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Research Article

Spatio-temporal distribution of renewable freshwater resources and their availability in Kosovo—an analysis from the Eastern Region

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Abstract

The study aims to analyze the availability of renewable freshwater resources and their spatiotemporal distribution in the Eastern Region of Kosovo (ERK). As a crucible resource for agricultural, industrial, and commercial activities, water scarcity will lead to water shortages. Kosovo is a landlocked country, and ERK is the most important region for industrial activities (coal, mines) and agricultural use (plains). Located in continental climate conditions, surrounded by middle to high-altitude mountains, the region does not have a favorable spatio-temporal distribution of freshwaters. The determination of the water resources is based on the amount of surface runoff, which being divided per capita, gives indications of the water resources of a region (catchment). For our aims, main river discharge and population statistics are used to analyze the spatiotemporal distribution and availability of renewable freshwater in ERK. Falkenmark Freshwater Indicator with 1.483 m³/capita/year shows that ERK lies under water scarcity, and existing water reservoirs offer low security for water withdrawals, and further reservoirs would prevent water scarcity in the region.

Key words: Continental climate, fluctuations, Falkenmark Water Stress Indicator, water scarcity

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1. Introduction

Water is the most essential natural resource on the planet. Quantity and quality of water supplies are critical to our survival and the natural environment. Water is required to continue civilization's agricultural, industrial, and commercial activities. As a result, the assessment and good water resource management is a means of ensuring food production, reducing poverty, and eliminating water-related diseases. On the other hand, freshwater availability is a primary global concern, particularly in developing countries.

At the beginning of the 1980s, water scarcity became an issue in a global context. Since then, many indicators have been developed to assess the availability of freshwater and water scarcity. Many regions in the world are experiencing water scarcity (Veldkamp et al. 2017). Fragile economies in the Balkans could be impacted by fluctuations of water resources (Markovski et al. 2017). The world's growing population is expecting to have water demand, especially in the water-stressed world, by which in 2050, 87 out of 180 countries will have annual freshwater resources below 1,700 m³/year (Baggio et al. 2021), while in Kosovo with increasing of economic level and living standard water demands are increasing.

It is well understood that rapid population increase and rising resource demand have significant effects on hydrological cycles and ecosystems (Elshafei et al. 2014). Rapid changes in land use, such as urbanization, affect flow regimes, especially in high mountains, and degrade water quality (Carpenter et al. 2011; Montanari et al. 2013; Seymenov 2019). Researchers (Alessa et al. 2008: Sullivan 2010; Plummer et al. 2013; Wu et al. 2013) conceptualized water resource vulnerability with physiographic and socioeconomic criteria, encompassing natural variables (physical and ecological), social and economic dimensions, water institutions and governance with the advent of climate change. It is difficult to know what elements are employed in a water vulnerability assessment and what methodological approach is required to conduct the assessment in this setting.

Many water resources indicators were developed to show the water resources of the region. One of the first links between population and freshwater resources was made by Falkenmark and Lindh, introduced in the Population Conference in 1974 in Bucharest (Falkenmark and Lindh 1976), which was later promoted, and became most prominent freshwater resources indicator. Gleick's (1996) water stress index is frequently used to estimate the scarcity of a country's renewable water supply to meet all water requirements for human needs in terms of drinking and hygiene services. Because the resource base is finite, the index predicts that as the world's population expands, there will be proportionally less water available per capita (UNESCO-IHE 2004; Rijsberman 2006; Zhao et al. 2011). The social water stress index is a variant of the Falkenmark Indicator that incorporates a society's "adaptive capacity" to examine how economic, technological, or other factors affect a region's total freshwater availability status, and it was created by Ohlsson (2000). The social water stress index weighs Falkenmark's Indicator with the United Nations Development Programme (UNDP) to account for the ability to adapt to water stress.

Water stress indicators are often used to visualize the vulnerability of water resources on a global scale. Since the Falkenmark Indicator was introduced in 1989, many alternative water stress indices have evolved, each with its assumptions and purposes (Brown and Matlock 2011). For this study, the population-based Falkenmark Indicator is used as a preliminary assess the monthly and yearly freshwater availability (Falkenmark 1979; Falkenmark et al. 1989).

Kosovo has insufficient water resources (National Water Strategy 2017–2036 2017; Kosovo Water Security Outlook 2018), while ERK as one of the main regions has less than the country average. Most of the ERK is located in a continental climate with annual fluctuation of river runoff during the year. Economic activities as pull factors for migration have led to an increase in population numbers in the past. The population census of 2011 showed that in ERK were 1,037,892 inhabitants in 882 settlements, which made up 58.3% of the country's population and 60% of settlements. The average freshwater per capita for the whole region was 1,483 m³/year, which was a reduction from the past as population number increased. According to the classification of the Falkenmark Water Stress Indicator, in ERK, there are periodic shortages and limitations in freshwater availability. The most recent cases were presented at the beginning of 2014 when the ERK (especially in the sub-basin of Sitnica and Morava e Binçës) was experiencing low rainfall during the winter season, which affected the reduction of water volume in artificial lakes, conditioned shortages in the water supply. Compared to the other river basins in Kosovo, the ones located in the Eastern Region are estimated to be under water stress conditions (Kosovo Water Security Outlook 2018).

This study aims to analyze the availability and distribution of renewable freshwater resource in the ERK. The analysis and interpretation of water resources will take into consideration the four main river basins and sub-basins: Ibri, Sitnica (with Llap and Drenica), Morava e Binçës (with Lumi i Shtrembër–Crocked River), and Lepenci, which belongs to ERK. All river systems are distinguished from each other in terms of natural conditions, which is also reflected in renewable freshwater resources and their distribution.

2. Materials and methods

2.1. Study area

As a landlocked country with an area of 10,905 km², Kosovo is the smallest country of the Balkan Peninsula and it is distinguished by continental climatic conditions, while the influence of the Mediterranean climate can be observed in the southwestern part (Fig. 1). It is surrounded by high and mid-altitude mountains, while in the central part, there are tectonic plains surrounded by mountains. The country has diverse natural conditions, which have also determined the main physical-geographic features. From the water sources in the mountains, the main water sources are created, while the groundwater aquifers are mainly found in porous medium in the plains, which until recently were the main sources for water supply.

