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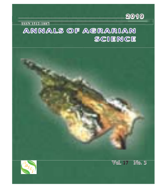

Water economy balance - the basis of water supply assessment

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A B S T R A C T

Georgia has reach water resources, however, their unequal distribution creates a gap between the amounts of available and consumed water. The main goal of the study is to identify most vulnerable regions as regards water resources on a basis of Water Economy Balance. Kvemo Kartli has been taken as the region under study. Its area is 6.5 thousands of square km (that is 9.3% of the country territory). There are 347 settlements – 7 cities, 6 towns and 334 villages. Its natural conditions are most favorable for agricultural purposes with 2-3 harvests per year that stipulate for high competitiveness of the region in comparison with other ones. Different branches of industry such as mining, metallurgy, chemical production of cement and construction materials, ceramics, glass, etc., along with power generation plants are the most active water consumers in the region. The main problem of nearly all municipalities in the region are irrigation schemes which are depreciated or in poor state today. The existing problems of water supply hinder development of agricultural branches considerably. The hydrography network of Kvemo Kartli is represented with trans-boundary river Mtkvari and its tributaries; 15 lakes are used for recreation, irrigation and fishing purposes; 6 reservoirs are used for fresh water supply, power and irrigation purposes. There are mineral, sulphur and thermal springs.

Keywords:Water resources, Management, Water economy balance, Deter-ration, Climate change, Hydrography network.

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Introduction

Georgia has reach water resources, however, their unequal distribution creates a gap between the amounts of available and consumed water. In east Georgia, which is considered to be the main water consumer part of Georgia, water consumption rates are four times lower compared to the West. In West Georgia, South and South-East parts are suffering from the most severe conditions. From main adverse factors influencing on water resources of Georgia are: the increasing pollution of hydrosphere and environ-ment (atmosphere, lithosphere). The causes of qualitative deter-ration of water resources are: irrigation, land-reclamation of salinized lands, run-off waters, malorganization of reservoirs' foundation pits, et cetera. The importance of the problem is proved by the fact that even purified, recycled waters need dilution 15 times with clean water to regain natural water quality [1]. Here, river water flows are often lower than the environmental minimum during low water level periods. Considering the processes of climate change, we predict that freshwater availability issue will become more significant in the future. In large parts of eastern Georgia annual precipitation sum decreased at a rate of 1e3% per decade. Most precipitation decreasing decadal trend is observed in Kvemo Kartli region, south of Tbilisi, and is more than 5% [2]. Nowadays, in Georgia water resources are managed by an administrative principle. The administrative model cannot ensure efficient water management, considering the needs of water consumers' as well as environmental protection concerns. Therefore, there is a necessity for the shift to pound manageable water consumption [3, 4]. At the same time, Kvemo Kartli's administrative-territorial division model excellently illustrates the specificities of the region's natural and socio-economic conditions. The hydrography network of Kvemo Kartli is represented with trans-boundary river Mtkvari and its tributaries. Tbilisi – the capital of country is located next to Kvemo Kartli region. The nearby Azerbaijan and Armenia republics, Tbilisi international airport, high level of urbanization, transport and power corridors, etc., favor development of the region.

Georgia strives for deeper cooperation with Euro Union. Among the priority spheres of that cooperation one of the most important ones is sustainable development of water resources. Inculcation of controlled water consumption system will create better conditions for the rational and more efficient use of the budget expenditures that will have positive effect on economics and social sphere of the country.

Methods and Materials

Kvemo Kartli was choose as a study area. Agriculture is the central area of Kvemo Kartli's economics. 29% of the total population and 48% of the countryside population are employed/self-employed in agriculture. Compared to the other regions, there is an upgrowing Natural Population Growth trend in Kvemo Kartli. Considering this, it is likely that in a longterm perspective, there will be a higher demand for social infrastructure, utilities, and employment. Hence, there will be a greater need for water resources.

The main goal of the study is to identify most vulnerable regions as regards water resources on a basis of Water Economy Balance. This is essential for long-term and short-term planning.

Kvemo Kartli is located in the Southeastern part of Georgia. It is surrounded by Samtskhe-Javakheti on the west; surroundings of Tbilisi, Shida Kartli and Mtskheta-Mtianeti on the north; Kakheti on the east; and the republics of Armenia and Azerbaijan on the south.

In the region, 45% of the population is ethnically Georgian; 45% - Azeri; 6% - Armenian; 4% - Abkhazian, Osetian, Russian, Greek, Ukrainian, Kurd. Self-governing units of the region are the Municipalities of Bolnisi, Gardabani, Dmanisi, Tetri Tskaro, Marneuli and Tsalka, and the city Rustavi.

