodynamical properties of aquifer rocks (hydraulic conductivity, storativity, etc), have measured, which was necessary for numerical modelling will be evaluated.

Additional monthly monitoring of ^{18}O, ^{2}H and ^{3}H in rainwaters and streamwaters was established in the study area. From the GNIP (^{18}O, ^{2}H) stations in 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.

Modelling

A mathematical model of groundwater hydrodynamics was elaborated for the area based on the conceptual model, which based on the provisional data (geological, geophysical, hydrogeological, hydrological, etc). Model of the aquifer have been processed by special software VisualModflowPro package.

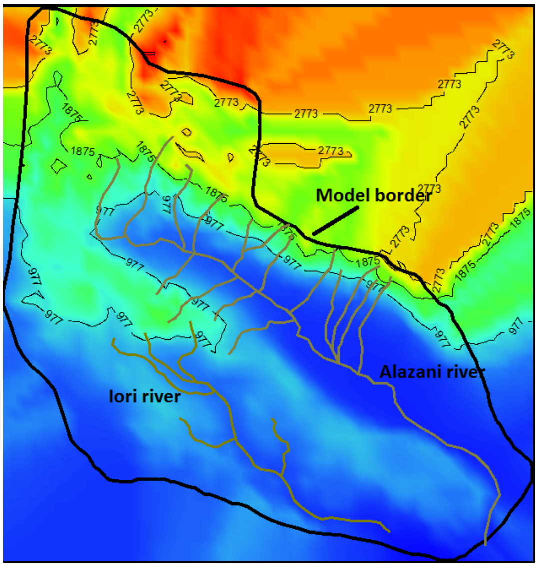

Fig.1 Model boundary

On the Fig.1 we can see the border of the area includes Iori and Alazani rivers. For creation conceptual model available geological profiles were used. On the base of these data 3D model were created. Model is rather complicated. It includes many layers (See Fig. 2).

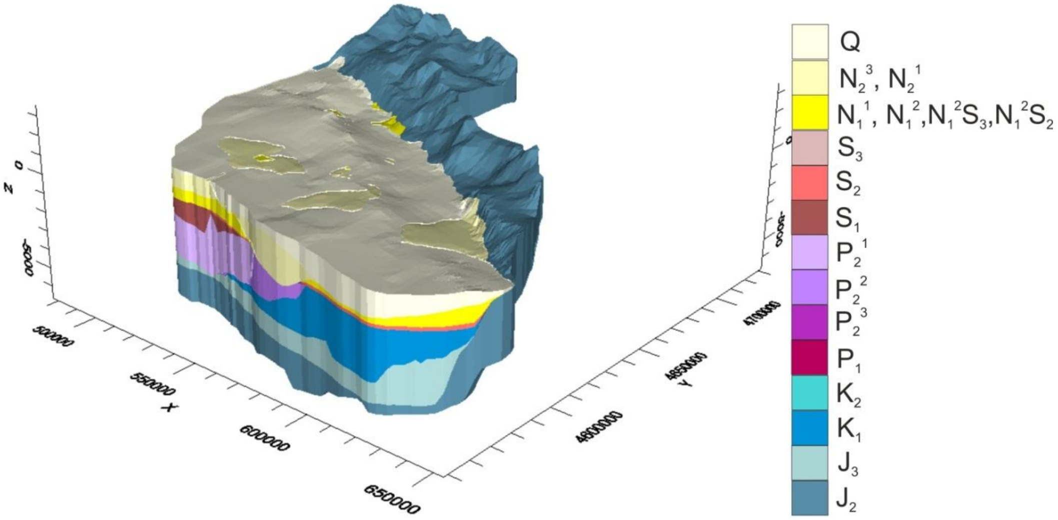

Fig. 2 Conceptual model

Conceptual and numerical model were developed in Visual Modflow Flex 2012 and Visual Modflow Classic 2011 programs. Conceptual 3D model consists of 14 layers (Q, N, J, S3, S2, S1, P21, P22, P1, K2, K1, J3, J2). Each layer represents a porous material with different infiltration properties. Data from geological profiles and maps where used to recreate layers. Upper layers (Q and N) are designed as unconfined. Each layer, as single hydro stratigraphic unit, was determined by hydraulic conductivity, specific storage, and effective porosity (Tab 1.).

