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Water balance components evaluation using hydrological and balance approach for Vit River basin

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Abstract. The aim of the article is the application of hydrological and balance method in estimating the resources of surface waters and the other components of water cycle. Information on the annual values of the registered outflow of the Vit river basin was used. Data on the consumption of surface water from various sources and measurements of the annual amounts of precipitation in the valley for the years: 2015, 2016 and 2017 were also used. For this study, the evapotranspiration is considered unknown, but its quantification is planned for the next study using e.g LSA SAF data. An analysis of the types of water consumption which increase evaporation losses was performed. The significant difference in consumption information from different sources is shown. A comparison of surface water resources, estimated by hydrological and balance method, was performed. The precipitation input part of the balance was determined with the help of information from the available monitoring stations. Various gradient and interpolation methods were used for spatial estimations, conclusions were made on their applicability. The inflow and outflow of the water were quantified for the mentioned three years, and substantial assumptions were made on the factors, like soils and snow cover, responsible for the water system quantity variations.

Keywords: resource assessment, precipitation, balance and hydrological method.

1. INTRODUCTION

Information on water resources is most essential for optimal and conflict-free water management. This Information can be obtained through water balance methods. By "water balance" we mean (WFD, 2015) the digit expression of inflowing water

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(precipitation), the outflows (river runoff) and the change in their volume in a system (e.g. watershed, dam, etc.) for a certain period, caused by natural and/or anthropogenic factors. The problem is solved on the example of the Vit River until its confluence with the Danube River, using annual observations for the years: 2015, 2016 and 2017. There are a number of difficulties in determining the quantitative parameters of the balance components, their temporal and spatial variability. They are primarily related to the uneven distribution of the observation stations, the lack (in some cases) of observations of the used waters, the lack of settlements and respectively observations of the precipitation in the high mountain part of the valley. Empirical and statistical methods for processing and analyzing information are used to solve the mentioned difficulties.

1.1. Pilot basin

The choice of the pilot river basin was realized taking into account the following requirements: average for the country catchment area (3-5 th.sq.km), varied relief, flat, hilly, mountainous, the presence of significant customers, whose influence on water balance on an annual basis can not be ignored, availability of basic hydro meteorological observations of substantial duration. According to these requirements, for the purposes of the present study, a pilot valley of Vit River basin with a catchment area of 3227 sq.km was selected. There are 5 hydrometric stations in the basin with a significant observation period (Fig. 1). There are also 23 stations for monitoring of precipitation and snow cover of different classes, which are shown in the same figure. All three dams, significant in terms of annual water balance, are shown in (NIMH, 2014). The figure shows: the river network and significant dams, Sopot Dam, which has a catchment area of 76 sq.km and a derivation to the Lesidrenska River with a similar area. The figure also shows the Gorni Dabnik dam with derivation to the Vit River from the Boaza catchment, as well as the smaller Telish dam. There are other smaller dams in the river basin, the influence of which on the annual water balance has been neglected.

Information on registered surface water users, consumption targets and permitted limits was used by the Danube River Basin Directorate (DRBD) (*www.bd-dunav.org*). The measurements of the used waters are a task of the user, who declares in the BD the quantity used annually. The individual consumer declarations are confidential and for this study data were obtained on the declared water use by groups of consumers located along the entire area of the river basin. Similar information was obtained from the National Statistical Institute (NSI), but the purpose of consumption was grouped differently. Information on the water balances of the three significant dams in the catchment area and the supplied irrigation waters was also received from the Irrigation Systems EAD (IS) (*https://nps.bg*).

