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# CLIMATE CHANGE IMPACTS ON WATER BALANCE COMPONENTS IN BOSNIA AND HERZEGOVINA AND CROATIA

## SUMMARY

The climate of Southeastern Europe, where Bosnia and Herzegovina (BiH) and Croatia are located, is changing in line with the global trends. The spatial and seasonal distribution of precipitation is changing, while the temperatures increased 0.4-0.8 $^{o}$C on average compared to 1961-1990, most notably during summer (1.0-1.2 $^{o}$C). Depending on the different Representative Concentration Pathway (RCP) scenarios, the temperatures in this area are projected to further increase by 1.7-4.0 °C. In order to understand the effects of climate change on regional water resources, it is important to assess the impacts of these changes on the components of the water balance. The aim of this study was to determine and compare the severity of changes in annual water balance between two climate periods (1961-1990 and 1991-2020). The results indicate that climate change has a different temporal and spatial effect. All areas showed a positive trend in mean air temperature (0.29-0.36 $^{o}$C per decade), reference evapotranspiration (5.96-32.14 mm per decade) while precipitation, total runoff, amount of snow and actual evapotranspiration vary depending on the location and time period. The key characteristic of the 1991-2020 period compared to 1961-1990 is the greater variation of all components of the water balance.

**Keywords**: climate change, soil water balance, soil moisture deficit, evapotranspiration

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## INTRODUCTION

Analysis of meteorological parameters plays the important role in a changing environment, especially in agricultural water management. The trends of different meteorological parameters, such as temperature, precipitation and relative humidity have been the parts of many studies across the world (Gocic and Trajkovic 2013, Nikzad Tehrani *et al*. 2019, Pandey and Khare 2018).

In Bosnia and Herzegovina (BiH), a significant body of research is focused on the analysis of changes and increase in air temperature (Popov 2020, Popov *et al.* 2019, Popov *et al.* 2018, Popov, Gnjato *et al*. 2017), amount and distribution of precipitation (Popov *et al*. 2019, Popov *et al*. 2017, TNC 2016), as well as changes in the water balance (Čadro *et al*. 2020, Ljuša *et al*. 2020). As for Republic of Croatia, recent studies have been conducted to address the climate change phenomenon (Beslik and Causevic 2019) and to examine the main climate trends (Bilandžija, 2019, Bilandžija and Martinčić 2019, Cindrić *et al*. 2016, Čepo, 2021, Ferina *et al*. 2021, Marinović *et al.* 2021).

In many studies of climate change, the region where Bosnia and Herzegovina and Croatia are located is defined as the Western Balkans or Southeastern Europe. This area is under the great impact of global warming and highly vulnerable to climate change, with an observed temperature increase of 1.2ºC and projected to warm further by 1.7-4.0°C depending on global efforts in greenhouse gas (GHG) emission reduction or RCP models. This temperature increase would lead to a reduction in precipitation by up to 30% (Ali, *et al*., 2022).

BiH and Croatia are countries whose larger parts are located in continental and Mediterranean climate zones (Peel *et al*. 2007). These two zones differ in all basic characteristics, most notably in temperature and amount of precipitation (Bajić and Trbić 2016). The Mediterranean region is considered to be warming 20% faster than the global average (Ali, *et al*., 2022). Therefore, climate change has a different impact on these two climates.

Such negative trends will have an impact on agriculture as this is crucial for development and employment in BiH and Croatia. Agriculture is highly sensitive to climate conditions and it is expected to be strongly affected by climate change, potentially resulting in the loss of livelihoods and jobs Rüttinger, *et al.*, 2021). The aim of this study was to determine and compare the severity of changes in annual water balance between two climate periods (1961-1990 and 1991-2020) and two climate zones (BiH and Croatia), in order to analyze the impact of climate change on soil water balance.

## MATERIAL AND METHODS

Research was carried out for the wider area of two countries - Croatia and BiH. Croatia is located at the crossroads of southeast and central Europe, Balkan peninsula, and southern Europe (45°8′30″N, 16°13′45″E). BiH is located in south-eastern Europe, at latitude 43°52' N and longitude 18°25' E. The basic country profiles are given in Table 1.

Table 1. Main characteristics of the study areas

| Characteristic | Croatia | Bosnia and Herzegovina |
|---|---|---|
| Area ($km^2$) | 56,594 | 51,129 |
| Water (%) | 1.09 | 1.40 |
| Coastline (km) | 1,777 | 20 |
| Mean elevation (m) | 331 | 500 |
| Highest point (m) | 1,831 | 2,386 |
| GDP (nominal) per capita[1] ($) | 17,337 | 7,078 |
| Population | 3,888,529[2] | 3,531,159[3] |
| Population density (per $km^2$) | 68.70 | 69.06 |
| HDI[4] for 2022 | 0.837 | 0.769 |
| Köppen climate classification[5] | Dfc, Dfb, Dfa, Cfb, Cfa, Csb, Csa | ET, Dfb, Cfa, Cfb, Csa |
| CRI[6] average for 2000–2019 | 47,00 (53) | 68,17 (122) |