Tab. 1. Hydrologic property of layers

Layers	Hydraulic conductivity (m/s)	Specific storage (m^{-1})	Effective porosity
Q	$7.6042x10^{-5}$	$3x10^{-6}$	0.05
N	$1.6204x10^{-6}$	$5x10^{-5}$	0.03
J	$1.8519x10^{-6}$	$9x10^{-4}$	0.07
S3	$2.257x10^{-6}$	$9x10^{-4}$	0.05
S2	$3.8588x10^{-6}$	$7x10^{-4}$	0.05
S1	$4.653x10^{-6}$	$6x10^{-4}$	0.05
P21	$0.8557x10^{-6}$	$5.5x10^{-5}$	0.04
P21	$0.9520x10^{-6}$	$2x10^{-5}$	0.04
P22	$0.7900x10^{-6}$	$3.2x10^{-5}$	0.05
P1	$2.8471x10^{-6}$	$4x10^{-6}$	0.06
K2	$1.5824x10^{-6}$	$4.5x10^{-6}$	0.06
J3	$1.2511x10^{-6}$	$3x10^{-6}$	0.07
J2	$1.0047x10^{-6}$	$2x10^{-6}$	0.075

Rivers were used as boundaries of the model area. They were assigned as specific flow boundary conditions (Tab. 2).

Tab. 1. Size of rivers

River	Riverbed thickness (m)	River width (m)	Riverbed conductivity (m/day)
Alazani	5	50	20
Iori	3	30	10

Visual Modflow Flex supports the standard Drain Boundary Package; we used it to simulate the boreholes under artesian conditions. 20 drain boundary conditions were added to the model. Next table shows parameters which were assigned to drains. Debit rate depends on the position of well screen.

Tab. 3 Boreholes' data

Artesian boreholes screen geology	Debit rate (L/sec)
Q	Up to 165
N	Up to 60
P	Up to 70
J	Up to 10

Conceptual model were converted to numerical one and further development. Debits rate of artesian wells where used for to calibrate model in steady-state mode. Precipitation value (800 mm/year) was assigned to upper right zone of model. Location of artesian wells marked as triangles on the Fig.3

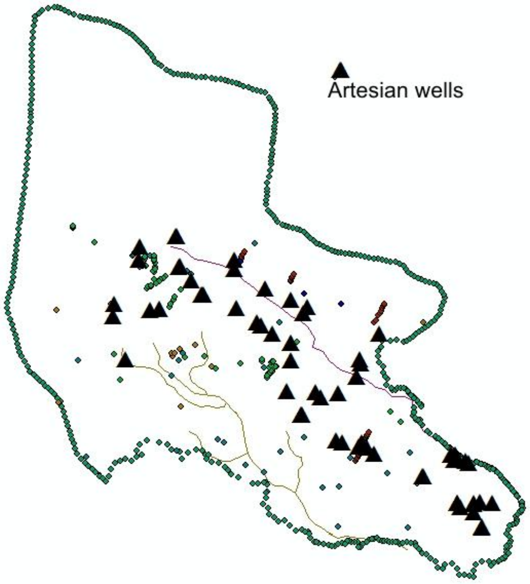

Fig. 3 Location of artesian wells.

Had calibrated water table of the study area, based on the initial heads values. Had indicated dry area in the centre of model (Fig. 4).

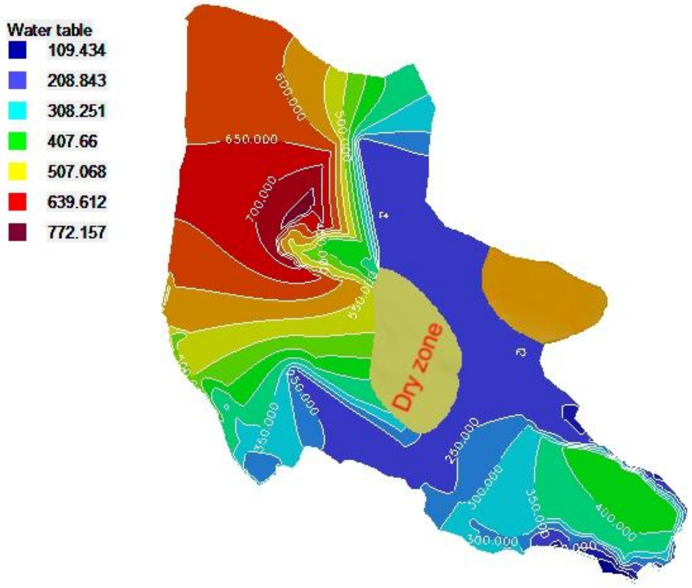

Fig. 4 Water table

In the model was fixed water level in absolute elevation on the difference layers and was simulated Flow velocities for Alazani-Shiraki area together (Fig. 4).