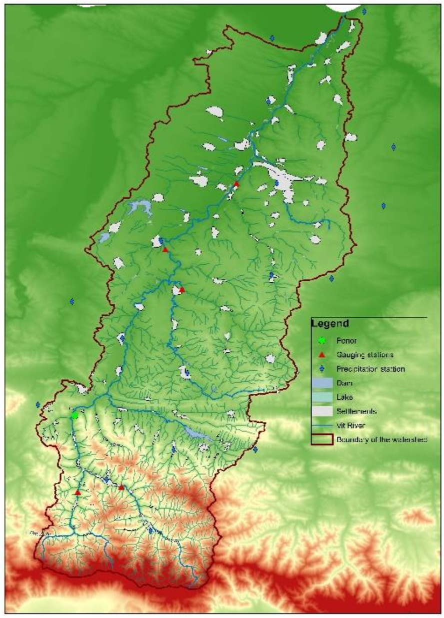

Fig. 1. Vit River watershed, hydrometric and precipitation network, significant dams

For the three-year period under review (2015-2017), there are a total of 96 users in the main categories defined in Rankova (2019). We distinguish two main types of users. Some have a significant anthropogenic impact on the annual water balance. This is irrigation, where part of the river runoff steam away from irrigated areas and plants. In the same way, we report evaporation losses from large dams and industrial cooling water.

Other user groups do not have a significant impact on the annual water balance. These are, for example, instantaneous power plants, aquaculture, water supply - drinking and industrial, etc. For them, we consider that the used water is transferred instantly without losses back to the water intake point. In the production of electricity, water is used repeatedly, using the differences in altitude in the pool. For example, in the upstream of the Vit River, after the Beli Vit flows into Cherni Vit there are seven hydropower plants that produce the same water.

2. EQUATION OF BALANCE

According to the accepted definition of water balance (WFD, 2015) and given the specifics of the selected pilot basin, the balance equation can be written as:

$$INPUTS = OUTPUTS \pm \Delta S$$

$$INPUTS = P \pm ExIn + RET$$

$$OUTPUTS = Eta + Outflow + ABS$$

In this case $\pm \Delta S$ is the change in the volume of water in the basin for the considered one-year period. This represents the change in the amount of water in the river bed of the entire river network, the change in the accumulated water in the significant dams and the change in the quantities of accumulated water in the soil and the snow cover. We can directly determine only the change of the accumulated water in the significant dams and the snow cover. We are ignoring the change in the other volumes mentioned, but in the course of the study we are trying to assess their order. The errors of this assumption affect the determination of the volume of evapotranspiration.

$\pm ExIn$ is the inflow/outflow from external systems or catchments. The configuration of the surface catchment and the groundwater body often does not coincide and groundwater transfer to neighbouring bodies is possible. Indeed, in the upper part of the basin there is a karst aquifer, which feeds the springs of the Panega River at the expense of the river outflow of Vit River.

RET includes the volumes of water use returned to the hydrological system - transmission losses or residues after use. As we already mentioned before, this is the case with irrigation waters. Some of them are lost due to evaporation and transpiration, others are returned to the river network through the shallow groundwater. We are ignoring the factor of delay of return waters in view of the annual period with which we work. We do not take into account the irreversible losses of deep groundwater supply as insignificant.

Eta is the general evapotranspiration, which in our case is an unknown quantity. It cannot be determined independently with sufficient accuracy, moreover it is the largest component of the water balance. All assumptions and approximations are at the expense of this estimate.

Outflow is the river outflow, the result of measurements of river levels and water quantities.

ABS is the total consumption, together with the losses, of the waters for electric production, (fish farming, drinking and household water supply, etc. are excluded from this consumption).

The balance approach is partially used for the Struma river basin (Tech. Rep., 2006) where the inflow to the natural river outflow is determined statistically for the tributaries and the outflow of the main river is determined according to the balance path.

3. ASSESSMENT OF THE COMPONENTS OF THE BALANCE

3.1. River runoff - Hydrological method

River runoff is a major cost component in the balance equation. Its quantification is based on the available hydrological observations in the gauging stations. As can be seen from Fig. 1, the lowest part of the Vit River catchment area before the confluence with the Danube River is not illuminated by observations. The hydrological method shown below makes it possible to estimate this additional inflow (NIMH, 2014).

