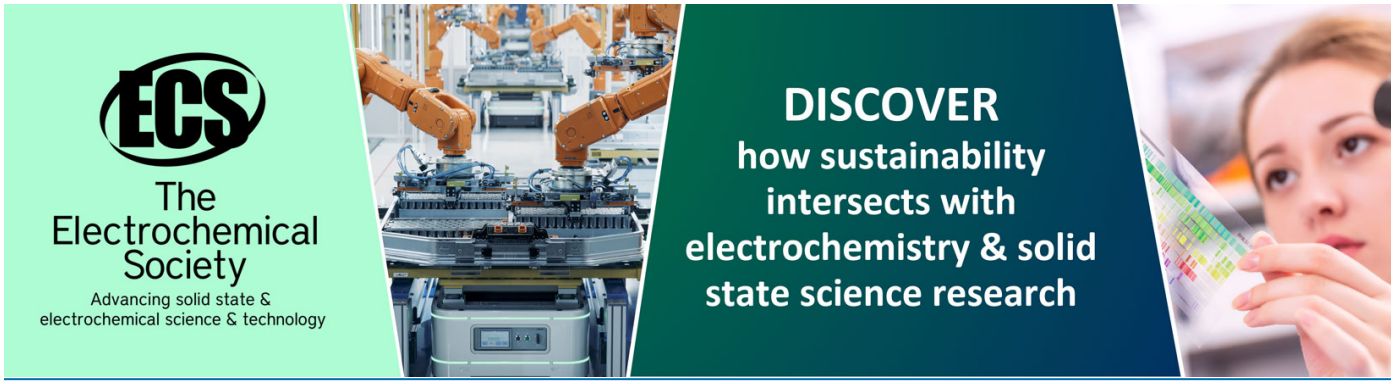
Inland water in Bosnia and Herzegovina



Inland water in Bosnia and Herzegovina

B Drašković and M Gutalj

University of East Sarajevo, Faculty of Agriculture, Vuka Karadžića 30, 71126 East Sarajevo, Bosnia and Herzegovina

branislav.draskovic@pof.ues.rs.ba

Abstract. Modern researches of the Earth's surface by remote sensing are mainly based on photointerpretation of satellite images. Copernicus is the most important European program of satellite observation and monitoring in 33 countries of the European Union and 6 cooperating countries including Bosnia and Herzegovina. Within the program, there are several databases on inland waters, including EU-Hydro and Water and Wetness. Also, CORINE Land Cover is database containing water information within five main categories. The paper analyses data on water bodies that include lakes, reservoirs, rivers and wetlands. According to the EU-Hydro database for Bosnia and Herzegovina there are 251 water reservoirs with an area of at least 1 ha. The amount of precipitation is higher than the European average and density of the river network is relatively high. Since it is not a densely populated country, the amount of water per capita is 8 times larger in comparison with Germany or 3 times larger than in France. However, renewable water resources are not evenly distributed, neither temporally nor spatially, so this is a challenge for their management.

1. Introduction

Bosnia and Herzegovina (B&H) is a country in the Western Balkans, with an area of 51.209 km^2. The distribution of the total land area is as follows: 5% lowlands, 24% hills, 42% mountains, and 29% karst regions [15]. According to the last census from 2013, B&H has about 3.53 million inhabitants [1], or 69 per square kilometre. Annual precipitation varies from 800 mm in the north along the Sava River, to 2000 mm in the central and south-eastern mountain regions [11]. According to water strategic documents, the average annual rainfall in B&H is 1250 mm [13, 14], while the Food and Agriculture Organization (FAO) data says the average annual rainfall is 1028 mm. Total renewable water resources per capita in B&H amount to 10.592 m^3/per capita/per year [9], which ranks it among the countries rich in water (countries with amount of 10.000-20.000 m^3/per capita/year). Considering the average runoff from the territory of B&H which is 1200 m^3/s, the average runoff coefficient is 0.57. Such a high runoff coefficient indicates some circumstances: river runoff regimes are torrential with fast flows, so losses are reduced; hydrogeological boundaries of some basins are larger than orographic ones, so that in some basins underground inflows from the territories of other countries also participate [13]. The high slope values of the terrain, i.e. the predominantly mountainous character of the country, where 25% of the territory is above 1000 m above sea level, contribute to the rapid runoff.

The runoff is towards the Danube River basin from an area of 38.719 km^2 (75.7% B&H) and towards the Adriatic Sea from an area of 12.410 km^2 (24.3%) with the total amount of water towards the Danube River basin of 722 m^3/s, and in the direction of the Adriatic Sea 433 m^3/s [14]. Densely

populated agricultural regions of Posavina and Semberija in the north and along the middle course of Bosna river valley in the central part of the country have less water per capita than the average.

