THE ROLE OF GREEN AND BLUE WATER IN ECOSYSTEM SUSTAINABILITY

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Abstract:

Water is a substance that was among the first discovered and abundantlyusedby the man. Although it is well studied from both, a scientific and a philosophical point of view, its new characteristics and features are still being discovered. Thanks to the development of the science of water, man learned that there are different types of water by its origin, use, characteristics and content of other substances in it. The term „green" and „blue" water was introduced into the scientific literature by Swedish ecohydrologist Malin Falkenkamp from the Water Institute (SIWI) in Stockholm. Although this term has been used in the world for years, it has remained closed in the narrow circles of scientific specialists. The term is used especially at the level of consideration of global problems of water and land management and the problem of water crisis that threatens the world. In addition to our daily use of water, water is probably a natural resource that the ordinary world understands the least, so it is rightly considered that this resource is not sufficiently understood even by the engineering educated world. Not without reason, Einstein warned: „There is more perfection in an ordinary drop of water than in all the machines that people have invented." Green Water has neither managers nor hosts who care about sustainability and its more rational management, unlike managers and government agencies that care about blue water.

Key words: *green and blue water, sustainability, ecosystem*

1. INTRODUCTION

Increasing demands for quality drinking water require more and more reviews of water quality standards. In that sense, standards are accepted that cannot be reached in practice, primarily due to (for now) the poor financial position of our society. But even so, water quality must be brought to a level that will not endanger the health of the population. At the same time, we must work on informing the public, ie maximally mobilizing all the potentials of our society in terms of achieving the set goals. In the current economic crisis of our society, there must be no possibility of making mistakes in planning the optimal water supply system [1, 2].

Water has a vital role in the biosphere, because it is one of the components that participates in the construction of biological materials - plant, animal and human tissues. It is a medium in which the living world exists - from microorganisms to mammals and is used in everyday life: for nutrition, hygiene, in industry, for food and energy production, for sports and recreation, transport, etc. For the survival of individual states, regions, but also civilization as a whole, water is so important that, in this century, there will be great conflicts for the preservation or conquest of water resources.

Water is a substance that man was among the first to discover and use abundantly. Even though well studied both from a scientific and a philosophical point of view, its new characteristics and features are still being discovered. Thanks to the development of the science of water, man learned that there are various types of water by origin, use, characteristics and content of other substances in it. Approaches to defining the concept and meaning of water are very different. This is best illustrated by its universality and the different understanding of scientists from various scientific disciplines about its significance [1].

The universality of water is reflected in:

1) *presence in nature,*
2) *properties and*
3) *simultaneous occurrence in three aggregate states.*

The need for water and consumption of fresh water is constantly growing, due to various factors such as: population growth, industrial development, intensification of agricultural production, which is the largest consumer of water in the world, increasing standards of hygiene, irrational consumption and others. The largest renewable water supplies are concentrated in the six largest countries in the world: Brazil, Russia, Canada, the United States, China and India [2]. In the last thirty years, intense anthropogenic changes in the hydrological cycle of surface waters, water characteristics and in general in water resources and water status have taken place all over the world. Table 1 shows renewable water resources and available water continent in 2050.

Table 1. Renewable water resources and available water by continents in 2050

Continent	Area, mil. km^2	Population, 2050 (in mil.)	Water resources, km^3/year (average value)	Available water, 10^3m^3/year (per capita)
Europe	10.46	631.9	2 900	4.58
North America	24.30	705.5	7 890	11.18
Africa	30.10	1 803.3	4 050	2.24
Asia	43.50	5 222.1	13 510	2.59
South America	17.90	510.1	12 030	23.58

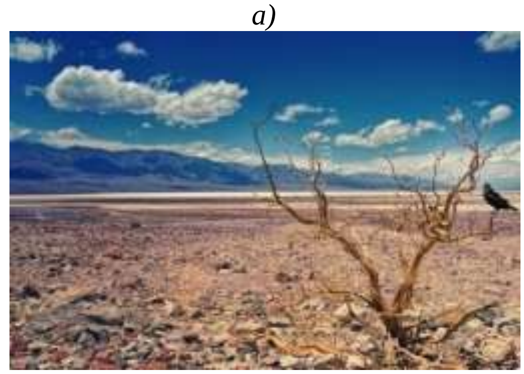
Australia and Oceania	8.95	45.8	2 404	52.49
Total Earth	135.91	8 918.0	42 785	4.80