The hydrological method is based on statistical relationships between hydrological observations and other factors forming the river flow, for example: catchment area, average altitude and others. This method provides certainty in the estimates (NIMH, 2014), but uses observations on the registered runoff, which limits its use in systems severely disturbed by anthropogenic factors. Since the shape and runoff characteristics of the Vit River and Osam River basins are similar, the data from the gauging stations of the two catchments were used to study the resource of the two river basins. In this study we are determining the river flow generated by the entire area of the Vit basin. Therefore, using the method of hydrological regionalization, a relationship was sought between the areas and water quantities of gauging stations in the middle and lower stream of Vit and Osam. They are in a region covering the part of the catchment located in the Danube plain and parts of the Fore-Balkans. The observation period 1981-2019, for which the series of the average annual outflow were used, was accepted as working. The data from the following gauging stations were used: 21500 - Kamenitza River near the village of Bezhanovo; 21750 - Vit River near the village of Krushovitsa; 21800 - Vit River near the village of Disevitsa; 22800 - Osam River near the village of Izgrev, shown in Fig. 1. According to the determined regional relations, the resource of the Vit River for 2015, 2016 and 2017 has been calculated, with correlation levels exceeding 0.95 (Fig. 2).

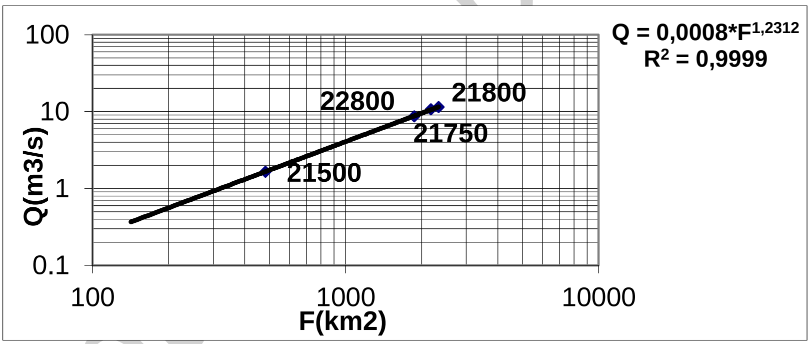

Fig. 2. Regression regional relationship "water quantity - catchment area"

Hydrological assessment of the waters transferred to the Panega River

The configuration of the surface catchment and the groundwater body often does not match. In the upstream of the watershed there are karst zones in the land of the village of Glozhene, which feed the springs of the Panega River in the Iskar River basin. The hydrometric measurements made by NIMH teams in this area at the end of 2018 show that 1.07 ms^{-1} is lost during the pot-hole in the Asen neighbourhood of the village. We assume that the total amount of water to the Iskar River basin is about 33740 x 10^3m^3.

Consumers, goals and quantities

The information on the used volumes of water is obtained from the three sources mentioned in Table 1 administratively, only the registers of the consumers and their limits are public. The grouping of consumption goals is done by the information source organizations. The most informative is the grouping of the Danube database, but the differences for the same groups of users are significant and therefore the analysis is performed with due caution. It is also very impressive that the limits exceed by an order of magnitude the volumes used, for which we use the term "declared water use", insofar as these quantities are obtained from the annual consumer declarations.

For the purposes of this study, we are focusing on information on water used for irrigation. We assume that this information submitted by BD and IS is similar and is based on the waters used by the dams. It should be noted that the information of the BD agree with that one of the IS for the invoiced volumes for 2015 and 2016, and for 2017 with that for the volumes submitted by the IS, which is confusing. We also assume that the information on surface water irrigation of the NSI significantly exceeds that of the IS and BD, because it is based on water abstraction from dams and directly from the river network and we use it in the balance calculations as reliable.

In this study the information about the losses from evaporation from the three dams is very important, which is used as irreversible consumption. We also use the information of the IS to change the volume of accumulated water in the three dams.