[1]*Gross domestic product (IMF, 2019)*
[2]*Census of population, households and dwellings in the Republic of Croatia in 2021, source: Central Bureau of Statistics of the Republic of Croatia, 2021*
[3]*Agency for Statistics of Bosnia and Herzegovina, Census 2013 (Jukić, 2016).*
[4]*Human development index, source: United Nations Development Programme.*
[5]*Dfb - humid continental climate, Cfa, Cfb - temperate warm and humid climates, Csa - mediterranean climate and ET - tundra climate (Peel et al. 2007).*
[6]*Global Climate Risk Index (Eckstein et al. 2021)*

Both countries have similar Köppen climatic types (Geiger, 1961, Peel *et al*. 2007), area and population. The biggest difference is the large coastal area that Croatia has (1,777 m), ie the higher mean altitude (500 m) in BiH. BiH is mainly hilly to mountainous, with 5% is lowlands, 24% hills, 42% mountains, and 29% of karst area (TNC 2016, Žurovec *et al*. 2017).

The most recent Global Climate Risk Index (CRI) places BiH at 122 place, and Croatia at 53td in terms of exposure and vulnerability to extreme weather events (Eckstein *et al*. 2021).

**Climate data**

Ten weather stations (WS) with long-term continuous climate data records, were selected for this research, five in Croatia: Osijek (Čepin), Dubrovnik, Rijeka, Split (Marjan), and Zagreb (Maksimir); and five in BiH: Livno, Sanski Most, Sarajevo (Bjelave), Tuzla and Mostar. Daily weather data, including mean ($T_{mean}$), maximum ($T_{max}$) and minimum ($T_{min}$) air temperature, sum of precipitation (P), mean relative humidity ($RH_{mean}$), wind speed at 2 m height ($u_2$) and sunshine hours ($n$) for the period 1961-2020 were collected and averaged over each month.

The 60-year period is divided into two climatic periods, the climatic period of the reference normal: 1961-1990 and the last climatological standard normal 1991-2020 (WMO, 2017).

Data were provided by the Federal Hydrometeorological Institute Sarajevo and Croatian Meteorological and Hydrological Service. Basic location characteristics are shown in Table 2.

Table 2. Location and climate characteristics of 10 studied weather stations

| WS | Country | A (m) | °E | °N | $T_{mean}$ (°C) | $T_{max}$ (°C) | $T_{min}$ (°C) | $RH_{mean}$ (%) | $u_2$ (m s$^{-1}$) | *n* (h) | *P* *(mm)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Osijek | CRO | 89 | 18.561 | 45.502 | 11.29 | 16.78 | 6.26 | 77.91 | 1.74 | 5.33 | 676 |
| Dubrovnik | CRO | 52 | 18.085 | 42.644 | 16.71 | 24.62 | 8.57 | 61,83 | 2.38 | 7.21 | 1157 |
| Rijeka | CRO | 120 | 14.442 | 45.336 | 14.17 | 23.81 | 4.88 | 62.80 | 1.66 | 6.09 | 1576 |
| Split | CRO | 122 | 16.426 | 43.508 | 16.40 | 24.35 | 7.61 | 50.03 | 2.79 | 7.23 | 814 |
| Zagreb | CRO | 123 | 16.033 | 45.821 | 11.07 | 23.98 | -0.54 | 74.75 | 1.43 | 5.28 | 863 |
| Livno | BiH | 724 | 17.016 | 43.816 | 9.51 | 15.77 | 3.61 | 71.15 | 1.68 | 6.36 | 1153 |
| Sanski M. | BiH | 158 | 16.666 | 44.750 | 10.64 | 17.05 | 5.19 | 78.87 | 1.81 | 5.12 | 1042 |
| Sarajevo | BiH | 630 | 18.433 | 43.866 | 10.05 | 15.67 | 5.33 | 70.63 | 1.65 | 5.00 | 939 |
| Tuzla | BiH | 305 | 18.700 | 44.550 | 10.51 | 16.84 | 5.46 | 76.06 | 1.21 | 5.01 | 909 |
| Mostar | BiH | 99 | 17.800 | 43.350 | 15.09 | 20.47 | 10.53 | 62.02 | 2.48 | 6.44 | 1482 |

*Note: A – altitude; °E – longitude; °N – latitude;* $T_{max}$ *– mean maximum air temperature;* $T_{min}$ *– mean minimum air temperature;* $RH_{mean}$ *– mean relative humidity;* $u_2$ *– mean wind speed at 2m height; n - actual duration of sunshine; P - precipitation.*

WS Dubrovnik, Rijeka and Split and Mostar are located in the area of the Mediterranean climate. WS Osijek, Zagreb, Livno, Sanski Most, Sarajevo and Tuzla are located in continental climate. Most of the selected stations are located in the urban zones of this area, and due to the development of these cities in the period from 1960 to 2020, the urban heat island (UHI) effect can be present. Given that there are no studies that determine the extent of this impact, nor are there any rural stations that meet the criteria, we can say that the selected WS best represent the selected climates in Croatia and Bosnia and Herzegovina.