The main river basins within B&H which gravitate to the Danube river are: Drina, Bosna, Sava, Vrbas, Una and Sana. The basins of Neretva, Trebišnjica and Cetina belongs to the Adriatic Sea. The watershed is a mountain massif of the Dinarides, over 300 km long and 80-200 km wide. The height of the mountains exceeds 2000 m, the highest peak is at the mountain Maglić with 2367 m. It is a karst area with powerful carbonate geologic layers containing significant groundwater reservoirs drained at lower valleys in the form of abundant karst springs. The largest are: Vrelo Buna, Vrelo Bunica, Klokot, Vrelo Bosna, etc.

Annual flows in river basins can decrease to only about 40% of average values. However, an even bigger problem is the inequality within the same years. Analyses show that in over 50% of the time during a year the flows are lower than 80% of the average. This means that most of the water flows in short-term high flows, followed by long periods with low flows, endangering water ecosystems. In that period it is not possible to capture any water without inflow from the reservoirs. In the months of the highest consumption (July, August, September), the average flows decrease to only 40%, and even 30% of the average annual values, while the low-water periods can last continuously for two or three months. Also, analyses show that on all watercourses in B&H there is a phenomenon of consecutive repeating of dry/low water years, which can be neutralized only by the implementation of complex systems with large reservoirs [13]. In the period 1961–2016 most of the territory of B&H was characterized by a slight increase in the amount of annual sum of precipitation. However, due to the increased intensity and variability of precipitation as well as the increased share of heavy rains in the total amount of rainfall, there is the increased risk of flooding, landslides, hail and soil erosion especially in the north-eastern part of B&H. During summers, the reduction in rainfall is evident. In the past two decades the sum of rainfall by the seasons and the distribution of it are much disrupted, which along with the increase in temperatures causes problems with droughts and floods [15].

The advantages of building water reservoirs are multiple: in addition to drinking water supply system it can be used for other purposes: tourism, hydropower, agriculture, etc. These are usually sparsely populated areas, so large investments are not needed for the population displacement, water is stored during the rainy period and retain for the periods with a shortage [7]. Therefore, the strategic plans envisage the construction of several reservoirs that will be used for various purposes, from electricity production (hydroelectric power plant Buk-Bijela), water supply (reservoir Crna rijeka near Sarajevo), flood protection (along the river Sava and Drina), tourism, etc. Artificial water reservoirs are very popular around the world. According to Dukić [6], there are over 1.5 million in the USA and 250.000 in Japan.

In the structure of the total water intake, 46.7% of water comes from underground sources, 36.1% comes from surface sources, 14.7% comes from river courses, 0.8% comes from reservoirs, and 1.7% comes from lakes [15]. The population is concentrated around larger cities while rural areas are sparsely populated. As a result, some cities have problems with water supply. Well-known example is the capital of the country – city of Sarajevo, which due to lack of water plans to build water reservoirs.

Given that there is a sufficient amount of water, in the past, artificial lakes and reservoirs were built mainly for the construction of hydroelectric power plants, very rarely for other purposes. Due to the predominantly mountainous relief and a relatively high amount of precipitation, the hydropower potential is still poorly used. In 2020, hydropower plants participated in the total electricity production with 30.1%, thermal power plants with 68.9% and solar and wind power plants with 1% [2].

2. Materials and methods

The paper will analyze the data from Copernicus Land Monitoring Service (CLMS). The EU-Hydro database consists of data on river networks and water bodies based on photo-interpretation and remote sensing methods. Satellite imagery mostly date from 2006, 2009 and 2012. Minimum Map Unit (MMU) is 1 ha, so all water bodies with an area ≥ 1 ha were recorded. In addition to EU-Hydro, under the same service (CLMS) CORINE Land Cover (CLC) database registers water bodies larger than 25

ha and linear wider than 100 m. Also, for the analysis of surface humidity, the Water and Wetness (WaW) database from 2018 with a resolution of 10 m will be used, as an indicator of the spatial coverage of temporary wet and flooded areas in the period 2012-2018 (areas with 25% to 75% wet, including areas of changing soil moisture and intermittent wetlands).

The EU-Hydro database for water reservoirs is available in the ESRI Geodatabase shapefile format in the form of polygons consisting of water bodies surrounded by land. The river network is divided into two types: polygons (rivers wider than 50 m) and polylines (rivers narrower than 50 m). Water bodies belonging to the territory of B&H have been extracted from the database and analyzed according to purpose, area, genesis of basin and other characteristics. The CLC database is given in both vector and raster format, while WaW is given only in raster format. The data is processed in GIS software and exported to Microsoft Excel for classification and calculation by individual types, areas and percentages.