Table 1. Information on water consumption in Vit River basin from various sources

BD information on declared water use and annual limits [$10^3.m^3$]				
Purposes of water use	2015	2016	2017	Limit
drinking - water supply	61	211	171	3200
water supply for irrigation	1399	1886	4843	19196
water supply for aquaculture	835	835	835	6659
industrial water supply incl. cooling	1392	1561	1333	57089
water supply for other purposes	5.9	4.6	0.0	7667
water for electricity production	189834	172764	137707	1550000
NSI information on declared water use [$10^3.m^3$]				
Agriculture, forestry and fisheries, incl. Irrigation	4297	11694	8478	
- including irrigation systems	3946	11343	7526	
Industry, incl. Plumbing	7586	10986	8244	
- including. Water supply and sewerage - public water supply	6997	10048	7879	
Services	483	94	496	
Information of IS for declared water use [$10^3.m^3$]				
Submitted volumes	2187	8207	4435	
Invoiced volumes	1376	1862	867	
Losses from evaporation Sopot dam, Telish, G. Dabnik	24695	24867	20380	
Change in volume in the three dams during the year	-24617	-22666	6755	

When this volume is positive, the stocks in the dams grow at the expense of precipitation, ΔS is positive and is added to *OUTPUTS*. Otherwise, the stocks in the system decrease and in practice the respective year uses water from the previous one.

Precipitation

To determine the annual precipitation volumes entering the territory of the basin, data of 24 precipitation stations located on the territory of the watershed and along its borders was used. The problem of the lack of observations in the high part of the mountain has been overcome by using the gradients of precipitation with altitude (Koleva&Peneva, 1990). Based on these gradients, two points on the southern boundary of the watershed were added. The spatial distribution was modeled with GIS interpolation tools ArcGIS for Desktop 10.4.1, 2015. Experiments were performed with *IDW*, *NN*, *Spline* and *Kriging* interpolation method. In *Kriging*, the weights of the points in the neighbourhood of the interpolation of the field Z_1 are determined statistically on the basis of the autocorrelation and this method gives better results than the others. However, this method does not provide a good enough opportunity to model the relationship of precipitation and altitude. Therefore, the *Co-Kriging* method was used, in which the connection of the field Z_1 with another field Z_2 - the relief is added, by studying their mutual correlation. The connection between the relief and the precipitation is related to the general and significant changes in the altitude, so when choosing the field Z_2, experiments were made with both the popular in our country relief layers and with generalized ones. The software product *ArcGIS* is allowing the use of combinations of point and raster variables. When using *Co-Kriging*, it is no longer necessary to add additional gradient points in the high mountains where there are no precipitation stations, because this relationship is modeled using the relief raster Z_2 . An important indicator for the choice of this interpolation method is the achieved accuracy, determined by *cross validation*. In this case, several variants of the statistical error are calculated by comparing the observations with the results of interpolation at the observation points based on multiple random samples. The errors calculated by ArcGIS are shown in Table 2.

Table 2. Statistical errors of the interpolation models for the precipitation -Vit River, 2016

Indicator / Model	**IDW**	**Kriging**	**Co-Kriging**
Samples	25	25	25
Mean	-5.5	-2.1	-3.6
Root Mean Square	98.8	96.4	93.3
Mean Standardizes		0.008	0.003
Average Stnd. Error		120	69.7

The values of the root mean square error and the standardized one decrease when using the selected interpolation model - *Co-Kriging*, which does not use additional gradient points in the high mountains, and the relationship on altitude is achieved by including a generalized raster of relief in the interpolation. An example of a precipitation map obtained as described above is given in Fig. 3.

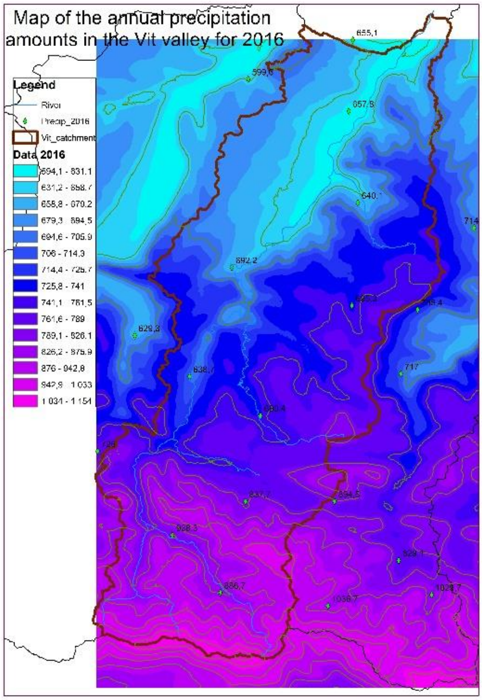

Fig. 3. Map of the annual precipitation amounts in the Vit basin for 2016

In the described way, the precipitation maps of the Vit watershed for 2015 and 2017 were created and the average values for the landfill polygon were calculated, as well as the formed annual precipitation volumes, which are given in Table 3. The parameters of the snow cover, which concern the change in the volume of water in the system, are also given in the Table.