**Water balance calculation**

Monthly water balance was calculated using the modified Thornthwaite-Mather method (Dingman, 2002, Thornthwaite and Mather 1955, Thornthwaite and Mather 1957) as shown in Figure 1. Thornthwaite-Mather method (TM) required data on monthly precipitation (P), average monthly air temperature (T), reference evapotranspiration (ET0) and soil available water content (SOILmax). The value SOILmax = 100 mm was used (McBean *et al*. 1995) since this is the most commonly used value for the types of soil that are found in the study locations (Čadro, 2019, Šimunić, 2013).

Dingman's (2002) modification of the Thornthwaite-Mather water balance includes calculation of the amount of snow (SNOW), which is determined based on a defined temperature threshold, i.e. the temperature at which precipitation reaches the ground in the form of snow (sn_threshold), P is divided into snow (SNOW) and rain (P_remain). This snow remains on the ground and is carried over to the next month (PACK). In the case of a temperature rise in one of the following months, the snow melts (MELT) and if possible, infiltrates the ground. Rain (P_remain) and snowmelt water (MELT) represent the total water input to the soil (W).

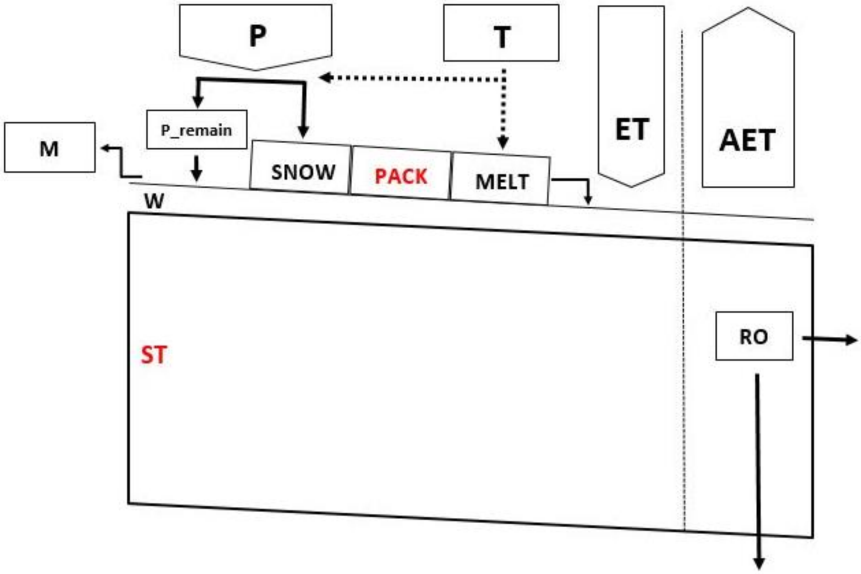


Figure 1. Graphic representation of Modified Thornthwaite-Mather method

Reference evapotranspiration ($ET_0$) was calculated using the standard fao-pm equation (Allen *et al*. 1998):

$$ET_0 = \frac{0.408\Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T_{mean} + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad (1)$$

where $ET_0$ is the reference evapotranspiration (mm day$^{-1}$), $R_n$ is net radiation at the crop surface (MJ m$^{-2}$ day$^{-1}$), G is the soil heat flux density (MJ m$^{-2}$ day$^{-1}$), $t_{mean}$ is mean daily air temperature at 2 m height ($^o$c), $u_2$ is the wind speed at 2 m height (m s$^{-1}$), $e_s$ is the saturation vapor pressure, $e_a$ is the actual vapor pressure, $e_s$–$e_a$ is saturation vapor pressure deficit, δ is the slope of the vapor pressure curve (kPa $^o$c$^{-1}$) and ỿ is the psychrometric constant (kPa $^o$c$^{-1}$).

All necessary parameters required for the calculation of $ET_0$ were computed following the procedure developed in FAO-56 (Allen *et al.*, 1998) via REF-ET: reference Evapotranspiration Calculator (Allen & Zhenguli, 2016) software.

After the calculation of annual means (μ) and the standard deviation (σ) for all analysed water balance components, a statistical measure of the dispersion of data points and the coefficient of variation (CV) were calculated. To detect the trends (b) within annual time series of water balance components (Reference evapotranspiration – $ET_0$, actual evapotranspiration - AET, soil moisture deficit - SMD, total runoff - RO and SNOW) parametric method of linear regression was used.

The severity of climate change effects was analyzed for the period of 1961-1990, defined as "reference normal" (RN), and 1991-2020 defined as "current normal" (CN). All analyzed parameters are divided into climate parameters (CP) including T, P, $RH_{mean}$, n, and water balance components (WB) including calculated values of $ET_0$, AET, SMD, RO and SNOW.

## RESULTS AND DISCUSSION

### Climate parameters

The difference shown in the following tables is the result of subtracting all the values of the obtained parameters for the current climate normal (1991–2020) from the data values for the reference climate period (1961–1991). Positive changes are shown in red, and negative in blue. The intensity of the colour indicates the strength of the change. Air temperatures for the analysed period are shown in Table 3.

In the both climate periods, the highest mean monthly temperature ($T_{mean}$) is in Dubrovnik (RN 16.26 $^{o}$C and CN 17.14 $^{o}$C), and the lowest is in Livno (RN 8.93 $^{o}$C and CN 10.08 $^{o}$C). The coefficient of variation (CV) shows the largest temperature variations in the area of Tuzla and Sarajevo. An increase in temperature was found in all WS, ranging from 0.86 $^{o}$C in Dubrovnik to 1.61 $^{o}$C in Zagreb. In addition, an increase in variations of monthly air temperatures was found at all locations.