Climate is moderately humid in Kvemo Kartli. Towards east, humidity decreases. Winter is moderate cold, summer – hot. In the region, northern, north-western and south-eastern winds dominate. Average minimal temperature is not lower than $0,2^0$C. Average maximal temperature usually occurs in August and amounts to 23.9^0C. The average sum of annual precipitate is 146 mm. The most precipitated month is May, the dryest – January.

Compared to the other regions of Georgia, the volumes of local mineral and thermal waters are lower. Among them, the most significant rivers are the transborder river Mtkvari and its tributaries. Existing water resources are efficiently consumed in the region. Water Supply Data of Natural Water Objects (underground and surface) from 2011 year shows that water supply amounts to 452 million m^3, from which 2% was used for drinking-agricultural means, 30% - for hydro energetic means, 55% for the industrial means, 11.7% for irrigation, 0.7% for agricultural water supply, and the rest - for pond economics and recreational means.

Climate conditions are convenient for producing agricultural products in the region. Harvesting is conceivable 2-3 times a year, which makes this region highly competitive (outstands the region) to the other regions of Georgia. There were no major changes in the structure of agricultural areas of the region during the past 5-7 years. However, there is an upward trend in the number of the farmers occupied in animal breeding and a decrease of the interest in seeding. The dysfunction of the irrigation system is a basic obstruction for land cultivation.

Irrigation system area amounts to 46 754 ha, which is 50% of the local arable land. Out of it, 20 274 ha (43%) requires rehabilitation. There are identical conditions in inner networks of irrigation systems since they are absorbed and broken. Water supply from water object surfaces are prevailing. At the time of stil and temperature inversion, cold air masses accumulate. The average minimum air temperature is not below $0,2^0$ C, the average maximum temperature in August reaches 23.9^0 C. The average annual precipitation does not exceed 550 mm. The most precipitation is May, and dry – January.

Territorial water supplement is usually assessed using the structure of Quantitative Water Economy Balance (QWEB). The Water Economy Balance of a river basin, sub basin, or every part or economical region is the balance between water resources and water supply in certain time trims. Water economy balance (WEB) can be employed for multi-year goals as well as for certain periods (such as arid-climate year, vegetative season, etc.). As a rule, maximum of water-consumption indices are taken into account for developing water economy balance.

While developing Water Economy Balance, sequentially along the river (from the outfall to the estuary), Water Economy Units (WEU) are allocated. WEU is the part of the territory and its parameters are used to assess water intake limits of the water object, Water Supply, and different water consumption parameters. For each water Economy Units, parameters of the structure of water Economy balance are developed. Based on them, status for each can be generated using the following classification:

- WEB can be secured by local flow;
- WEB includes local flows as well as flows that are transmitted from the upper side of the Unit's adjacent territories;
- WEB consists of local water, water transmitted from the upper side of the Unit's adjacent territories and returned water;
- Asides mentioned water resources, environmental minimum water also participates in WEB supplement.

In the mentioned classification, the first one is the most convenient for water suply, while the last one describes the most difficult conditions. Each WEB that includes returned or environmental minimum waters, face certain issues. Not to mention the last one, the water that is necessary for returned polluted water dilution might create severe problems related to water supply. Considering the aforementioned, Water Economy Balance also possesses a qualitative aspect.

The main goal of the study is to develop the Quantitative-Qualitative WEB for Kvemo Kartli using updated data and its analysis. The calculations are based on information from the 80s of the last century, which was extrapolated to 2011. It should be considered that during this time almost all fields of agriculture functioned normally in Georgia. The amount of the water necessary for dilution, was assessed using secondary data analysis (previous reports, projects, mentions, scientific works, etc.). In Kvemo Kartli saturation of Returned water in QQWEB was assessed using previous research findings of the surveys conducted in the region. Moreover, expert assessments were also considered by following scheme: Tsalka, Tetritskaro(Basin of the River Khrami), Dmanisi, Bolnisi – 5 times more; Marneuli (Basin of the River Khrami) - 8-times more; Tetritskaro (Basin of the River Alngeti), Marneuli (Basin of the River Algeti) - 10-times more.