The rapid increase in water needs and consumption leads to a gap between needs and the ability to meet them. In addition, the increasing degree of water pollution is jeopardizing life on Earth. Irresponsible use of water as a natural resource, excessive use of chemicals and their uncontrolled discharge into watercourses, leads to deteriorating water quality, as a result of which fewer watercourses, whose water is unusable for use without prior treatment, are increasingly „blooming sea "[13], fish stock disappears, etc. It is worrying that most areas of the Earth are facing a shortage of drinking water, on a planet where even ¾ the surface is covered with water. Projections of water consumption in the world are not at all optimistic [2, 3]. It is predicted that by 2025, the areas of economic water scarcity in the world will significantly expand, both due to increased consumption and due to certain economic and environmental factors.

2.GREEN AND BLUE WATER

Green water *is a part of infiltrated rain* which the soil retains in its sorption, molecular and capillary forces, and then evapotranspiration processes, the influence of solar energy, gradually returns to the atmosphere, thus feeding water to plants (arable crops, grasslands and forests). The very name ***green water*** is adequately chosen because without that ***land water***, ie. the greenery of arable land, lawns and forests would be absent, and the whole ecosystem would collapse. The continuity of soil monitoring with green water by evapotranspiration processes depends on *atmospheric conditions, the developmental stage of plants and the successive rhythm of soil water reserve renewal, ie. green water* through rain. *Green water* plays the biggest role, both in food production and in the sustainability and stability of the entire ecosystem. *Green water* is considered to be the most responsible for most of the world's food and biomass production.

a)



b)

Figure 1. Green water in food production, a) and an undesirable phenomenon - drought (water stress is the biggest crisis that is little or almost not reported), b)

[13] Flowering of the sea is a phenomenon of mass reproduction of algae or cyanobacteria. This mass reproduction green the surface of the water and in special cases floods or reddens the water, the water becomes cloudy and full of clouds. The reason is most often an excessive amount of nutrients, most often in the form of phosphate in water. (N. Herceg: Environment and Sustainable Development, Mostar, 2013)

In some countries, even the overall food production and ecosystem sustainability depends on *green water.* In part, this is the case with Bosnia and Herzegovina. Given that *green water* is essential for food production and environmental stability, the goal is to move away from the "tunnel" (dark) vision of stereotypical management of only *"blue water"* and dedicate it to better management of *"green water"* [4]. In previous scientific hydrological and numerous statistical analyzes, *green water is not represented*, as if it does not exist in the hydrological balance. Figure 2 shows the hydrological cycle of water. In the analysis of renewable water resources as an indicator of water stress, the focus is only on the analysis of *blue water* (green water is neglected)[14].

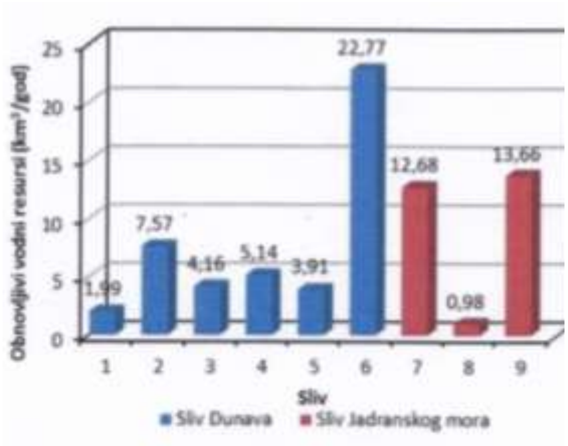
Figure 2. Water circulation in nature - hydrological cycle