Table 3. Mean air temperatures ($T_{mean}$) and differences between the analysed periods

| Air Temperature ($^{o}$C) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 8.93 | 10.12 | 9.55 | 10.01 | 10.82 | 10.26 | 14.57 | 13.63 | 15.94 | 16.28 |
| | σ | 0.41 | 0.52 | 0.42 | 0.47 | 0.71 | 0.54 | 0.44 | 0.41 | 0.39 | 0.34 |
| | CV | 4.62 | 5.15 | 4.43 | 4.69 | 6.59 | 5.22 | 3.05 | 3.04 | 2.43 | 2.08 |
| Current normal 1991-2020 | $\bar{x}$ | **10.08** | 11.16 | 10.56 | 11.01 | 11.77 | 11.87 | 15.61 | 14.71 | 16.86 | **17.14** |
| | σ | 0.61 | 0.69 | 0.73 | 0.81 | 0.76 | 0.79 | 0.59 | 0.68 | 0.63 | 0.67 |
| | CV | 6.02 | 6.22 | **6.96** | **7.35** | 6.47 | 6.69 | 3.77 | 4.65 | 3.75 | 3.91 |
| Difference | $\bar{x}$ | 1.15 | 1.04 | 1.01 | 1.00 | 0.95 | **1.61** | 1.05 | 1.09 | 0.92 | 0.86 |
| | σ | 0.19 | 0.17 | 0.31 | 0.34 | 0.05 | 0.26 | 0.14 | 0.27 | 0.24 | 0.33 |
| | CV | 1.40 | 1.07 | 2.53 | 2.65 | -0.12 | 1.48 | 0.72 | 1.61 | 1.32 | 1.84 |

Such increases in air temperature were also recorded in other studies in BiH and Croatia. Annual temperature trends are positive and statistically significant throughout the territory of BiH. The values of this change, depending on the period of analysis and the location, vary between 0.16 and 1.2 $^{o}$C per decade (Čadro *et al*. 2022, Čadro *et al.* 2020, Jurkovic *et al*. 2021, Popov, 2020, Popov *et al.* 2019, TNC 2016, Trbic *et al.* 2017).

Large temperature variations, especially in the continental climate, indicate an increase in the annual frequency of summer days and tropical days. Popov *et al*. (2018) found an increase in the annual frequency of summer days in the range of 3.0–8.2 days per decade and tropical days 1.2–8.1 days per decade.

Čepo (2021) claims that Croatia, as a Mediterranean country marks the average temperature increase of +1.54 °C and estimates that by 2040 it will be +2.2 °C compared to the pre-industrial level. According to Bilandžija and Martinčić (2019), in comparison to 1961-1990 period, the 1991-2018 period marks higher mean air temperatures followed by increased actual evapotranspiration and prolonged vegetation periods. Table 4 shows data for precipitation in the analysed periods.

Table 4. Mean annual precipitation (P) and differences between analysed periods

| Precipitation (mm) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | x̄ | 1144 | 1024 | 929 | 896 | 650 | 852 | 1516 | 1561 | 825 | 1199 |
| | σ | 161 | 125 | 143 | 123 | 102 | 136 | 297 | 229 | 138 | 257 |
| | CV | 14.08 | 12.22 | 15.40 | 13.79 | 15.77 | 15.98 | 19.58 | 14.66 | 16.72 | 21.45 |
| Current normal 1991-2020 | x̄ | 1163 | 1061 | 948 | 923 | **701** | 874 | 1447 | **1590** | 801 | 1115 |
| | σ | 224 | 180 | 148 | 193 | 157 | 156 | 362 | 302 | 183 | 276 |
| | CV | 19.30 | 16.98 | 15.64 | 20.88 | 22.40 | 17.82 | **25.01** | 18.99 | **22.83** | **24.70** |
| Difference | x̄ | 18.73 | 37.76 | 19.00 | 27.37 | 51.34 | 21.70 | **-68.26** | 28.92 | -24.57 | **-83.14** |
| | σ | 63.40 | 55.16 | 5.35 | 69.73 | 54.61 | 19.54 | 64.99 | 73.16 | 44.85 | 18.43 |
| | CV | 5.23 | 4.75 | 0.24 | 7.10 | 6.63 | 1.84 | 5.43 | 4.33 | 6.11 | 3.25 |

The highest annual amount of precipitation (P) is in Rijeka with 1590 mm, followed by Mostar with 1447 mm. The lowest amount of precipitation is in Osijek (701 mm). The largest variations in precipitation are in the Mediterranean part, i.e. in Mostar, Dubrovnik and Split. The area where the annual amount of precipitation decreased highest is in Dubrovnik (83 mm). All WS in the continental climate had an increase in annual precipitation, with the highest increase in Osijek, where the average annual precipitation in CN has increased by 51 mm. It is interesting to note that the coefficient of variation increased at all WS.