Methodology for compiling Water Economy Balance has been carefully developed [5]. Its results are widely used in the regulation/planning of water relations. The general pattern QWMB is displayed by the following equation:

$$B_q = W_l - W_i + W_r \geq G \qquad (1)$$

In this formula, B_q represents Quantitative Water Economy Balance (flow given to neighbor/low riverside Water Economy Section). W_l represents a local flow, formed in the Water Economy Section. W_i refers to water in take, W_r - returned water, G – environmental minimum.

In general, conditions are tensed when water remaining in the river (transferred to the neighboring WEB) equals or is less than the environmental minimum. In this case, Water Economy Balance is considered to be in shortage.

Nowadays, the rule of computing environmental expenditure is not defined by Georgian law. Acknowledging largely admitted water expenditure computing methods, we presume that it would be advisable to use 25% of the river multi-year expenditure as the mean of the environmental expenditure in Kvemo Kartli, considering it's natural resources.

In order to preserve water background quality, which is one of the main demands of EU Water Frame Directive, a minimum amount of the water is needed in the object which is a receiver of polluted water flows. This minimum amount is enough for water dilution to certain concentrations. Therefore, indices that show a quality of polluter water flow, is reduced to the quantitative indices as it considers the amount of the water needed for dilution.

To address freshwater-related issues caused by contemporary natural, demographical and economic conditions, it is necessary to modify Water Economy Balance. Precisely, it is important to involve the amount of the water needed for polluted water dilution. In other words, for complex assessment of territorial water supply, it is important to develop quantitative-qualitative water economy balance. According to the modified new approach (1), we should add to the display a new member that would count the amount of the water needed for the polluted water dilution.

Supplied returned water – $W_r = K_{r\,*} W_{i;}$ Water needed for polluted water delution – $W_d = K_{r\,*} W_{i\,*} K_{d,}$ where K_r and K_d are return and delution amount coefficents. As a result, after simple transform, we can compute volume of the returned water at Water Economy Balance, needed for delution:

$$W_d = W_{r\,*} (K_d+1) \qquad (2)$$

Calculation of Quantitative-Qualitative Water Economy Balance is even more complex. This is due to the limited availability of observed data needed for computation. Because of that, pollution of received and returned waters are often ignored and they are taken as deemed and as appropriate to the established normative. Grin [5] and Lvovich [6] who are highly qualified and well know specialists in this area, also confirm that even clean flows should be diluted at least 5-10 times [5, 6]. At the same time, complex and costly activities are needed for consumed water dilution, that flows in in the water objects in order to be relevant for standards, rather than reducing its volume. In case high volume of water is needed for flown consumed water solution, it is recommended to reduce them.

After assessing the probity of compilers and existing data, as a rule, the number of compilers gets significantly reduced. Considering conditions of Kvemo Kartli, just 6-8 compilers can be enough for computing Quantitative-Qualitative WEB. Therefore, we develop a scheme of Quantitative-Qualitative WEB by sections:

WEB 1 – $W_1 = W_0 + B_1 + A_1 + Q_1 - E_1 - D_1 - C_1 \pm \Delta V_1 \geq F_1 * (K_d + 1) \geq G_1,$

WEB 2 – $W_2 = W_1 + B_2 + A_2 + Q_2 - E_2 - D_2 - C_2 \pm \Delta V_2 \geq C_1 + C_2 * (K_d + 1) \geq G_2,$

WEB 3 – $W_3 = W_2 + B_3 + A_3 + Q_3 - E_3 - D_3 - C_3 \pm \Delta V_3 \geq C_1 + C_2 + C_3 * (K_d + 1) \geq G_3,$ (3)

WEBn – $W_n = W_{n-1} + B_n + A_n + Q_n - E_n - D_n - C_n \pm \Delta V_n \geq \sum_{i=1}^{n} Ci * (K_d + 1) \geq G_n,$

(3)

Were W_n is WEB in n cross,

B_n – Local flow;

Q_n - All types of returned water on the WEB,

A_n - Water flow in WEB, with territorial diversification systems of flows (between basins, inside basin),

$\pm \Delta V_n$ - Refilement/operation of pools, puddles and reservoires on the WEB. During the computation period, it is defined as a corrective of available water resources that takes levels of incoming and outgoing parts of balance.

E_n - Water loss in the reservoirs due to water evaporation on the balance of WEU.