From the geographical point of view, Kosovo can be divided into two large regional units: the Western Region of Kosovo (or Dukagjini Plain) and the Eastern Region of Kosovo (or Kosovo Plain) (Çavolli 1997), which have specific climatic conditions. Kosovo's regional division is also closely related to the hydrographic division, where the four main river systems correspond to the territorial division, in which case three of them Ibri, Morava e Binçës and Lepenci are located in the Eastern Region, while Drini i Bardhë (White Drini) is in the Western Region (Bytyqi 2017). Climatic conditions in Kosovo are determined by its position to the Mediterranean and continental influence on the Balkan Peninsula, while the ERK where the three main river systems are located has continental climate. In the easternmost parts, the degree of continentality is high and rainfalls are less than country's average. The average annual rainfall in the plains of the ERK is about 635 mm, while in the hilly-mountainous areas, the average annual rainfall is higher, especially in the Sharri Mts., (south) and in the Kopaonik Mts. (north) (Pllana 2013, 2015).

From a geological point of view, ERK has complex geological settings with rocks of different origins and specific hydrogeological features. Sedimentary rocks of lacustrine and fluvial origin are dominant in plains (Pruthi 2013). The

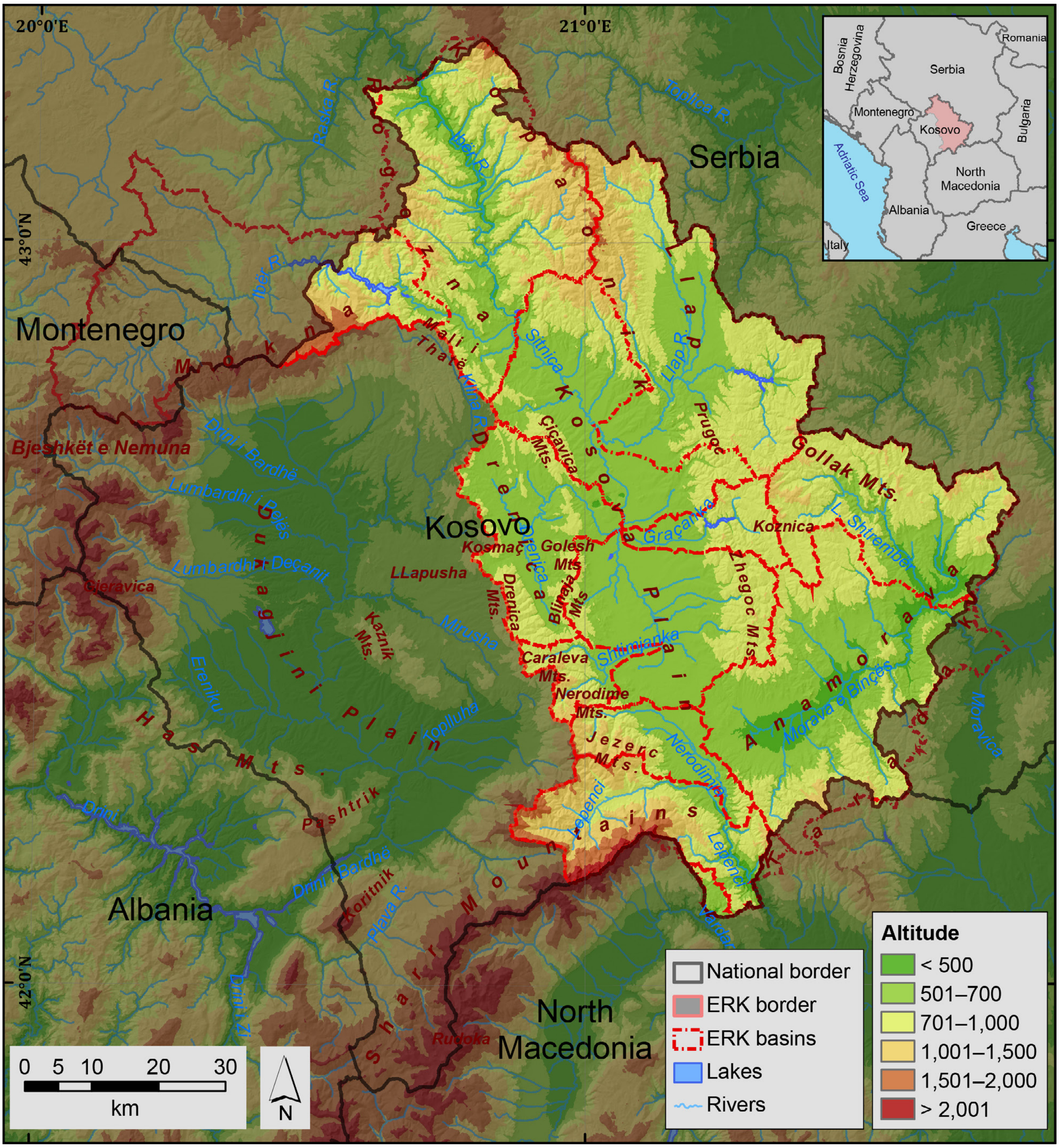

Figure 1. Location of ERK and analyzed basins (compilation by authors; DEM source from ALOS PALSAR; rivers from copernicus.eu).

main resources are energy (coal), minerals, and thermal-mineral waters. The most important water resources of the ERK are considered groundwater, especially those of intergranular porosity (sand, gravel and clay), found in most of the plains, such as Kosovo, Anamorava, Llapi and Drenica (Hydrogeological map of Kosovo 2006). Of particular importance are the karst aquifers, which, due to their dissolution, can accumulate significant amounts of water (Stefanov et al. 2023); however, their distribution in the ERK is limited, because of small areas of carbonatic rocks, which mostly appear in the form of oasis surrounded by other rocks.