Digital elevation model (EU DEMv1.1.) with a spatial resolution of 25 m has been used for distribution of water reservoirs by altitude zones. Given the range of altitudes of 0-2367 m, the territory of B&H is divided into three altitude zones: 0-500 m (39.47%), 500-1000 m (35.53%) and over 1000 m (25%).

3. Results and discussion

According to the EU-Hydro database on the territory of B&H, there are 251 reservoirs larger than 1 ha. These are mostly small reservoirs in lower altitudes, as much as 91% are smaller than 100 ha (1 km^2) (European Water Framework Directive recommend that water bodies larger than 50 ha or 0.5 km^2 should be registered in national hydrological information system). As many as 38 water bodies have an area of only 1 ha. The total area of all water reservoirs cover 19.921 ha (199.21 km^2) or 0.39% of the country's territory.

Lakes can be natural or artificial. According to Spahić [12], natural lakes cover an area of 6510 ha (65.1 km^2), or 0.11% of the territory of B&H, which is significantly less than the world average. Mountain lakes have mostly glacial and lower ones fluvial origin. However, other factors also participated in the formation of lake basins: tectonic, aeolian, karst and others. Thus, natural lakes cover one third of all lakes in B&H.

Table 1. Top 10 largest reservoirs in B&H.

	Lake	Elevation (m)	Purpose	Area (ha)
1	Buško	700	Hydropower	4757
2	Bilećko	380	Hydropower	2139
3	Jablaničko	263	Hydropower	1415
4	Modračko	192	Tourism	1272
5	Saničani	134	Fishpond	1253
6	Ramsko	578	Hydropower	1152
7	Svitavsko	0	Tourism	1024
8	Zvorničko	152	Hydropower	779
9	Drinsko	337	Hydropower	727
10	Brodsko	85	Fishpond	558

The largest is Buško Lake in southwest B&H with about 5000 ha (the area varies depending on the phase of the water regime). It is a former natural lake that was used for an accumulation on which the hydroelectric power plant "Orlovac" was built during the 70s of the 20th century. Other artificial reservoirs were also mostly built by damming river watercourses to produce electricity. The biggest challenges of large reservoirs are related to the backfilling of the lake basin which decreases volume

over time, water losses (seeping under the dam), unreliable hydrological data, etc. Regarding small hydropower plants, the observed shortcomings are mainly related to the disturbance of aquatic ecosystems in mountainous areas. Among other purposes, water reservoirs are used as fishponds (Saničani, Brodsko jezero, Prnjavor, Janj, etc.), tourist and recreational complexes (Modračko jezero), for flood protection, etc. Table 1. provides an overview of the 10 largest water reservoirs (lakes) with an area of over 500 ha.

According to the CLC database for 2018, there are 48 water bodies larger than 100 ha (1 km^2) in B&H, with a total area of 18.985 ha (189.85 km^2). CLC Nomenclature defines for this subclass as: Natural or artificial water bodies with presence of standing water surface during most of the year. (Code 5.1.2; for a more detailed description see [8]). According to this database, inland waters (rivers and lakes) occupy a total of 0.67% of the territory of B&H, and wetlands including inland marshes and peatbogs 0.12%.

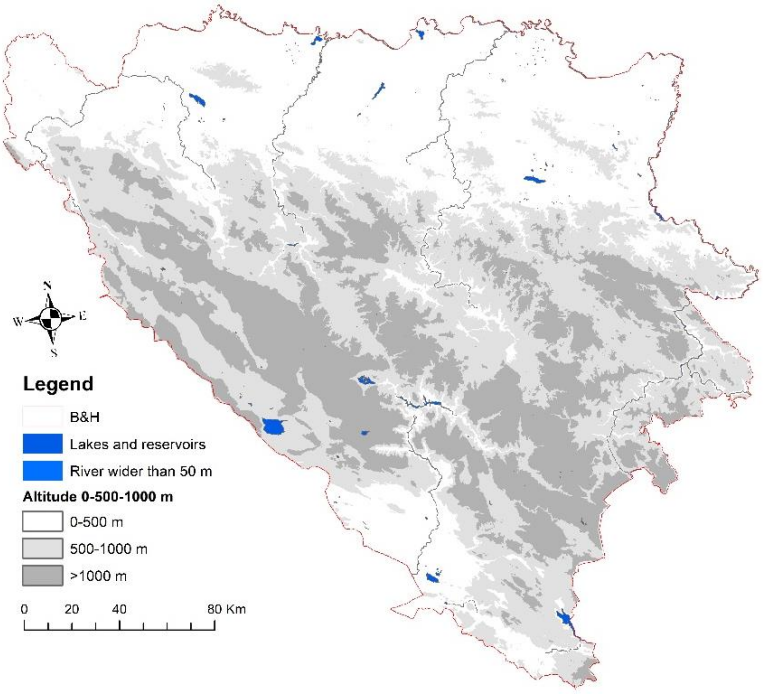


Figure 1. Lakes, reservoirs and major rivers in B&H.