In contrast to the consistent warming trend found for the entire research area, changes in the precipitation regime did not show spatially and temporally coherent trends. Many other authors also came to similar results (Čadro *et al*. 2020, Popov, 2020, Popov *et al*. 2019, TNC 2016). Analysis for Croatia shows that at the state level, the average annual amount of precipitation has increased very little. However, the changes are very different depending on the region meaning that in most parts of Croatia, a significant decrease in the total amount of precipitation is observed, mainly during the summer, at the level of 7-2% per decade (Čepo, 2021).

Also, the result of our study shows that there are certain differences between the studied Mediterranean and continental areas. In the Mediterranean, especially in the south (Mostar, Split and Dubrovnik), i.e. in locations with a large amount of annual precipitation (1115-1590 mm), there was a decrease (24-83 mm) while in the continental part the amount of precipitation increased (18-51 mm).

For the area of southern Croatia and BiH, this change, combined with increase in variability and extreme rainfall events (Popov *et al.* 2017), can cause significant problems, because even though there are large amounts of precipitation, most of them fall in the period when the vegetation is dormant. The summer period is very dry and this kind of change only deepens the problem of water supply for all sectors (agriculture, industry and domestic) during the summer months. Table 5 shows data for the relative air humidity in the analysed periods.

Table 5. Relative air humidity ($RH_{mean}$) and differences between analysed periods

| Relative air humidity (%) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 68.99 | 79.48 | 71.19 | 77.58 | 79.35 | 76.57 | 62.04 | 62.88 | 58.41 | 63.24 |
| | $\sigma$ | 6.24 | 1.33 | 2.76 | 2.65 | 4.18 | 1.64 | 3.13 | 2.33 | 2.16 | 2.14 |
| | CV | 9.04 | 1.67 | 3.88 | 3.42 | 5.27 | 2.14 | 5.04 | 3.70 | 3.70 | 3.38 |
| Current normal 1991-2020 | $\bar{x}$ | 73.31 | **78.28** | 70.08 | 74.53 | 76.47 | 72.93 | 62.00 | 62.73 | **57.64** | 60.41 |
| | $\sigma$ | 8.02 | 2.04 | 3.05 | 2.69 | 2.76 | 2.06 | 3.96 | 3.12 | 2.45 | 3.52 |
| | CV | **10.94** | 2.60 | 4.35 | 3.61 | 3.61 | 2.82 | 6.39 | 4.97 | 4.26 | 5.82 |
| Difference | $\bar{x}$ | 4.32 | -1.20 | -1.11 | -3.05 | -2.88 | -3.64 | -0.05 | -0.16 | -0.76 | -2.83 |
| | $\sigma$ | 1.78 | 0.71 | 0.29 | 0.04 | -1.42 | 0.42 | 0.83 | 0.79 | 0.30 | 1.38 |
| | CV | 1.90 | 0.93 | 0.47 | 0.19 | -1.66 | 0.69 | 1.35 | 1.27 | 0.56 | 2.45 |

The lowest values of mean relative humidity ($RH_{mean}$) are in the Mediterranean (Split, Dubrovnik, Mostar, Rijeka), and the highest in the continental part (Sanski Most, Osijek, Tuzla). WS Livno stands out as the location with the greatest variations in $RH_{mean}$ and the only location where there was an increase in humidity in the period 1991-2020 compared to the previous climate normal. Reduction of $RH_{mean}$, in other locations ranges from 0.05 in Mostar to 3.64 in Zagreb.

Decrease in relative humidity of air indicates an increase in the potential for the process of evapotranspiration, i.e. faster drying of the soil and eventually more severe droughts. On the other hand, this can also be positive because in conditions of excessive rainfall, the soil will dry out sooner and can be used earlier in agriculture. For a better understanding of this parameter, an analysis at a detailed temporal (season, month) and spatial scale is needed.

Solar radiation (n) is one of the basic factors of evapotranspiration and the change of this parameter significantly affects all phases of Water cycle. Solar radiation data for this study is shown in Table 6.

Table 6. Mean solar radiation (n) and differences between analysed periods

| Solar radiation (h/day) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | x̄ | 6.10 | 4.82 | 4.82 | 4.79 | 5.08 | 5.02 | 6.25 | 5.86 | 7.08 | 7.12 |
| | σ | 0.45 | 0.38 | 0.35 | 0.44 | 0.41 | 0.39 | 0.35 | 0.37 | 0.33 | 0.29 |
| | CV | 7.40 | 7.89 | 7.28 | 9.14 | 8.10 | 7.82 | 5.54 | 6.35 | 4.73 | 4.03 |
| Current normal 1991-2020 | x̄ | 6.60 | 5.42 | 5.19 | 5.35 | 5.57 | 5.54 | 6.64 | 6.33 | 7.38 | 7.30 |
| | σ | 0.46 | 0.49 | 0.37 | 0.48 | 0.40 | 0.42 | 0.38 | 0.45 | 0.39 | 0.37 |
| | CV | 7.04 | 8.98 | 7.04 | 9.00 | 7.16 | 7.67 | 5.66 | 7.16 | 5.30 | 5.02 |
| Difference | x̄ | 0.50 | 0.60 | 0.36 | 0.56 | 0.49 | 0.52 | 0.40 | 0.47 | 0.29 | 0.18 |
| | σ | 0.01 | 0.11 | 0.01 | 0.04 | -0.01 | 0.03 | 0.03 | 0.08 | 0.06 | 0.08 |
| | CV | -0.37 | 1.09 | -0.24 | -0.14 | -0.94 | -0.15 | 0.12 | 0.80 | 0.57 | 1.00 |

The most hours of sunshine are in WS Split and Dubrovnik (more than 7.3 hours per day), and the least in Sarajevo (5.19 hours per day). This parameter shows increase at all investigated WS, ranging from 0.18 to 0.6. The biggest increase is in Sanski Most.