Table 3. Annual precipitation and snow cover on January 1, 2015 – 2018

Indicator	**2015**	**2016**	**2017**	
Precipitation average for the watershed [mm]	728	748	870	
Water volume [m^3x10^3]	2350030	2413635	2806393	
	01/2015	**01/2016**	**01/2017**	**01/2018**
Average Snow height [cm]	18.1	0.7	17.4	1.5
Water volume [m^3x10^3]	175226	6777	168449	14522
Change in volume $\pm\Delta S$ [m^3x10^3]	-168449	161673	-153928	

Determining the change in the amount of water in the system ± ΔS

- *Snow cover*

Snow cover is one of the significant factors for changing the amount of water in the system, the beginning and end of the balance periods are in seasons with a high probability of stable snow cover. The data from the already mentioned 24 precipitation stations in the catchment area were used for the determination of the accumulated water in the snow. With the data for the altitude of the snow cover on 01/01/2015, 16, 17 and 18 the water reserves in the snow are calculated using the technology already described during precipitation. It turns out that there is significant snow cover on 01/01/2015 and 2017, which is the reason for significant changes in the amount of water in the system $\pm \Delta S$. The results of the calculations performed using a snow density of 0.3 are shown also in Table 3. It can be seen that the quantities are in the range of 20 - 30% of the annual river flow volume. The general conclusion is that significant water volumes can accumulate in the snow cover and the change in water content in the system due to this factor must be taken into account in the balance equation.

- *Soils*

The change in the amount of water in the soil can be determined by modeling (Artinyan et al., 2008) or from the information on the moisture content in the one-meter soil layer. In the Vit River basin there are only three points with one for which the agro-meteorological network of NIMH performs such measurements. At these points the humidity is in the range of 330 to 410 mm, and at the beginning and end of the studied years it fluctuates in the range of 10 - 20 mm and forms $\pm \Delta S$ in the range of 2 to 5% of the annual volume of the river outflow. Therefore, given the small measurement points and the significant soil diversity (JICA, 2008) in the catchment area, this component is neglected in the balance equation.

- *River network*

The Vit River and its main tributaries are monitored by five gauging stations, which forms about 230 km of observed river network. According to Marinov (1957), due to the significant slope - an average of 9.6 ‰, and the elongated shape, the Vit basin has an average density of the river network of only 0.5 km / km^2, or at least 1000 km of unobserved river network of lower order. Knowing the values of the observed water quantities at the beginning and end of each year, we can calculate that the change of water reserves in the observed river network does not exceed 0.002% of the annual river outflow. Therefore, we are ignoring this component of the change in the volume of water in the system $\pm \Delta S$ in the balance equation.

- *Dams*

The change in the quantities of accumulated water in the dams is determined directly by the balances of the three significant dams, by the information on the recorded volumes at the beginning and end of each calendar year of the studied period. They are mentioned in Table 1.

4. DISCUSSION OF THE RESULTS

The specificity of the collected information on surface water consumption leads to some assumptions and neglect of some factors as insignificant. We have already mentioned that for this study and given the one-year balance period, these types of consumption are important which lead to irreversible losses of surface water for evaporation. Therefore:

- we ignore all types of consumption such as: electricity generation, aquaculture, services, domestic and industrial water supply, considering that the used water is returned to the river network without losses and the time delays are insignificant given the one-year balance period;

- we assume that 70% of the water supplied for irrigation, according to NSI, is lost as evaporation and transpiration, and 30% is returned to the river network (NIMH, 1989). The other component of *ABS* is the loss of evaporation from the lakes of the three significant dams, according to the IS. It is known that water used in the cooling industry also leads to evaporation losses, but the structure of the data obtained does not allow for their quantification.