The area of the Balkan Peninsula lies in the transition zone between temperate climate inside subtropical climatic zones in the area around the Mediterranean Sea; thus, the climate in the northern inland parts is classified as continental temperate, and the southern coastal parts are classified as maritime subtropical (Peneva et al. 2023). As a transition zone in climate, the Balkan Peninsula will face changes in temperature and precipitation in the future (Charalampopoulos 2021) which can led to changes in water resources. To evaluate climatic changes, the analysis of climate conditions in plain areas in Kosovo is needed. Climatic conditions in Kosovo were analyzed by authors who proposed different climate regionalizations (Ducić and Radovanović 2005; Pllana 2015; Milovanović et al. 2017; Gavrilov et al. 2018).

Although the ERK does not have large differences in extent along latitude or longitude (135 km; 80 km), in a small region there are large differences in climatic conditions. While in the south lies Sharr Mts., with an altitude above 2,500 m, in the north Kopaonik Mts., are found (2,017 m). Eastern Mts., in the east, and Karadak Mts. (Kopilaqa peak: 1,492 m) in the southeast, and Central Mountains range in the west are surrounding main plains of the region. The extent of mountains and valleys is very important. While Sharr and Karadak Mts. in the south prevent air masses penetration from the Aegean Sea, only through Kaçanik gorge along the Lepenc River small penetration without major impacts on the climate are enabled. The plain part of the ERK is characterized by a continental climate, where the amount of precipitation is greater during the summer season (continental regime), while in other seasons the amount of precipitation is less. The plain area is traversed by the average annual isotherm of 10°C, while with the increase in altitude, the average annual air temperature decreases to 4°C (Sharr Mts.).

Kosovo and Anamorava are plains with the least amount of annual rainfall in the country, with 591 mm in Mitrovica, 599 mm in Prishtina, 612 mm in Lipjan, and 691 mm in Ferizaj. The average annual rainfall for the lower parts of the Kosovo Plain is estimated at 635 mm, with the smallest amount in the central and northern part of it, while moving to the south, under the influence of the Sharr Mts., the values are higher (Komogllavë, 717 mm, Kaçanik 859 mm). From the Kosovo Plain, the trend of decreasing annual rainfall amounts continues towards the Anamorava Plain, located in the southeastern part of Kosovo, with high degree of continentality, and average annual rainfall from 607 mm in Gjilan and 584 mm in Kamenica (Fig. 2). The highest amount of rainfalls are found in Sharr Mts. (1,200 mm), than in Kopaonik Mts. (1,000 mm), and as a consequence, the rivers originated from them have high river discharge and specific runoff.

2.2. Materials

To analyze the spatio-temporal availability of freshwater resources in ERK, hydrological data of the main rivers, mainly monthly and yearly surface runoff, together with rainfall amounts of the main weather stations are obtained from the Hydrological Yearbook published by the Hydro-meteorological Institute of Kosovo. While surface runoff is a product of climatic conditions, rainfall amounts are used to calculate the hydroclimatic conditions. Population statistics over the years were taken by the Statistical Agency of Kosovo, where census data from the years 1948 until 2011 are published. Data variables are analyzed with ArcMap 10.8 professional software and are presented with thematic maps.

2.3. Methods

To calculate the freshwater availability and their spatio-temporal distribution, water resource indicators were calculated over time according to census data for representative years. Statistical analysis for spatial and temporal distribution was made with findings of the mean annual surface runoff of main rivers in the ERK, and water resource indicators were found. Based on data from weather stations, rainfall maps are created for all the river basins. Also, specific runoff data are interpolated to show the distribution of waters in river basins. The creation of water resources in a certain region is best analyzed within the framework of the main hydrological unit—the river basins, which are delineated from topographic maps of scale 1:25,000.

To understand the freshwater availability the Falkenmark Indicator (FI) is used as the most widely accepted indicator. It takes into consideration surface runoff (m^3/year) and population number over the years (Falkenmark 1989).

$$FI = \frac{Surface\ Runoff}{Population} \tag{1}$$

The indicator is easy to analyze, and for its purpose, just the annual surface runoff and basins' population statistics are needed. Putting both variables into the equation gives the freshwater availability per capita. According to FI different classes of freshwater availability are found. A region is considered under stress in the supply of water if the threshold drops below 1,700 m^3/c/yr. If renewable water supply drops below 1,000 m^3/c/yr, the region is considered as under chronic water scarcity. However, if a region's renewable water supply drops below 500 m^3/c/yr, the region is under absolute scarcity (Table 1).

Table 1. Water stress index proposed by Falkenmark (1989).

FI (m^3/capita/year)	Stress level
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

3. Results and discussion

The water resources of a region are unevenly distributed, while their availability is determined by climatic conditions, especially rainfalls. Quantity and their spatio-temporal distribution of rainfalls enable the creation of water resources, while in Kosovo they are shaped according to the climatic conditions, and topographical features. The amount and distribution are determined by the location of Kosovo in the Balkan Peninsula. All basins in ERK have distinguished hydro-climatic features and as a consequence different amount of freshwater availability. The analysis of the spatio-temporal distribution of freshwater resources and their availability is done by analyzing the main hydrological features of the main rivers in ERK. By analyzing monthly and yearly surface runoff as the main variable of freshwater resources, and putting them into comparison into FI indicator we obtained the monthly and yearly availability of freshwater resources per capita in Kosovo. To have a clearer picture of the freshwater resource availability in ERK, the climatic features of the main river basins have been analyzed. Surface waters in the ERK gravitate towards two seas: the Black Sea (Ibri and Morava e Binçës Rivers systems) and the Aegean Sea (Lepenci River). In the watershed between the Black Sea and the Adriatic Sea, the bifurcation of the Nerodime River has developed a unique phenomenon in the country and Europe.