The increase in solar radiation is accompanied by increase in air temperature across all investigated WS. This indicates that the amount of solar radiation that reaches the earth's surface is the main cause of the increase in air temperature. The exception is Zagreb, where there is a disproportionate increase in air temperature (1.61 $^{o}$C). However, it is an urban environment, and probably the effect of urbanization in the period after 1990 contributes to the increase in temperature.

**Water balance components**

As shown in Table 7, an increase in ET0 was determined at all WS for the current normal climate period, most pronounced in WS Dubrovnik. The determined increase in n, T and RH also resulted in an increase in $ET_0$.

Table 7. Reference evapotranspiration ($ET_0$) and differences between analysed periods

| Reference evapotranspiration (mm) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 786 | 752 | 761 | 724 | 738 | 876 | 1065 | 952 | 1218 | 1128 |
| | $\sigma$ | 40 | 43 | 41 | 39 | 34 | 39 | 64 | 42 | 52 | 59 |
| | $CV$ | 5.15 | 5.78 | 5.41 | 5.33 | 4.65 | 4.40 | 5.98 | 4.40 | 4.28 | 5.27 |
| | $b$ | 2.83 | 1.23 | 0.25 | -0.52 | 1.68 | 0.09 | -0.33 | -0.88 | -0.21 | 2.70 |
| Current normal 1991-2020 | $\bar{x}$ | 825 | 802 | 810 | **752** | 811 | 939 | 1103 | 1018 | **1265** | 1227 |
| | $\sigma$ | 39 | 44 | 44 | 51 | 46 | 44 | 66 | 51 | 55 | 65 |
| | $CV$ | 4.67 | 5.45 | 5.47 | 6.81 | 5.68 | 4.67 | 6.00 | 5.00 | 4.37 | 5.31 |
| | $b$ | -0.37 | 0.35 | 1.79 | 11.55 | 2.17 | 1.44 | -2.58 | 1.74 | 1.38 | 3.16 |
| Difference | $\bar{x}$ | 39 | 50 | 49 | 28 | 73 | 63 | 38 | 66 | 46 | 99 |
| | $\sigma$ | -2 | 0 | 3 | 13 | 12 | 5 | 3 | 9 | 3 | 6 |
| | $CV$ | -0.48 | -0.33 | 0.06 | 1.49 | 1.03 | 0.28 | 0.02 | 0.60 | 0.09 | 0.04 |

The highest $ET_0$ values were determined in the south, more precisely in Split (1265 mm), followed by Dubrovnik (1227 mm) and Mostar (1103 mm). The lowest values were in Tuzla, where they amount to 752 mm per year.

The analysis of trends shows significant differences both between the periods and the locations. The highest positive trend was recorded in Tuzla, 11.55 mm/year. It is interesting to note that two locations show a small negative trend for this parameter: Livno and Mostar (from -0.37 to -2.58 mm/year).

The highest amount of snowfall is in WS Livno: 265 mm per year, while in WS Dubrovnik and Split it almost never snows and therefore could not be the subject of these calculations. From the data (Table 8), it can be seen that in the CN period in all WS locations there is a decrease in the amount of snow.

Table 8. Mean annual amount of snow and differences between analysed periods

| SNOW (mm) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 326 | 192 | 219 | 172 | 133 | 135 | 65 | 43 | | |
| | $\sigma$ | 130 | 84 | 91 | 69 | 74 | 56 | 71 | 54 | | |
| | *CV* | 40 | 44 | 41 | 40 | 56 | 42 | 110 | 125 | | |
| | *b* | -2.69 | -2.96 | -2.63 | -2.08 | -2.81 | -1.37 | -1.87 | 0.21 | | |
| Current normal 1991-2020 | $\bar{x}$ | **265** | 173 | 191 | 144 | 105 | 98 | 24 | 22 | | |
| | $\sigma$ | 127 | 82 | 98 | 79 | 52 | 49 | 34 | 28 | | |
| | *CV* | 48 | 47 | 51 | 55 | 50 | 50 | 138 | 132 | | |
| | *B* | -0.21 | -2.27 | -2.58 | -1.95 | -2.24 | -1.45 | 0.11 | 0.09 | | |
| Difference | $\bar{x}$ | -61 | -19 | -28 | -28 | -29 | -37 | -40 | -22 | | |
| | $\Sigma$ | -2 | -2 | 7 | 11 | -22 | -7 | -38 | -25 | | |
| | *CV* | 8.20 | 3.44 | 9.77 | 15.20 | -6.11 | 8.78 | 27.85 | 6.90 | | |

This reduction ranges from 19 mm in Sanski Most up to 61 mm in Livno. The decrease is accompanied by a negative trend in both analyzed periods, ranging from -0.21 to -2.96 mm per year, with the exception of Mostar and Rijeka, where there is a stable trend. However, these are locations with very rare snowfall, so few years with snow were taken into account and the trend data should be taken with caution.