- There is one big unknown in the balance equation - evapotranspiration. We assume that we have quantified the change in the volume of water in the system $\pm \Delta S$. Then we can define *OUTPUTS* as the difference between *INPUTS* and $\pm \Delta S$. Then in the already known *OUTPUTS*, the only unknown remains *Eta*.

Table 4. Water resources ($10^3.m^3$)

Component / year	**2015**	**2016**	**2017**
Income, *INPUTS = P - ExIn*	2316290	2379895	2772653
Precipitation, *P*	2350030	2413635	2806393
Water to Zlatna Panega, *- ExIn*	33740	33740	33740
Expense, *OUTPUTS = INPUTS -* ($\pm \Delta S$)	2509356	2240888	2919826
River outflow, *Outflow*	560237	592115	695614
Loss of consumption, *ABS* =	27457	32807	25648
70% water for irrigation, NSI	2762	7940	5268
Evaporation dams	24695	24867	20380
Evapotranspiration - *Eta = OUTPUTS – Outflow – ABS*	1921662	1615966	2198564
Changing the volume of the system $\pm \Delta S$ =	-193066	139007	-147173
Change the accumulation in the snow cover	-168449	161673	-153928
Change the accumulation in significant dams	-24617	-22666	6755
Resource assessment, = *Outflow + ABS*	587694	624922	721262

The required balance resource assessment is obtained by the sum between the registered river runoff and surface water losses caused by the anthropogenic factor. In other words, in a natural environment, losses from *ABS* consumption would not occur and the available resource would be equal to the river flow. We must immediately emphasize that in the Vit River basin, even in the presence of more than 30% regulation of runoff with the three major dams, the anthropogenic impact does not exceed 5% of the volume of river runoff.

5. CONCLUSION

The identification of surface water resources by water balance is possible and provides very good information for the purposes of water management, definition of measures, consumer policy and economic development. Compared to the one-year water balance period, the volume of consumption leading to irreversible losses from evaporation is small - about 5% of the volume of the registered river outflow. We should emphasize that this is not the case when the balance period becomes a season or a month. Then the consumption may, in some cases, become comparable and in low-water years exceed the river outflow, at the expense of the water masses accumulated in the dams, which is the subject of future research.

The method is time consuming, requires significant efforts to collect hard-to-access information that is not structured in a way that is appropriate for balance purposes. The lack of real-time consumption measurement makes the result applicable only for the purposes of the analysis of past events.

REFERENCES

Artinyan, E., F. Habets, J. Noilhan, E. Ledoux, D. Dimitrov et al., (2008) Modelling the Water Budget and the River flows of the Maritsa Basin in Bulgaria, Hydrology and Earth System Sciences, 12, 21-37. https://doi.org/10.5194/hess-12-21-2008.

JICA (2008), JICA Project: Study for Integrated Water Management in the Republic of Bulgaria, 2008 (in Bulgarian).

Koleva, E. & R. Peneva, (1990) Climate guide - Precipitation in Bulgaria, BAS, Sofia (in Bulgarian).

Marinov, I. (1957) Hydrological Handbook of Rivers in Bulgaria, Vol. I, edited by I. Marinov, NIMH, 1957 (in Bulgarian).

NIMH (1989) River water resources of Bulgaria and their change as a result of anthropogenic activity, NIMH, Sofia (in Bulgarian).

NIMH (2014) Reference guide: Surface water and precipitation, Danube River Basin Directorate, NIMH, Sofia (in Bulgarian).

Rankova, M. (2019) Surface water resources assessment methodologies application in case of Vit river, Proceedings IV Conf. Conserving soils and water, Burgas, 28.08-31.08.2019.

Tech. Rep. (2006) Technical Report, Water use and water balance of the Struma River basin part 1 and part 4, IWP-BAS, Project Manager O. Santurdjian (in Bulgarian).

WFD (2015) Guidance document on the application of water balances for supporting the implementation of the WFD, EU 2015.