3.1. Hydrological features of the main rivers

In order to analyze the hydrological features of main river basins in ERK, monthly and yearly surface runoff and rainfall data are analyzed. While, the physical-geographical features of the river basins are different, river basins are distinguished by rainfall amounts and discharge (Table 2). The Lepenci River Basin receives the largest amount of rainfall (yearly average 893 mm), which is above the average of the ERK, whereas the amount is related to the mountainous relief of the Sharr Mts. (>2,500 m). On the other side, the smallest amount of rainfall occurs in Drenica River basin (650 mm) and Sitnica River basin (664 mm). Rainfall amount directly reflects the surface runoff and other hydrological features including basins' water balance. Sitnica River basin together with its main tributaries (Drenica R. and Llapi R.) has an area 4.24 times larger than the Lepenci River basin (2,867:660 km²) but has only 1.31 times greater runoff (12:9.1 m³/s). The small difference in surface runoff between Sitnica and Lepenci is related to the location of the respective basins. Rainfall amount in the Lepenci River basin is greater than in the Sitnica basin, and also the air temperatures are lower in the Lepenci River basin than in Sitnica, so the amount of evaporation is more tremendous in Sitnica than in Lepenci. Another important

Table 2. Hydro-climatic features of rivers in the ERK (source: Hydro-meteorological Institute of Kosovo).

River	Area of basin (sq.km)	Rainfalls (R) (mm)	Total discharge (T) (mm)	Evaporation (E) (R-T) (mm)	Surface runoff (S) (T-I) (mm)	% (S)	Infiltration (I) (T-S) (mm)	% (I)	Soil humidity (W) (E+I)	Feeding coefficient K_u %	Evaporation coefficient K_e %	Discharge coefficient C % (T/R*100)
Ibri	1,122.8	682	232	450	133	57	99	43	549	18	82	34
Sitnica	1,481.1	664	158	506	92	58	66	42	572	11	89	24
Llapi	942.1	700	160	540	89	56	71	44	611	12	88	23
Drenica	443.7	650	170	480	94	55	76	45	556	14	86	26
Morava e Binçës	1,716.8	715	151	564	76	51	75	49	639	12	88	21
Lepenci	659.9	893	471	422	287	61	184	39	606	30	70	51

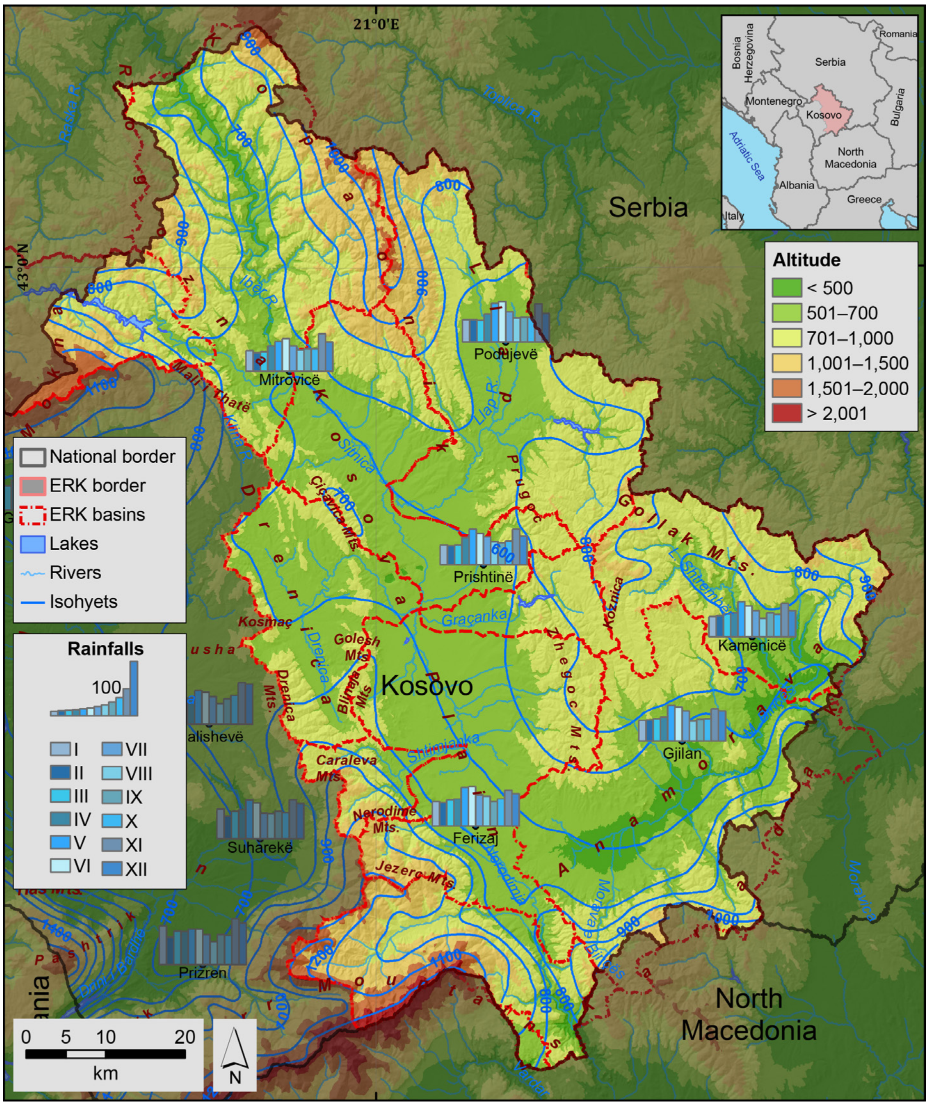

Figure 2. Isohyets and rainfall diagrams for selected stations in ERK.

element is the slope gradient. Lepenci has a higher surface runoff than Sitnica and other rivers of the ERK due to its longitudinal profile and steeper slopes of mountainous terrain. The greater longitudinal profile in Lepenci River (14.7 m/km) than all the other rivers in ERK, means smaller possibilities of surface water infiltration. The surface runoff of Lepenci is 32.1%, while that of Sitnica is 13.9%. Snowfall in the Lepenci River basin is greater than that of Sitnica, which is determined by the mountainous relief of Sharr Mts. and the plain of Kosovo, where the amount of snow is closely related to the length of the winter season.