D_n - Withdrawal the parts of waterflow outside WEB

C_n - Sum of demand on water among WEB cosumers

F_n - Water needed for returned water delution

K_d - Saturation coefficient of returned water delution

G_n - Environmental minimum

If the mentioned conditions are not fulfilled, WEB is considered to be under a shortage. The shortage can be addressed by:

- Transmitting of water release point to the cross of WEB which is better secured with water;
- Reducing water intake in crosses located above WEB;
- Reducing water release in the river (water object);
- Building complex management water reservoirs and increasing water expenditure, considering it's beneficial volume during water release period.
- Concerning last activity, it is worth to mention that recent events (forest fires) perfectly illustrated the necessity for having small anti-fire reservoirs when the territory has a difficult relief. The reservoirs described above might combine anti-fire function as well.

We modified existing data related to water flows [7], which is a part of WEB return water, using contemporary, high-resolution digital elevation model of relief. We computed precise multi-year flows for ponds, sub basin, and municipalities.

Results

In order to better identify impacts of social-economic conditions, QQWEB was developed for municipalities and river basins (Table 1). Table 2 shows the vulnerability levels considering WEB and QQWEB. A vulnerability is defined as a difference between the Quantitative and Quantitative-Qualitative Water Economy Balances.

We assume that QQWEB structure analysis, expressed into different coefficients, is more feasible compared to absolute data (Table 2). The coefficients showing WEB balance are following: WEB coefficient, which is a ratio of WEB to an environmental minimum; Water Consumption Coefficient – a ratio of local flow to total water consumption; Potential Water Consumption Coefficient – a ratio of accessible flow to total water consumption.

The main part of Kvemo Kartli water resources is formed in the basin of the River Khrami, in the municipalities of Tsalka, Tetritskaro, and Dmanisi. WEB structure in the basin of the River Khrami is satisfactory - withdrowed and accessible flows are significantly higher than water consumption and environmental minimum. In each municipality, WEB coefficient is higher than 1 and variate between 2.2-3.7. In the municipalities of Tsalka, Tetritskaro, and Dmanisi, WEB and its' Structure Coefficients are the most convenient. Only Marneli Municipality shows tensed condition.

Table 1. *Kvemo Kartli Quantitative-Qualitative Water Economy Balance, Million m3*

Municipality		Local Flow	Total waterintake	Returned Water	Total Flow	QWEB	Environmental Minimum	ConsumedWater	Delution Water	QQWEB
	River Khrami									
Tsalka		457	37.5	37.5	457	420	114	37.5	0	420
Tetritskaro		142	34.5	34.5	599	532	150	29.8	23.5	508
Dmanisi		152	77.0	77.0	751	621	188	63.1	69.5	551
Bolnisi		87.1	65.4	65.4	838	652	210	55.9	47.5	604
Marneuli		103	240	240	941	523	235	232	59.2	463
	River Algeti									
Tetritskaro		111	61.5	61.5	111	49.5	27.8	61.5	0	49.5
Marneuli		16.7	48.8	48.8	128	27.7	31.9	38.5	103	-75.3

The flow in the River Algeti is mostly formed (>80%) in the territory of Tetritskaro Mnicipality. In this part of the basin, WEB structure is satisfactory.

Table 1. *WEB Structure of Municipalities in Kvemo Kartli*

Municipality, River Basin	WEB Coefficient	Water Consumption Coefficient	Potential Water Consumption Coefficient
Tsalka - Khrami	3.7	12	12
Tetritskaro – Khrami, Algeti	3.3	2.8	7.3
Dmanisi - Khrami	3.1	2.0	9.9
Bolnisi - Khrami	3.0	1.3	12
Marneuli – Khrami, Algeti	2.2	0.7	3.2

In Kvemo Kartli most tensed conditions are in the area where a minimum volume of local flow is 16.7 million m3. This is in the basin of the River Algeti in Marneuli Municipality. In this area, accessible water resources consist of the sum of flows and returned waters from Tetritskaro Municipality. In the Municipality every WEB Structure Coefficients are minimal for the region. WEB coefficient lower than 1 exists only in this region, therefore, here environmental minimum particulates in water consumption (Fig.).

Tsalka is the most well-ensured municipality of the region, while Bolnisi is the least ensured.

In the region, highest amout of water is needed in Marneuli Municipality, lowest – in Tsalka Municipality.

Nowadays, in the municipalities of Markenuli and Tetritskaro, only 20%-30% of the total population can be secured using local water resources. At the same time, the municipalities of Tsalka and Bolnisi have the capacity to supply 20 times more population (for city residents – 500 Liters per day; for village residents – 300 Liters per day).

Conclusion

Based on analysis of Kvemo Kartli Water Economy Balance, we can conclude the following:

Sum WEB of basins of the main rivers in Kvemo Kartli (Khrami, Algeti), is higher than the environmental minimum. Therefore, it is satisfactory.