In terms of the number of units and the covered area, over 93% of the lakes are below 1000 m, and almost 60% below 500 m (table 2). They are distributed evenly throughout B&H (Figure 1). Above 1000 m, there are mostly natural lakes with an area of 1238 ha (6.21%). Most of them are formed in the cirques of the former glaciers. A slightly higher concentration of small water bodies is in the north of the country in the valleys of the Sava and Drina rivers. These are areas with frequent water spills from riverbeds and areas where three catastrophic floods were recorded in recent decades (once in 2010 and twice during 2014). Only the floods in May 2014 caused damage of about 2 billion euros.

Table 2. Lakes and reservoirs by altitude zones.

	0-500 m	500-1000 m	>1000 m	Total
P (ha)	11.817	6.865	1.238	19.920
P (%)	59.32	34.46	6.21	100

The condition of flood control facilities is very poor as a result of wartime damage, many years without maintenance, and minefields around some facilities. Extreme climate events often happens.

For example in 2009 and 2010 major floods were recorded, in 2011, 2012 and 2013 there were severe droughts and waves of high/tropical temperatures, early in 2012 there was the wave of extreme cold and the occurrence of windstorms in mid-2012. April and May 2014 had the record of rain series (over 420 mm) in the northern part of the country, which caused disastrous flooding in the catchment area of the Vrbas and Bosna rivers, as well as in the area of Semberija. [15]. The most endangered area in B&H is the valley of the river Bosna with medium-high overall water risk (overall water risk measures all water-related risks, by aggregating all selected indicators from the Physical Quantity, Quality and Regulatory & Reputational Risk categories) [10], where about 40% of the population lives. Other areas have low-medium overall water risk.

In addition to the uneven spatial distribution of water (southern parts of the country receive 2-3 times more precipitation compared to the north) there is also time inequality regarding a lack of water in periods when it is most needed and overmuch water during the wet period. According to the Water and Wetness (WaW) database, in 2018 the areas under the category of permanent and temporary water occupy 33.257 ha (0.64%) and 1464 ha (0.03%), which is a total of 0.67% of the territory of B&H (matches CLC 2018 data). Temporary wet areas cover 128.680 ha (1286.8 km^2) or 2.5% of the country's territory. These are flooded areas in the west Bosnia and south of the country (Herzegovina region), mainly within the karst fields (Livanjsko, Glamočko, Kupeško, Gatačko, etc.) and areas in the north nearby large rivers Sava and Drina. Karst fields are temporarily flooded due to the insufficient capacity to receive large amounts of precipitation (over 1500 mm per year), which mostly sink into the underground layers by a system of cracks in limestone rocks. Going deeper into the layers of limestone, the cracks narrow and cannot let all the water through, so there is an ascending movement and the appearance of water at the bottom and periphery of karst fields. After the rainy period, water recedes and plunges into deeper layers again along the same paths. However, despite frequent flooding, thanks to the low population of the region, there is no major damage to the temporary wet karst fields. On the other hand, large damage in the past decade has been recorded during floods in densely populated areas in the north, in lowland areas when there are overflows from the riverbeds in the valleys of the rivers Bosna, Sava and Drina. The most endangered regions are Posavina and Semberija, ie the areas around the cities of Bijeljina, Modriča, Doboj, Brčko, Brod, Gradiška, Odžak, Bosanski Šamac etc. Therefore, every year, significant funds are allocated for the construction of protection facilities in order to protect settlements from flooding.

When it comes to river sources, according to the EU-Hydro database in B&H, there are 2958 sources that form surface watercourses. Their average altitude is 854 m, and the highest source from which the permanent watercourse begins is at 1865 m. The junction of two watercourses (or river and water reservoir) is 3616. The total length of all rivers, except for the largest which width is greater than 50 m, is 20.217 km and the density of the river network is about 0.4 km/km^2 ($D = \Sigma L/F$; D-density, ΣL-sum of length, F-area). When the length of the largest rivers is added, the density increases to 0.43 km/km^2.