Because of the different physical features in the Lepenci and Morava e Binçës River basins, they have developed distinguished characteristics (Fig. 2). Morava e Binçës River basin has an area 2.54 times larger than the Lepenci's basin (1,717:660 km²), but the rainfall regime and total amount are not the same (Carević 1997). Based on rainfall stations, the Lepenci River basin receives more rainfall than the Morava e Bincës River basin (893:715 mm), however, the discharge of Morava e Binçës in the mouth near Konçuli gorge is almost equal to the river discharge in the Lepenci River (9.1:9.0 m³/s).

In comparison between the Sitnica and Ibri River basins (up to their confluence in Mitrovica), some small differences in their hydrological characteristics can be observed. The area of the Sitnica basin with its tributaries is 2.55 times larger than that of the Ibri until its confluence in Mitrovica (2,867:1,123 km^2), but their discharge is almost equal (12.0:12.5 m^3/s). This phenomenon occurs due to the hydro-climatic conditions in the respective basins. Ibri River basin, from its sources in Montenegro, flows through mid- to high-altitude mountains (Bjeshkët e Nemuna/Accursed Mts. and Mokna Mts.), which have a crucial role in creating surface waters, and snow melting play an important role in feeding the rivers, where most of the flow has nival-pluvium (snow-rain) regime. The Sitnica River basin has the smallest amount of precipitation, mostly rain and rather snow. These two basins have another distinguished element, which characterizes them (Fig. 3). Monthly and annual air temperatures are lower in the Ibri River basin than in Sitnica, which affects the evaporation amount. Northward to Leposaviq hydrometric station, Ibri River has an average annual discharge of 30.8 m^3/s, which is mostly due to surface water from Kopaonik and Rogozna Mts., flowing directly into Ibri River.

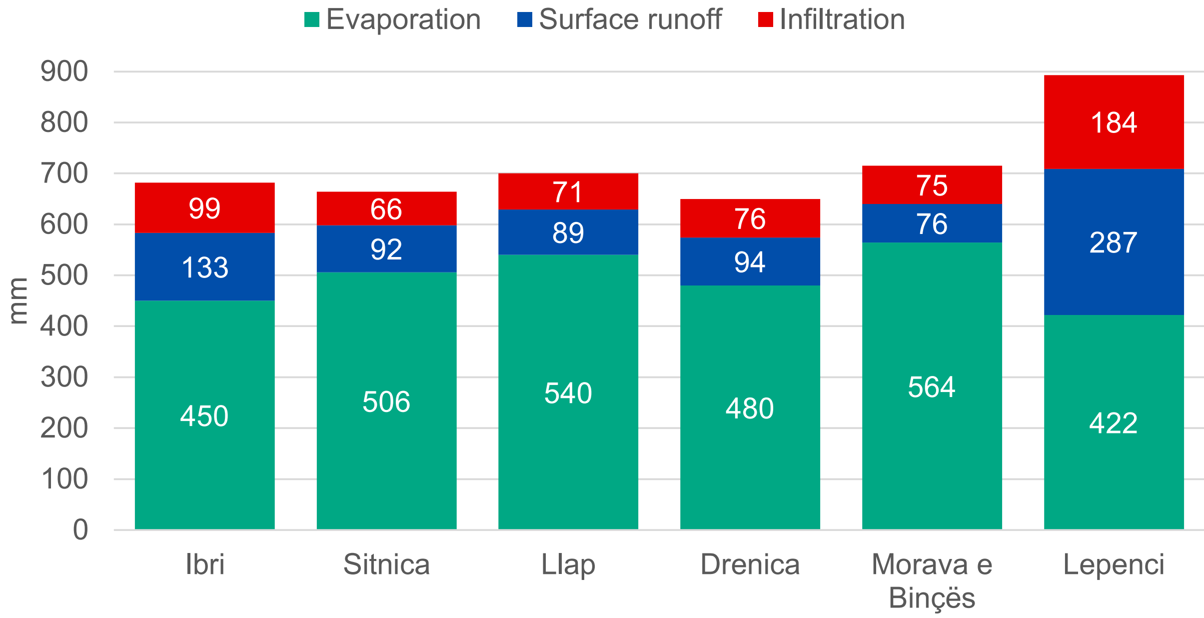

Figure 3. Evaporation, runoff and infiltration of main rivers in ERK.

Table 3. Basins' area, average annual discharge, and total annual discharge of the main river system.

River basin	Total area (km^2)	Area inside Kosovo (km^2)	Average annual discharge (m^3/s)		Total annual discharge ($10^6 m^3$)
Ibri	5,018.47	4,038.87	30.76		970.05
Morava e Binçës	1,716.85	1,545.11	8.96		282.56
Lepenci	675.80	659.89	9.10		286.98
	7,411.12	6,243.87	Σ=48.8	Avg=16.27	1,539.59

Based on the hydrometric stations located in the outgoing border between the Easter Region of Kosovo, which is also the international border between Kosovo, Serbia, and North Macedonia, the average surface runoff is 48.8 m³/s, which corresponds to the total volume of surface runoff of 1,539x10⁶ m³ of water per year (Table 3). Most of these surface waters are created inside the ERK,