Similar trends were found in other studies, Čadro *et al.* (2020) reported a decreasing trend in the amount of snowfall for the area of Posavina (-0.67 to -1.66 mm/year). Similarly, the trends for snowfall ranged from -0.42 to -3.54 mm/year across the entire area of BiH (Čadro *et al.* 2019).

Large differences were found between locations in terms of mean annual runoff (Table 9). The highest value was in Rijeka (793 mm) and Mostar (684 mm), and the lowest in Osijek (124 mm). Differences between the two climatic periods indicate a decrease in RO in the southern locations, ie in Dubrovnik, Mostar, Sarajevo and Split. On the other hand, a significant increase is recorded at WS Rijeka (by 65 mm). However, by analyzing the trend, the earlier negative trend has been replaced by a positive one. This is particularly the case in Mostar, Livno and Dubrovnik.

Table 9. Mean annual runoff (blue water) in the analysed periods at 10 used weather stations

| Runoff (mm) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 500 | 357 | 301 | 263 | 118 | 143 | 745 | 729 | 172 | 435 |
| | $\sigma$ | 158 | 92 | 113 | 89 | 62 | 71 | 258 | 191 | 79 | 188 |
| | $CV$ | 32 | 26 | 38 | 34 | 52 | 50 | 35 | 26 | 46 | 43 |
| | $b$ | -6.11 | -2.23 | -1.67 | -1.85 | -2.20 | -2.24 | -10.28 | -1.40 | -3.57 | -13.82 |
| Current normal 1991-2020 | $\bar{x}$ | 527 | 393 | 289 | 287 | 124 | 160 | 684 | 793 | 163 | 360 |
| | $\sigma$ | 149 | 116 | 88 | 118 | 66 | 69 | 273 | 228 | 87 | 185 |
| | $CV$ | 28 | 29 | 31 | 41 | 53 | 43 | 40 | 29 | 53 | 51 |
| | $b$ | 5.20 | 0.73 | -1.30 | 1.48 | -0.95 | 1.74 | 5.76 | 5.21 | 2.32 | 6.36 |
| Difference | $\bar{x}$ | 27 | 36 | -12 | 24 | 6 | 17 | -62 | 65 | -9 | -75 |
| | $\sigma$ | -9 | 23 | -25 | 29 | 4 | -2 | 15 | 37 | 8 | -3 |
| | $CV$ | -3.36 | 3.56 | -6.96 | 7.17 | 0.68 | -6.38 | 5.29 | 2.51 | 7.13 | 8.08 |

The spring rain, which is present in this climate, often has a high intensity (Popov *et al.* 2017), therefore runoff (RO) is accelerated and the water does not stay long enough for the soil to absorb it, i.e. for the plants to use it. Under these conditions, soil erosion and flooding occur.

Table 10 shows the annual average soil moisture deficit (SMD). This parameter is often taken as an indicator of agricultural drought, or general needs for irrigation. Similar to runoff, there are large differences in SMD between the studied WS. The highest values were in Split (631 mm) and the lowest in Tuzla (103 mm). As was the case with temperatures and $ET_0$, the values of this parameter are higher in the CN period. This increase has a large range (12 – 101 mm), with highest increases in Dubrovnik and Rijeka, about 100 mm. The analysis of the trend (b) indicates an increase in water deficit in Tuzla and Osijek (2.4 and 2.6 mm per year), and reduction in Mostar. Such situations have already caused an increase in dry periods, and according to the obtained trend, especially in the continental part, even more negative effects can be expected.

Table 10. Mean annual soil moisture deficit (SMD) in the analysed periods at 10 used weather stations

| Soil moisture deficit (mm) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 147 | 88 | 134 | 91 | 205 | 168 | 301 | 125 | 565 | 369 |
| | $\sigma$ | 71 | 62 | 84 | 78 | 69 | 89 | 118 | 73 | 125 | 131 |
| | $CV$ | 48 | 70 | 63 | 85 | 33 | 53 | 39 | 58 | 22 | 36 |
| | $b$ | 0.77 | 1.12 | 0.75 | -1.31 | 3.24 | 1.49 | 1.74 | -0.18 | 1.05 | 5.33 |
| Current normal 1991-2020 | $\bar{x}$ | 193 | 134 | 150 | **103** | 234 | 226 | 340 | 224 | **631** | 470 |
| | $\sigma$ | 79 | 84 | 81 | 86 | 117 | 118 | 132 | 105 | 140 | 142 |
| | $CV$ | 41 | 63 | 54 | 84 | 50 | 52 | 39 | 47 | 22 | 30 |
| | $b$ | -0.58 | 0.53 | 0.47 | 2.40 | 2.60 | 0.18 | -2.10 | 0.56 | 0.16 | -0.27 |
| Difference | $\bar{x}$ | 46 | 45 | 17 | 12 | 29 | 59 | 39 | 99 | 66 | 101 |
| | $\sigma$ | 8 | 22 | -3 | 8 | 49 | 30 | 14 | 32 | 15 | 10 |
| | $CV$ | -7.17 | -7.29 | -9.13 | -1.80 | 16.65 | -0.55 | -0.54 | -11.62 | 0.04 | -5.47 |

Table 11 shows the annual average actual evapotranspiration (AET). Given that AET represents the water that has actually evaporated and transpired, often called “green water”, it can also be taken as an indicator of the plant growth and is therefore very important for analysis of the climate change impact to the region of Bosnia and Herzegovina and Croatia.