Blue water *is a part of rain (precipitation) that the soil cannot keep above its retention capacity, so it flows away, partly surface, partly underground, thus feeding watercourses (streams and rivers), lakes, springs and underground aquifers. Hydrology* deals with the study of ***blue waters,*** while their management in the state and public administration has an administrative water management structure. Only in recent times, there are branches of hydrology such as: hydrogeology, agrohydrology, ecohydrology, hydrometeorology, pedohydrology, potamology and others. The current management of water resources is mainly focused on *blue water*, ie the part of precipitation that we call runoff. Various objects are being built on the blue waters, such as canals, dams, cascades, waterfalls, fountains, etc. Interest in the use of green water arises only in cases where irrigation projects need to convert *blue water* into green, and drainage, *green into blue water.*

3.RENEWABLE WATER RESOURCES IN BiH

The average renewable water resources in Bosnia and Herzegovina, expressed through the average surface water runoff, amount to ***1,155 m³/s,*** or 36.4 km^3/year. ***The spatial and temporal distribution*** of these waters is very uneven. Thus, 22.77 km^3 flows annually from the Danube catchment area, Figure 3, which is about 62.5% of the total amount of water flowing from the territory of BiH, while the area of this catchment area is about 76% of the territory of BiH. 13.66 km^3/year flows from the remaining territory of BiH. in the direction of the Adriatic Sea.

[14] Green Water has neither a manager nor a host to take care of its sustainability and more rational management (Savenije, 1998).



1. Direct Sava River Basin; 2. Una sub-basin; 3. Vrbas sub-basin; 4. Subdivision of Bosnia; 5. Drina sub-basin; 6. Total Danube basin; 7. Neretva and Trebišnjica basins; 8. Krka and Cetina basins; 9. Total Adriatic basin.

Figure 3. Total renewable sources in BiH

Spatial unevenness becomes even more pronounced if individual sub-basins are observed. The largest renewable water resources are available in the Neretva and Trebišnjica basins (12.68 km^3/year), while the smallest are in the Krka and Cetina basins (0.98 km^3/year).

However, the situation is significantly different if the available water resources per capita are observed.

The highest available water is in the Neretva and Trebišnjica basins, around 29.06 m^3/ apartment/year. Figure 4. The most endangered is the Bosna River Basin, where the available amount of water is only 2.82 m^3/dwelling/year. This is a basin that occupies 20.4% of the territory of BiH, inhabited by about 40.2% of the population, with only about 14.1% of available water resources flowing from this area. Figure 4 shows the total renewable water resources in BiH per capita.

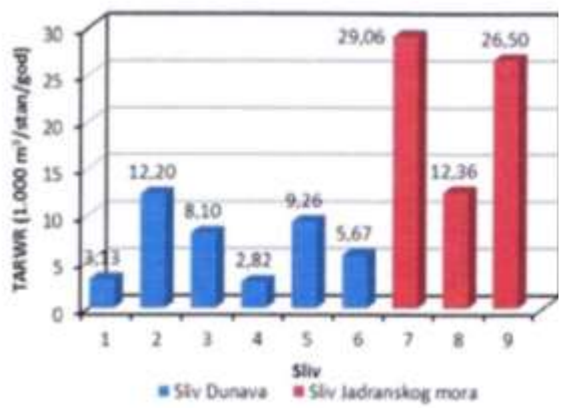


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Figure 4. Total renewable water resources in BiH per capita

These indicators for certain areas of BiH are even more unfavorable if the *time variability of available resources is observed.* Namely, in dry years, many times less water is available in BiH than the previously mentioned average. Thus, e.g. on average every 40 years the available quantities of water resources fall to less than 60% compared to the previously mentioned average quantities, and once in two hundred years the available quantities fall below 40% of the average.

According to the data on water quantities in rivers shown in Table 1, within BiH, it can be concluded that significant amounts of water are located in the territory of Republika Srpska, which is a serious resource for water supply, irrigation, industry, electricity production and other needs.

Within the monitoring of surface waters, lake waters are poorly represented, because data on the quantities and quality of waters in lakes are insufficiently studied and systematized. From the aspect of the possibility of using it for water supply, the quality of groundwater on the territory of BiH is different. According to the quality of groundwater intended for water supply, we distinguish four groups:

The first group includes groundwater sources from which water can be used without prior treatment. These include arterial and subarterial issues of the Semberija and Brčko Posavina basins.