WEB structure in the basin of the River Khrami is generally satisfactory – withdrawed and accessible flows are significantly higher than water consumption and environmental minimum. The same balance is shown considering delutin returned flows (8 times) and inveronmental flow (25% of norm). Tensed conditions are in Marneuli Municipality due to high volume of consumed water.

Areas of the River Algeti basin that are located in Tetritskaro Municipality, WEB is satisfactory.

In terms of WEB, in Kvemo Kartli, most tensed conditions are in those areas of the River Algeti basin which is located in Marneuli Municipality. Here, we face a significant shortage in WEB.

Analysis of WEB by municipalities shows that in case of Marneuli Municipality there is a serious problem which becomes even more visible when considering approximate spillway.

In parts the River Algeti basin, located in Marneuli Municipality, accessible water resources consist of the sum of withdrawed flows and returned water from Tetritskaro Municipality.

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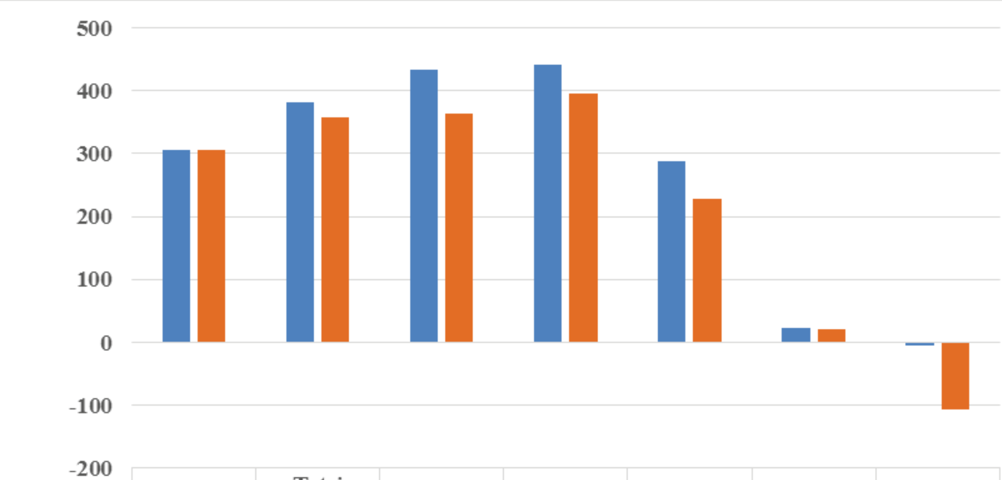
References

[1] Z. Lomsadze, K. Makharadze, M. Tsitskishvili, R. Pirtskhalava, Water resources of Kakheti and ecological problems. Annals of Agrarian Science, 15 (2017) 204-208.

[2] M. Elizbarashvili, E. Elizbarashvili, M. Tatishvili, Sh. Elizbarashvili, R. Meskhia, N. Kutaladze, T. Khardziani, Georgian climate change under global warming conditions. Annals of Agrarian Science, 15 (2017) 17-25.

[3] N. Bolashvili, T. Karalashvili, V. Geladze, N. Machavariani, Sustainable Management of Water Resources on the Background of Current Climate Change, Earth Sciences, Vol. 6, No. 5 (2017) 75-79.

[4] V. Geladze, N. Bolashvili, T. Karalashvili, N. Machavariani, Assessment of Water Resourc-



	Tsalka, riv. Khrami	Tetri Tskaro, riv. Khrami	Dmanisi, riv. Khrami	Bolnisi, riv. Khrami	Marneuli, Riv. Khrami	Tetri Tskari, riv. Algeti	Marneuli, riv. Algeti
QWEB	305	382	433	442	287	22	-4
QQWEB	305	358	363	395	228	21.8	-107

Fig. *Vulnerability of the municipalities in terms of river basins, million m3 s*

es and Inculcation of Controlled Water Consumption System. World Academy of Science, Engineering and Technology International J. of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:11, No:5 (2017) 430-433.

[5] A.M. Grin, N.I Koronkevich, Principles of Ccreation of Water Economy Balance. Voprosi Geografii, vol. 73, 1968 (in Russian).

[6] M.I. Lvovich, Human and Water, Gidrometeoizdat, Moscow, 1983 (in Russian).

[7] L.A. Vladimirov, Water Balance of Caucasus and its Geographical Patterns. Metsniereba, Tbilisi, 1991 (in Russian).