The highest values are in Rijeka (794 mm) and the lowest in Osijek (577 mm). The differences between the two climatic periods show an increase in the continental part (up to 44 mm in Osijek) and a decrease in the Mediterranean part (up to 33 mm in Rijeka). Therefore, the continental and Mediterranean zones are clearly different in regard to the impact of climate change on AET.

However, trends do not differ much, they are not uniform and do not match any temporal or spatial form. The most interesting trend is in the area of Tuzla, which shows an increase in AET of 9.15 mm per year. Also, there is an interesting change in the trend in the Mediterranean area, where in the RN period the trend was negative (from -0.70 to -2.63 mm per year), and in the current period the CN is close to zero or positive (from -0.48 to 3.43 mm per year). On the other hand, larger variations are noticeable at the WS located in the continental areas.

Table 11. Mean annual actual evapotranspiration (AET or green water) in the analysed periods at 10 used weather stations

| Actual evapotranspiration (mm) | | Livno | Sanski Most | Sarajevo | Tuzla | Osijek | Zagreb | Mostar | Rijeka | Split | Dubrovnik |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Continental climate | | | | | | Mediterranean climate | | | |
| Reference normal 1961-1990 | $\bar{x}$ | 640 | 663 | 627 | 632 | 533 | 709 | 764 | 827 | 653 | 759 |
| | $\sigma$ | 69 | 47 | 64 | 55 | 41 | 63 | 86 | 68 | 91 | 110 |
| | *CV* | 11 | 7 | 10 | 9 | 8 | 9 | 11 | 8 | 14 | 14 |
| | *b* | 2.06 | 0.11 | -0.50 | 0.78 | -1.56 | -1.39 | -2.07 | -0.70 | -1.25 | -2.63 |
| Current normal 1991-2020 | $\bar{x}$ | 632 | 668 | 659 | 649 | 577 | 713 | 764 | 794 | 634 | 757 |
| | $\sigma$ | 52 | 54 | 52 | 67 | 86 | 89 | 86 | 76 | 108 | 109 |
| | *CV* | 8 | 8 | 8 | 10 | 15 | 13 | 11 | 10 | 17 | 14 |
| | *b* | 0.21 | -0.18 | 1.32 | 9.15 | -0.43 | 1.26 | -0.48 | 1.18 | 1.22 | 3.43 |
| Difference | $\bar{x}$ | -7 | 5 | 32 | 17 | 44 | 4 | -1 | -33 | -20 | -2 |
| | $\sigma$ | -16 | 8 | -12 | 12 | 45 | 27 | 0 | 8 | 17 | -1 |
| | *CV* | -2.47 | 1.10 | -2.34 | 1.70 | 7.20 | 3.68 | 0.00 | 1.35 | 3.07 | -0.05 |

## CONCLUSIONS

Observing the changes that occurred between the reference climate period (1961-1990) and the current normal period (1991-2020), an increase in the mean annual air temperature (0.18–0.6 $^{o}$C), solar radiation (0.18–0.6 h per day), reference evapotranspiration (28–99 mm) and soil moisture deficit (12–101 mm) was determined across all studied WS in BiH and Croatia, while the air humidity (up to 3.64 %) and amount of snow (19–61 mm) was reduced.

The differences between the continental and Mediterranean parts of the research area are evident in the amount of precipitation, runoff and actual evapotranspiration. In the north, in the continental climate, an increase in the value of these parameters was found, while in the south, in the Mediterranean climate, a decrease was found.

The key characteristic of the current normal period compared to reference normal in both climates is the greater variation of all components of the water balance. As the result of such climate variations, the likelihood of occurrence of years with extreme rainfall in spring/autumn and extreme droughts during the summer is increased.

The reduction of snowfall in continental conditions has a whole range of negative consequences. Soils and plants are more exposed to low winter temperatures, the effect of soil erosion increases, and underground water sources are less likely to recharge.

Furthermore, the increase in soil moisture deficit and solar radiation, as well as decrease of air humidity, especially in conditions of dry spring or extreme rains increase drought severity, and the availability of water for all sectors can become an issue.

It is very important to carry out these analyzes in detail, at the level of seasons and even months in order to better understand the impact of these changes throughout the year, especially from the aspect of agriculture and the period when plants have the highest water requirements (vegetation period). Also, it is very important to determine the “urban heat island” effect (UHI) in order to reduce the effect of urbanization to a minimum and obtain the most accurate data for a wider area, not just the urban environment. In the future, with the development of remote sensing observation technologies, primarily satellites and local corrections with measurements from the ground, this problem will surely be solved.

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