The second group includes groundwater sources from which water can be used only after preparation (disinfection), which are waters accumulated in alluvium of crack, or crack-karst porosity.

The third group includes water that undergoes various treatments: coagulation, filtration, softening, disinfection, deferrization and demanganization, etc.

The fourth group of waters refers to waters that are treated even after various procedures they cannot bring it into a state ready for water supply.

Table 1. Basic data on river basins
(Water Quality Management at River Basin Level in Bosnia and Herzegovina 2006)

River basin / sub-basin	Surface area (km^2)					**Population**	**% of total population**	**The length of the river (km)**		**Medium flow (m^3/s)**	**Min. flow (m^3/s)**
	BiH			**In total (km^2)**	**% from the total area**			**BiH**	**In total**		
	BiH	**Federation**	**RS**								
Sava (inner basin)	3.758	1.217	2.541	96.694	3.89	635.353	14.04		940	**63.00**	**1.5**
Drina	7.185	875	6.310	19.677	39.52	422.422	9.33		460.8	**401.00**	**24.1**
Bosna	10.759	7.652	3.107	10.759	100.00	1.818.941	40.18	307.8	307.8	**163.00**	**24.2**
Ukrina	1.515	0	1.515	1.515	100.00	Included through the Sava		119.3	119.3	**14.80**	Derventa
Vrbas	6.289	2.543	3.746	6.289	100.00	514.038	11.3	240.3	240.3	**132.00**	**26.3**
Una-Sana: Una	7.962*	4.452	3.510	9.368	84.99	491.025	10.85	255.7	255.7	**240.00**	**41.9**
Una-Sana: Sana	4.024**			4.024	100.00			146.2	146.2		
Kupa	706	706	0	10.032	7.03	129.348	2.86	0	296.1		
Sava divorces	**37.689**	**16.960**	**20.729**	**96.694**	**38.98**	**4.012.266**	**88.61**		**940.00**	**722.00**	118.00
Neretva	7.948	5.780	4.422			381.279	8.42	218.2	240	**308.50**	**56.5**
Trebišnjica	2.255			2.555	100.00	54.992	1.21	93.8	93.8	**93.50**	
Cetina	2.753	2.753	0	1.949	61.22	79.089	1.75	0	100.5	108.00	
Krka				2.548				0	75.4	60.40	1.8
The Adriatic Sea divides	**12.956**	**8.533**	**4.422**			**515.360**	**11.39**			**433.00**	**58.3**
Total:	**51.129**	**25.977**	**25.151**			**4.526.487**	**100.00**			**1155.00**	**176.3**

**Una and Sana-total area; ** Sana- surface covered through the surface of rivers*

4. GREEN WATER BALANCE

For the purpose of scientific management of green water, it is necessary to obtain data or a ***balance of green water in an area***. The simplest way to achieve a *green water balance is to subtract blue water from the total average rainfall.*

Precipitation and runoff (blue water) have been registered for decades at numerous representative locations in BiH, *while the measurement of green water has not been registered.*

The highest average precipitation *is concentrated in the southeast of BiH, where it is 1500 to 2000 mm,* and going to the northeast, the value of annual precipitation decreases to about 700 mm. There is the least precipitation in the zones where the highest quality land resources are (Semberija, Posavina).

At the level of BiH, the average annual average precipitation is 1250 mm, and the average annual runoff or blue water is 750 mm (0.60), then green water is 500 mm (coefficient 0.40), (*ie green water = 1250 - 750 = 500).* For example, if the total average annual average rainfall in Popovo polje is 1957 mm, and the total runoff or blue water is 1324 mm (coefficient 0.68), then green water is 633 mm (coefficient 0.32). These balances show how much of the average rainfall fell on green water, but it is not known whether this green water was sufficient to meet the needs of human (anthropogenic) and natural ecosystem, whether the ecosystem was endangered in some years or at certain times of the year. water deficit or drought, *or lack of green water*. The area of BiH is 51,129 km^2. *Water balances for the state level of BiH* are based on data from 68 meteorological stations of different durations time series for 7 large basins (Una, Vrbas, Bosnia, Drina, Neretva and Trebišnjica, Cetina and Krka, immediate Sava basin) and refers to the following average conditions:

1) *average annual precipitation (P)*
2) *mean annual potential evapotranspiration (PET)*
3) *mean annual actual ET (SET - green water)*
4) *average annual water shortages (M)*
5) *average annual surplus water (V- blue water)*
6) *average annual SET/PET ratios*
7) *average annual V/P ratios.*

The introduction of the terms green and blue water provides brief explanations of some of the above average conditions, as well as the terms SET and PET evapotranspiration. For each of the above meteorological stations, it is necessary to make monthly and annual water balances in millimeter dimensions based on three input parameters, as follows:

1) *monthly precipitation,*
2) *monthly counts of potential evapotranspiration (or potential green space needs water) and*
3) *assumed soil water reserves of 100 mm.*

Based on the three input parameters for each month and each year, the following output parameters are obtained by calculation: actual evapotranspiration (SET or *green water*); water shortages (M-water deficit); excess water (V - runoff *or blue water*); ratios of surplus and precipitation (W/P or *runoff coefficient*) and ratios of actual and potential evapotranspiration (SET/PET or *drought coefficient*).

SET or actual evapotranspiration is the *amount of green water* that a plant is able to engage from the soil and deliver to the evaporating leaf surface in a unit of time, including direct evaporation from the soil. It is limited by the available amount of green water in the soil, and the depth and development of the plant's root system. This is what the plant can really take from land and offer atmosphere, so it is often called the supply of plants.

PET or potential evapotranspiration, often called *plant demand,* is the amount of water that could evaporate per unit time by the action of available energy in the atmosphere, provided an adequate supply is provided. This is a *potential need of the plant for green water.* Demand depends on the available energy in the atmosphere, so it is said

that the atmosphere of the ambience imposes demand, ie. no more water can evaporate than there is available energy in the atmosphere. That is why the calculation of PET is based on the available energy in the ambient atmosphere. Therefore, the *current need of plants for green water* will be met depending on whether the supply (SET) has reached the demand (PET). If the supply is less than the demand, the case when the plant is not able to deliver as much water as the atmosphere requires, then there is a disturbance in the physiological functions of the plant, which negatively affects the yield itself [7]. The influence of the SET/PET ratio on the programmed plant yield is shown in the diagram, Figure 5[15].

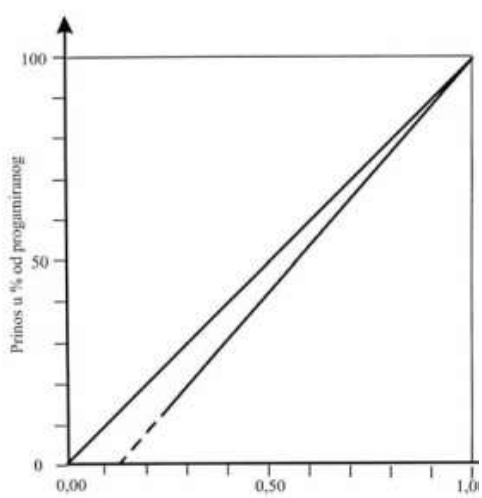

Figure 5. Influence of SET/PET ratio on programmed plant yield according to Robelin

If the supply reached the demand (coefficient SET/PET = 1), then the plant provided conditions for normal growth and development, so it is possible to achieve the maximum programmed yield (100%), even if at that time the plant had very modest amounts of green water in the soil. In years when the balance of actual evapotranspiration is equal to the potential, then it is considered that the conditions for the normal functioning of ecosystems are ideal, ie there is no deficit of water, and no delay in the production of organic matter in plants. In such cases, the needs of plants for green water are met. According to the works of some authors [6,7], such years are few. For example. in a series of 40 years, in Popovo polje, they were like that only every tenth year. Usually in the summer months, depending on the location, there is a deficit of green water that causes a delay in the production of organic matter in plants [8]. That deficit should be covered by irrigation, ie. by turning blue water into green. It is paradoxical that in Popovo polje, in addition to the abundance of precipitation, there are still significantly higher needs for irrigation water than at the level of BiH, which is a consequence of unfavorable precipitation distribution and discord between precipitation and PET distribution during the year. The balance situation in BiH is relatively favorable, indicating that it would be possible to meet the overall needs for