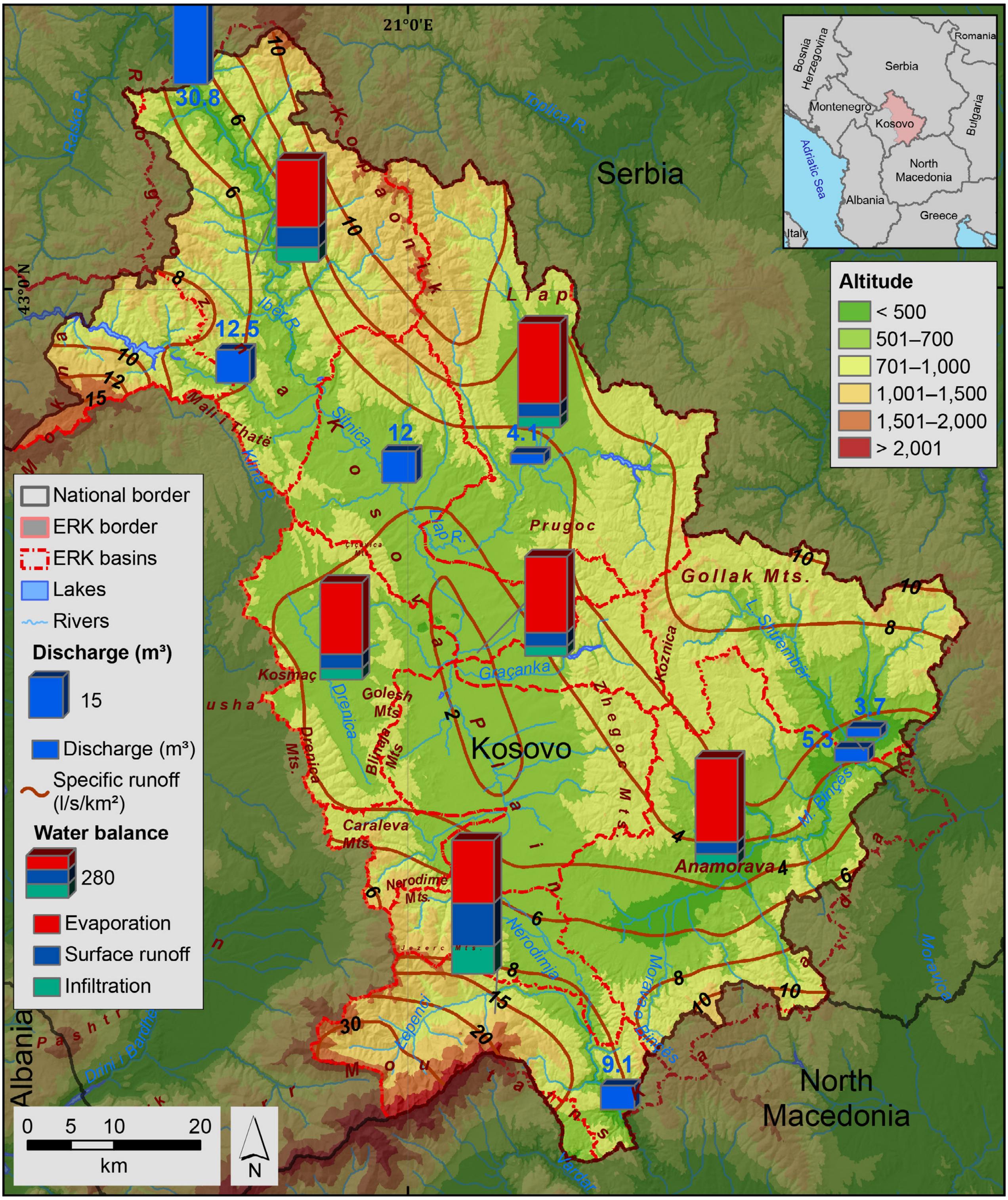

Figure 4. Specific runoff and other hydro-climatic features of the main rivers of ERK.

except for those of the Ibër River (Montenegro and Serbia), and the upper part of Morava e Binçës (North Macedonia), making surface water to be domicile (autochthonous) in their origin, but in the same time, they flow toward neighboring countries, turning into transit, respectively transboundary waters.

Based on hydrological analysis of the annual average surface runoff, it appears that from the ERK, on average, 16.27 m^3/s flow into the neighboring countries, with 63% of it flowing through Ibri River, and nearly 18% of each from Lepenci (9.1 m^3/s) and Morava e Binçës River (9 m^3/s). Based on the total surface runoff (48.8 m^3/s) of the rivers in the crossings from the ERK, it turns out that 207,740 m^3 of water is created per year from each km^2 of the rivers' total basin area (Fig. 4).

3.2. Monthly and yearly distribution of surface runoff

One of the challenges related to surface runoff is the temporal fluctuation during the year. Based on the river regime and the way of feeding, the amount of water in rivers and streams is closely related to the type of precipitation (rain or snow) and their yearly distribution. Rivers that are mainly fed by rains have the largest flows associated with the rainfall regime. Thus, rivers: Sitnica, Llapi, Drenica, Morava e Binçës, Lumi i Shtrembër have their highest flow in the first months of the year, while other rivers, Lepenci and Ibri, whose waters depend on snow melting from high mountains located in their basin, have the most increased flows at the end of spring. In general, the summer months have the lowest surface runoff, therefore it can be noted that there are fluctuations within the year, seasons, and months, as well as the uneven distribution of water resources in the river basins of the ERK (Fig. 5).

During the summer months, the amount of runoff through the rivers of the Eastern Region of Kosovo is at lowest. The differences between the annual average runoff and the monthly runoff during summer (June–September) are, on average, 1.84 times. The most negligible differences are observed in the Lepenci River (1.5 times), while the largest is in the Morava e Binçës River (2.2 times). At the same time, the differences in the Ibri River are 1.86 times (Table 4). The differences between minimum and maximum river runoff reflects the impact of climatic conditions, geological settings, relief features, vegetation cover, etc. (Pllana 1996).

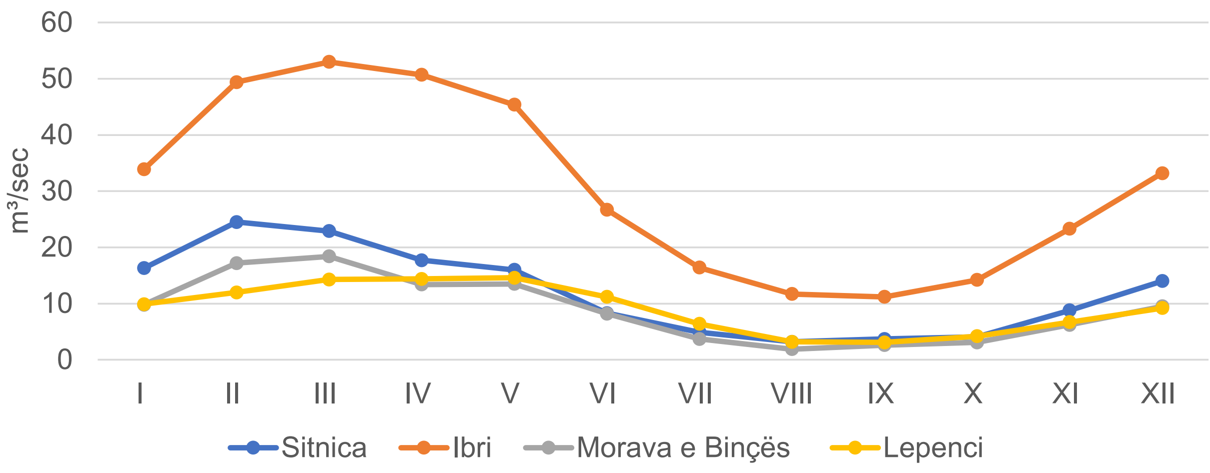

Figure 5. Annual fluctuation of river discharge in ERK.