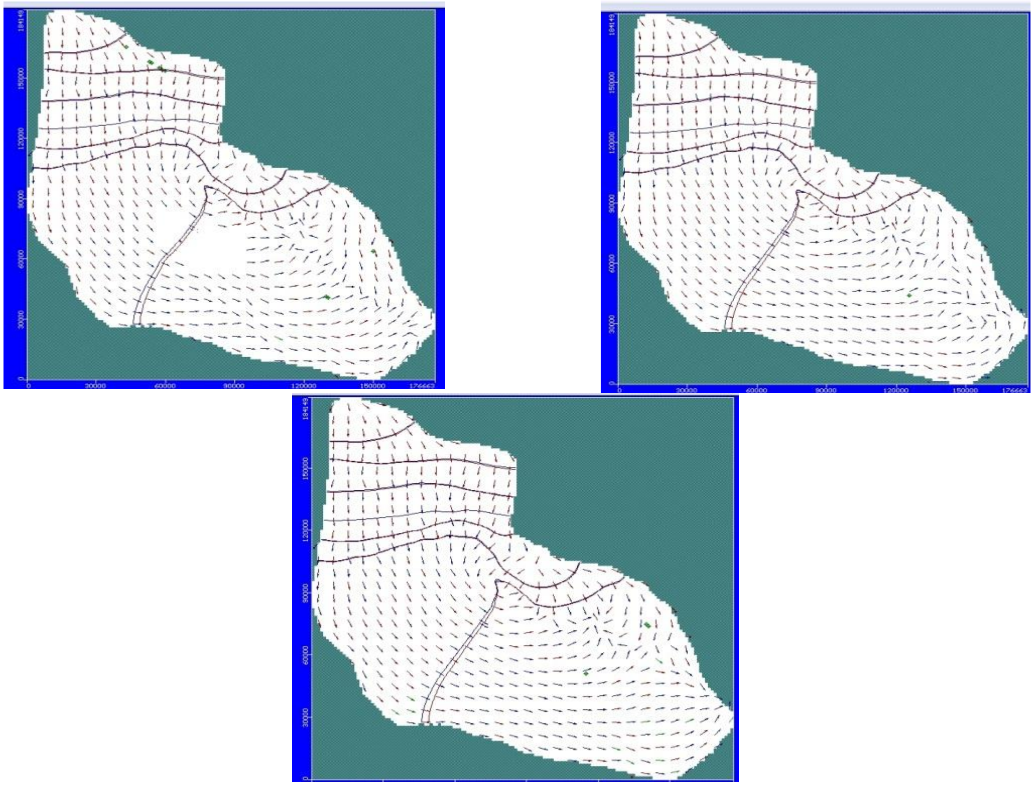

Fig. 4 Flowvelocities of a) 1st layer; b) 10nd layer; c) 20rd layer

Fig. 4 shows us flow velocities intensity and direction of simulated water system. As we can see water does not enter the system in upper horizon of central area .This part is weakly water-bearing and does not infiltrate water down. In the right zone water is discharged in the rivers. Middle horizon is recharged by groundwater flows. Intense of flow is increasing in the 10rd layer and keeps at the same stage up to 20 rd layer.

In order to calculate residence time of groundwater flows was used to Particle toolbox. From the mountain area groundwater moves to the Alazani site, average water age between 2 locations is about 90 days. From the Shiraki hills water moves to Alazani wells (Kasritskali and others), water age between 2 locations is about 90 days (Fig.5). From the lower area of central Shiraki hill water moves to the right direction and archives Alazani valley during 6 months.

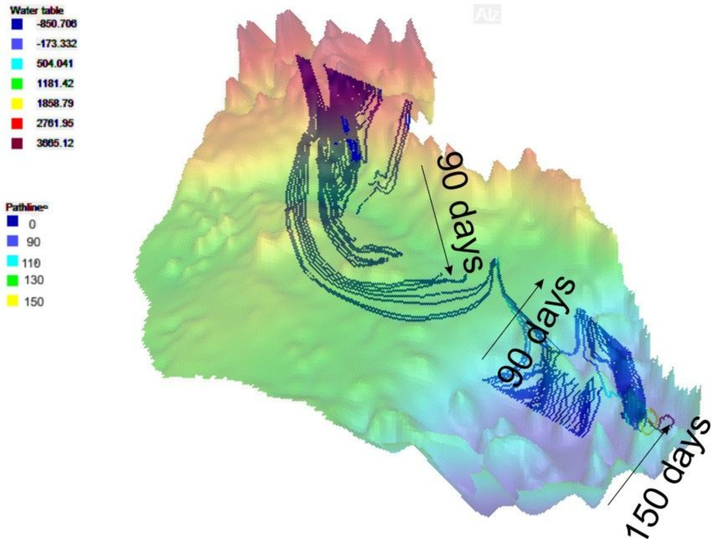

Fig. 5 Groundwater flow pathway and residence time

As we can see, zone# 2 (see Fig. 6) upper mountain area is recharged more intense than zone#3, but water discharged in general in the zone#3. Groundwater discharge of wells is rather slight compared to rivers. Furthermore, was calculating total flow budget in the model (Fig.7).