[15] Balances are made successively, month after month and year after year, so that not only actual data for each year can be obtained, but also the average for a multi - year period, then the frequency and trend for a certain time period (Robelin, 1958).

green water and establish a balance in the entire ecosystem of BiH. However, these are theoretical considerations of the most unfavorable situation of settling the green water deficit by irrigating the water of the entire ecosystem space, which will practically never come into consideration. Forests and natural grasslands are practically not irrigated, as well as arable land, only those with intensive crops. However, globally, green-blue water relations are not as optimistic as in BiH. Falkenmark and Rockstroem have been pointing to global water problems in the future for years.

5. GREEN WATER MANAGEMENT

Blue Water has its manager in state authorities located in water management bodies (municipal, cantonal, entity to state bodies). Their task is to take care of the rational management of blue water, to ensure water quality and to give consent for the use of blue water, so management should be established hierarchically for green water as well. Neglecting the importance of green water and irrational management of green water can lead to the collapse of anthropogenic and natural ecosystems. That management should primarily play the role of education, ie. to introduce people, from farmers to top politicians, to *what green water is, what it means for the survival of ecosystems, how much water is consumed each year, and how the sustainability of green water can be ensured.* The future of humanity will depend on how man will manage green water. *Green water* is practically *invisible, virtual,* but plants recognize it, while *blue water in rivers, lakes and aquifers* is visible to every layman. It is known that the existing blue water resources on the Planet 70% have already been used for irrigation, so further use of blue water for irrigation is in question.

Some of the improvements in green water management and sustainability are:

1) *Increasing the infiltration capacity of the soil while reducing runoff;*
2) *Increasing the retention capacity of the soil* (deeper plowing, shaking the soil, plowing greenery, organic residue and manure);
3) *Reduction of evaporation:* Evaporation is considered useful only insofar as it increases the humidity of the environment and thus contributes to better balancing between actual and potential evapotranspiration, but it can be ultimately a greater contribution to imbalance than water economy balance. reduction of evaporation covering bare land with organic material or residue, thus contributing not only to evaporation but also to better water infiltration, better moisture conservation and better protection of soil from erosion. he remains naked.
4) *Establishment of wind protection belts:* Wind protection belts affect the reduction of PET in two different ways, namely *a) direct reduction of wind speed and b) mobilization of moisture from deeper soil layers.* By reducing the wind speed, the potential evapotranspiration is also

reduced, because a higher wind speed causes higher PET, ie higher evaporation. The mobilization of water from deeper layers of the soil can be achieved by wind protection belts thanks to their deep root system, which is much deeper than in most agricultural crops.

6. CONCLUSION

A secure supply of food and water to the ever-growing world population must not be called into question, and therefore, the philosophy of sustainable development, in addition to controversy and conflict, must become a world paradigm and global ideology. *Green water* is vital for the survival of the human and natural ecosystem, especially for food production. *Blue water* is the running water of watercourses and aquifers, and so far it has been the focus of social and state interest, while green water, vital and important for food production, has not been taken into account. In water management so far, green water in the hydrological medium of the soil has been neglected. ie precipitation is the main water resource, so the future of water supply of the growing population, human and natural ecosystem will depend on the rational management of precipitation. The future of humanity *will depend on how man will manage green water*. The land is an extremely important and powerful storage space for green water, the largest natural water accumulation, which is filled with rain and emptied by evapotranspiration. BiH is in a privileged geographical position, given the rich rainfall of green and blue water, while the sustainable water future at the global level is very problematic. Now the way of supplying green water for food production must be considered, because blue water will not be enough to solve the problems of human nutrition by irrigation.

7. LITERATURE

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