4. Conclusions

Bosnia and Herzegovina is a country rich in renewable water resources. However, they are not spatially and temporally evenly distributed, so droughts and floods are shifting by years. Runoff regimes are very fast and even within the same year after torrential floods, periods of drought occasionally occur. The most endangered areas are agricultural zones in the north around the Sava and Drina rivers and the Bosna River basin in the central part of the country. These are also the most populated areas, so the challenge is relatively large for one of the poorest countries in Europe.

Natural lakes and artificial water reservoirs cover 0.39% of the country's territory. The reservoirs have been mainly built for the production of hydropower energy purpose. Given that the water energy potential is still poorly used, the construction of new reservoirs is planned. Also, several reservoirs for water supply are planned, especially in the vicinity of the capital. There is a growing awareness of the multifunctional importance of hydro-accumulations in flood protection, agriculture, tourism, fisheries, sports, etc.

About 0.67% of the country's territory is covered by water and about 2.5% are temporary wet areas. The largest temporary wet zones are karst fields on the west Bosnia, and on the south in the region of Herzegovina. There are two main reasons: a large amount of precipitation (more than 1500 mm annually) and geological layers in which limestone rocks predominate that cannot accept all the water during rainy period. Another region with large temporary wet areas is in the north of the country, in regions of Posavina and Semberija. In this case, the reason for wetness is related to the relatively frequent outflow of large rivers and their tributaries from riverbeds and alluvial plains.

References

[1] Agency for statistic of Bosnia and Herzegovina (ASB&H) 2016 Census of Population, Households and Dwellings in Bosnia and Herzegovina, 2013. Sarajevo. Statistical Database. [Available online: http://www.statistika.ba/]
[2] Agency for statistic of Bosnia and Herzegovina (ASB&H) 2021 *Short-term indicators of energetic statistics*, November 2020 [Available online: http://www.bhas.ba/data/Publikacije/Saopstenja/2021/ENE_01_2020_11_0_SR.pdf]
[3] Copernicus Land Monitoring Service (CLMS) European Digital Elevation Model (EU-DEM), version 1.1. Database [Available online: https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1/view]
[4] Copernicus Land Monitoring Service (CLMS) EU-Hydro, Database [Available online: https://land.copernicus.eu/imagery-in-situ/eu-hydro]
[5] Copernicus Land Monitoring Service (CLMS) Water and Wetness, Database [Available online: https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness]
[6] Dukić D and Gavrilović J 2006 *Hidrologija*, Zavod za udžbenike i nastavna sredstva, Beograd, P 386
[7] Drašković B, Gutalj M and Miletić B 2019 Black and White river reservoirs near Sarajevo (Bosnia and Herzegovina) - chalenges and problems, *VII All-Russian scientific-practical conf. with int. participation "Modern problems of reservoirs and their catchments"* **II** *Water quality, Geoecology* pp 80-85
[8] European Environment Agency (EEA) 2019 CORINE Land Cover Nomenclature Guidelines, [Available online: https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature-guidelines/html]
[9] FAO, AQUASTAT. 2017. Database, AQUASTAT Website (accessed on 13 February 2021)
[10] Hofste R S, Kuzma S, Walker E H Sutanudjaja et al 2019 "Aqueduct 3.0: Updated Decision-Relevant Global Water Risk Indicators." Technical Note. Washington, DC: World Resources Institute [Available online at: https://www.wri.org/publication/aqueduct-30]
[11] SNC BiH 2013 *Second National Comunication of Bosnia and Herzegovina under the United Nations framework convention on climate changes* P 196
[12] Spahić M 2001 *Prirodna jezera Bosne i Hercegovine*, limnološka monografija, HARFO-GRAF, Tuzla P 170
[13] Ministry of Agriculture, Forestry and Water Management of the Republic of Srpska (MAFWMRS) 2015 *Strategija integralnog upravljanja vodama Republike Srpske 2015-2024*. Banjaluka
[14] Ministry of Agriculture, Water Management and Forestry of the Federation of Bosnia and Herzegovina (MAWMFFB&H) 2010. *Strategija upravljanja vodama Federacije Bosne i Hercegovine 2010-2022*. Sarajevo i Mostar [Available online https://fmpvs.gov.ba/wp-content/uploads/2018/01/Strategija-upravljanja-vodama-FBiH-2010-2022.pdf]
[15] TNC and SBUR 2016 *Third National Communication (TNC) and Second Biennial Update Report on Greenhouse Gas Emissions (SBUR) of Bosnia and Herzegovina* P 258