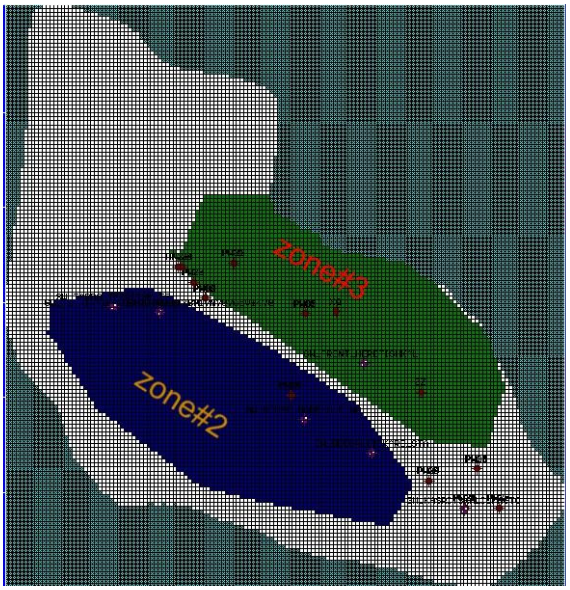

Fig. 6 Groundwater zone

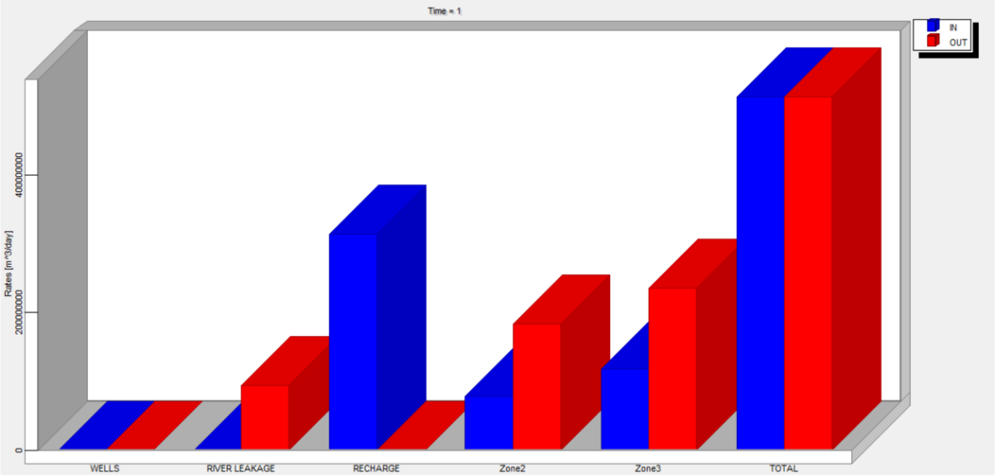

Fig. 7 Flow Budget, Blue is discharge, Red is recharge

Conclusions

Bases on the model the residence time of groundwater flows from the study areas of Alazani valley to the Shiraki area, average water age between 2 locations is about 4 months. Grounwater has confirmed the evolution in mineralization from Northwest to Southeast, with major increase in the Shiraki syncline area. Therefore, are observed changes of total mineralization in the vertical cross section of the boreholes. It is recommended to enhance the use of waters from the karstic formations such as the Kvareli and Dedoplitskaro Plain for alternative drinking water sources in the regions.

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Цифровое моделирование системи подземной вод Восточно Грузинской низмености

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РЕЗЮМЕ

С целью выяснения генезиса подземных вод численная модель грунтовой воды была разработана для области. Модель состоит из 20 слоев. Слои представлют собой геологические породы с различными фильтрационными свойствами. Модель определила области питания и разгрузки грунтовых вод, пути и скорость движения подземных вод,а также время задержки воды под землей.

აღმოსავლეთ საქართველოს დაბლობი რაიონების მიწისქვეშა წყლის სისტემების ციფრული მოდელირება

გიორგი მელიქაძე, ნატალია ჟუკოვა, მარიამ თოდაძე, სოფიო ვეფხვაძე

თორნიკე ჭიკაძე

ივ. ჯავახიშვილისსახ. თბილისისსახელმწიფოუნივერსიტეტი, მ. ნოდიასგეოფიზიკისინსტიტუტი

აბსტრაქტი

მიწისქვეშა წყლების გენეზისის შესწავლია მიზნით შემუშავდა საკვლევი რეგიონის ციფრული მოდელი. ის შედგება 20 ფენისგან. თითოეული ფენა შედგება სხვადასხვა გამტარებლობის ფოროვალი გარემოსაგან. მოდელში განსაზღვრული იქნა კვებისა და განტვირთვის არეალები. ასევე დაფიქსირდა წყლის გადაადგილების გზები, სიჩქარე და მიწისქვეშ მოძრაობის პერიოდი.