Table 4. Annual average flow and average flow during summer months in ERK.

River	Area (km²)	Average annual discharge (m³/s)	Total annual discharge (10⁶m³)	Average discharge VI–IX (m³/s)	Total flow VI–IX (10⁶m³)	Differences in discharge: annual–seasonal	Differences in total discharge: annual–seasonal
Ibri	4,038.87	30.76	970.05	16.50	173.92	1.86	5.58
Morava e Binçës	1,545.11	8.96	282.56	4.10	43.22	2.19	6.54
Lepenci	659.89	9.10	286.98	5.98	62.98	1.52	4.56
	6,243.87	**48.82**	**1,539.59**	**26.58**	**280.12**	**1.84**	**5.50**

3.3. Renewable freshwater resources per capita in ERK

Since the 1970s, in many international meetings, the idea of setting a relationship between surface water and population as an indicator of water scarcity has been presented. Therefore, the amount of renewable freshwater (surface runoff) per capita is taken as an indicator of water scarcity and the problems related to the lack of freshwater. The lack of freshwater up to 20% of the total reserves of renewable water, water scarcity can occur which can be a limiting factor for economic development, while the lack of up to 40% represents high scarcity.

In ERK there are not just spatial differences in freshwater resources, but also temporal differences with changes in population number. Thus, the amount of renewable freshwater per capita has decreased with population increase over the years. In the census of 1961 in Kosovo, 565,233 inhabitants were living in basins of the ERK, while the amount renewable freshwater resources was 2,724 m³/capita/year. In the following years, the population increased so in 2011, 1,037,892 inhabitants lived in ERK, while the amount of renewable freshwater per capita was 1,483 m³/year (Fig. 5). According to the Falkenmark Indicator classification, the region faces periodic shortages of water resources (water

Table 5. Basins, area of basins, runoff, population and FI through censuses in ERK.

River basin	Area inside Kosovo (km²)	Average annual discharge (m³/s)	Total average annual discharge (10⁶m³)	Population through years in ERK Falkenmark Index				
				1961	1971	1981	1991	2011
Ibri	4,038.87	30.76	970.0	367,874	480,726	613,924	771,044	717,267
				2,637	2,018	1,580	1,258	1,352
Morava e Binçës	1,545.11	8.96	282.6	141,580	166,249	192,247	226,301	196,101
				1,996	1,700	1,470	1,249	1,441
Lepenci	659.89	9.1	287.0	55,779	75,376	103,764	136,249	124,524
				5,145	3,807	2,766	2,106	2,305
Total	6,243.87	48.82	1539.6	565,233	722,351	909,935	1,133,594	1,037,892
				2,724	2,131	1,692	1,358	1,483

scarcity). The amount of renewable freshwater, according to the 2011 census compared to the 1991, has decreased because "present population" rule was applied in that year's census. All the inhabitants of Kosovo (mainly Kosovo Albanians) who were living abroad were not registered, so the indicator showed an increase in the freshwater per capita, while the reality was different. The pressure that can be exerted by many Albanians abroad is observed during the summer period when many of them spend their holidays in Kosovo (July–August), and the amount of freshwater during that time is at its low level, therefore in the cities where water supply is made through artificial lakes, water shortages occur (Fig. 6).

Our analyses of renewable freshwater and population distribution in the main river basins of ERK have shown significant differences between them. According to the number of inhabitants and renewable freshwater resources, the Lepenci River basin has the most favorable physical-geographical conditions (climate features with more rainfall, hilly-mountainous relief, high gradient terrain, plant cover) with high surface runoff and consequently is rich in freshwaters. Based on the population census in 2011, 124,524 inhabitants lived in the Lepenci River basin, while the amount of freshwater per capita was 2,305 m^3/year. Due to the abundance of surface runoff and other physical settings, in the past, Brod gorge was depicted as a future water reservoir (artificial lake), whereas the project could be implemented soon.

Different conditions are Morava e Binçës River basin. In 2011, 196,101 inhabitants lived in the basins' area, which includes the southeastern part of the ERK, while the amount of renewable freshwater was 1,441 m^3/capita/year, meaning water stress. As of today, the region faces water shortages. The basin is distinguished by the presence of volcanic and magmatic rocks in some parts, and limestone which are also limiting factors in the water resources.

Most of the inhabitants of ERK (69% or 717,267 inhabitants) live in the Ibri River basin and other sub-basins (Sitnica with sub-basins of Llapi and Drenica). The average amount of renewable freshwater per capita was 1,352 m^3/

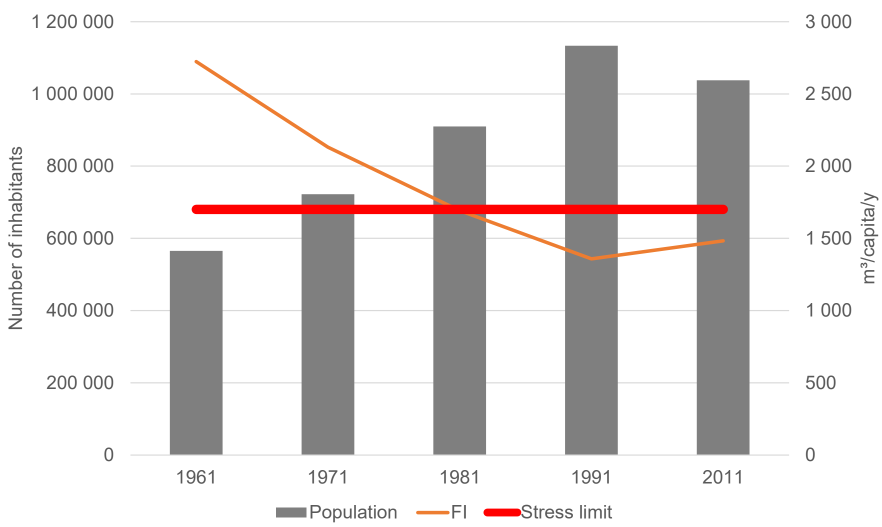

Figure 6. Variability of number of population and Falkenmark Indicator through years in ERK.

year meaning water stress. Within the Ibri River sub-basins, there are big differences in freshwater per capita. Less amount of freshwater is in the Sitnica River basin, where 420,720 inhabitants were living (area 1,481 km² without the Llapi and Drenica tributaries), while the amount of freshwater is 450 m³/capita/year, meaning water scarcity. The municipalities of Pristina (capital), Obiliq, Fushë-Kosovë, Lipjan, Shtime, Vushtrri, and most of Ferizaj are located in Sitnica basin. In the main tributary of the Sitnica River—Llap River basin, in 2011, 113,236 inhabitants were living, and the freshwater was 1,110 m³/capita/year. In the Drenica River basin, the second tributary of Sitnica, in 2011 85,515 inhabitants were living, while the amount of freshwater was 740 m³/capita/year. The main municipal center is Gllogoci, while there are 68 settlements in total. These analyses show that the ERK has differences in renewable freshwater per capita, in which there are sub-basins with values under water scarcity and water stress. Renewable freshwater availability in the ERK is under the threshold of 1,700 m³/capita/year, which shows water scarcity in the most populated region in Kosovo (Fig. 7).

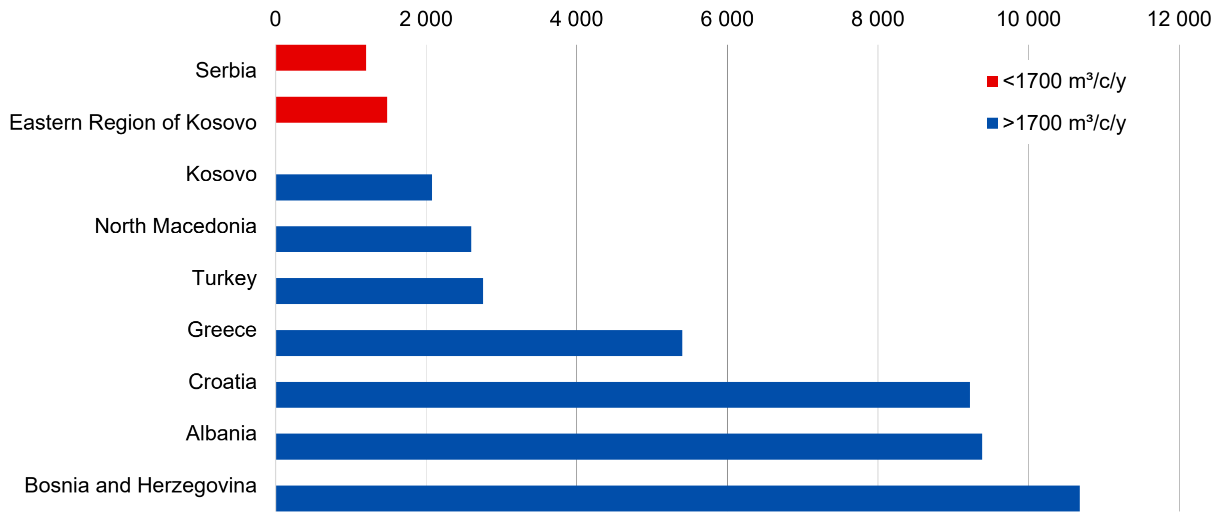

Figure 7. Renewable freshwater resources in some selected countries (source: FAO, AQUASTAT).

4. Conclusion

Kosovo's location in Balkan Peninsula, and the Eastern Region as its largest region, due to its geographical location, especially the climatic conditions, is distinguished by insufficient water resources. Located in continental climatic conditions, surface runoff in the ERK is vital in the creation of water reserves through existing accumulations. Surface runoff in the main rivers of the ERK has significant oscillations during the year. The runoff indicates the total amount of surface runoff that a river basin can create within months, seasons, etc. It shows the amount of water for various activities, such as agriculture, water supply through artificial lakes, etc.

Differences in physiographical features in main river basins in ERK has influenced different spatial and temporal renewable freshwater distribution, and in general under threshold amount per capita. A total of 48.8 m³/s flows outside ERK through three main river systems. There are differences between rivers, where 30.76 m³/s flows through Ibri River, while through two others Morava e Binçës and Lepenci an average 9 m³/s flows. There are fluctuations during the year, where average annual surface runoff is 1.84 time greater than during summer months (June–September) average, reflecting the amount of freshwater available for collecting in artificial lake and supply. Kosovo as a country is near of the limit of 1,700 m³/capita/year. The neighboring countries, as well as the members of the European Union, are above the threshold (EEA 2021). Whereas, the ERK is below the threshold (1,700 m³/capita/year) with 1,483 m³/capita/year, there is water scarcity and even water stress in some sub-basins. Some river sub-basins that have a greater concentration of population, such as Sitnica and Morava e Binçës, are even now facing water shortages, which become more sensitive during drought occurrence. The problem remains in the summer season, when the rivers are at their minimum surface runoff, while the demands for water are high, such as for the needs of consumption, irrigation, industry, etc. Therefore, such oscillations show that within the ERK, there must be proper management to deal with water scarcity and water stress.

Proper management of current water resources and the creation of other water reserves through accumulations in suitable locations would be the long-term solution for water security in Kosovo. Research and feasibility studies completed earlier and revised in recent years must be implemented to create water availability for Kosovo.

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Additional information

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.