Soil Water Balance Response to Climate Change in Posavina Region

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Abstract. Posavina region represents the area with the most favorable natural conditions for agricultural production in Croatia and Bosnia and Herzegovina. Increase in the air temperature and changes in the amount of rainfall results in changes in evapotranspiration and the values of main water balance elements indicating the need for a precise determination of the current and future state of basic water balance elements, such as soil moisture deficit and the amount of runoff. Linear regression was applied to determine soil water balance response to climate change in Posavina region. The air temperature, precipitation, reference evapotranspiration and water balance components: actual evapotranspiration, total runoff, soil moisture deficit and amount of snow trends were analyzed. Monthly weather data from 4 weather stations, two in Croatia: Slavonski Brod and Gradište; and two in Bosnia and Herzegovina: Doboj and Gradačac, for the time period of 58 years (1961–2018) were used. The results obtained show increasing trends in annual air temperature (0.032 °C–0.057 °C year^{-1}), sum of precipitation (1.424 mm–2.317 mm year^{-1}), reference evapotranspiration (0.462 mm–4.640 mm year^{-1}), actual evapotranspiration (0.019 mm–2.190 mm year^{-1}), soil moisture deficit (0.443 mm–2.672 mm year^{-1}) and total runoff (0.286–2.46 9 mm year^{-1}) series and decreasing trend in the annual amount of snow (0.676–1.664 mm year^{-1}). Results obtained are showing an urgent need to start with climate change adaptation measures and actions to combat the negative impact of climate change in the Posavina region.

Keywords: Water balance · Climate change · Posavina region · Sava River

1 Introduction

The Sava River Basin is located in the Balkan Peninsula and it extends to six countries: Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Albania. The Sava River Basin is a major drainage basin of the South Eastern Europe, covering the total area of approximately 97,713.20 km^2 and represents one of the most significant sub-basins of the Danube River Basin, with the share of 12% [1]. Most of this area is located in BiH (39.25%) and Croatia (25.97%) while the remaining four countries

M. Brka et al. (Eds.): AgriConf 2019, IFMBE Proceedings 78, pp. 11–24, 2020.
https://doi.org/10.1007/978-3-030-40049-1_2

account for 34.79% [2]. Posavina region represents the inner regions of the Sava River Basin, located in Croatia and Bosnia and Herzegovina (BiH).

As for Croatian territory, Posavina area is placed in continental part of the Republic of Croatia and it covers Vukovar-Srijem and Brod-Posavina Counties. Vukovar-Srijem County belongs to Slavonija and Srijem geographic region of eastern Republic of Croatia. It has geostrategic importance because of the boundary with BiH and Republic of Serbia. Regarding the geography, as the part of Panonnian basin the Vukovar-Srijem County is mostly plain with two main types of arable land, automorphic soil (45.38%) and hydromorphic (54.62%). Above 60% of land in Vukovar-Srijem County is arable land (126,968 ha) with average farm size below 10 ha while organic farming in Vukovar-Srijem County counts 1.944 ha [3]. Given that, improving of agricultural strategy in the area of Vukovar-Srijem County is a foundation for achieving the social economic development of this area [4]. The climate of the Vukovar-Srijem County is moderate continental with average annual temperature of 11.4 °C, average maximum air temperature is 16.5 °C, and average annual minimum temperature is 6.2 °C. The average annual rainfall is approximately 660 mm with summer maximum while the lowest amount of rainfall is recorded during the winter time. The average air humidity is 75% [5].

The area of Brod-Posavina County covers 46 soil unit [6] with the most suitable soils for cultivation located near the Sava river. Most of the arable land (63,702 ha) is sown with crops (57.6%). Climate of Brod-Posavina County is moderately warm and rainy continental climate with average annual rainfall 778 mm (spring and autumn maximum). The average annual air temperature is 10.4 °C. The lowland part of the County by the river Sava is mainly the flood-hit area because of the high amount of rainfall in this area and the type of soil (sandy loam and clay) that increases the surface drainage because of the low infiltration rate [7]. The results of RegCM (A2 scenario) simulation showed the increase of air temperature in two periods as follows: for 0.6 °C during the winter time and 0.8 °C during the summer time for 2011–2040 period, furthermore 2 °C during the winter time and 2.4 °C during the summer time for 2041–2070 period [8]

According to Branković, Srnec [9] in the forthcoming period 2041–2070 the expected increase in amplitude and air temperature during the winter time in continental part of the Croatia is approximately 2 °C, while during the summer months up to 2.4 °C. This is important for the future agricultural production in this area since both of the Counties are the regions with the most intensive crop and production in the Republic of Croatia [10].

The region of northern Bosnia, more precisely the Peripanese Bosnia (Bosnian Posavina) represents the area with the most favorable natural conditions for agricultural production. In the classification of land surface structures, BiH has 5% of lowland areas predominantly in the region of northern Bosnia [11]. Growing grain, vegetable-crops as well as livestock production are largely represented in this area. Of the total cultivable land in BiH, currently less than 20% of the land is suitable for intensive agriculture and is mostly located in the lowlands areas of northern Bosnia. In this part of the country, in recent years, due to global climate change, there has been an increase in air temperature, precipitation and wind speed [12–19]. Precipitation does not fully meet the needs of cultivated plants for water, which negatively affects the yield of most agricultural crops. In April and May 2014, record rainfall, over 420 mm [20], resulting in large floods, and in northern Bosnia caused, among other things, enormous damage to agricultural-food production.

The most vulnerable municipalities to climate change in BiH are located in the north part of the country [21], with few of them in Posavina region (Orašje, Bosanski Brod, Modriča). Based on available data and climate projections, exposure to climate change threats will continue to grow, suggesting the need for adaptation to both current and future climate change. This is particularly true for the agricultural sector, which is, due to its socio-economic importance in BiH, highly vulnerable to the negative impact of climate change [22].

The Global Climate Risk Index 2018 (CRI) analyses to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.). Less developed countries are generally more affected than industrialized countries [23]. The most recent data available from 1998 to 2017, places B&H at 67th place, and Croatia at 35th on the climate risk index list (CRI rank) [24].

Increase in the air temperature and changes in the amount of rainfall results in changes in evapotranspiration and the values of main water balance elements [25] indicating the need for a precise determination of the current and future state of basic water balance elements, such as soil moisture deficit and the amount of runoff.

Thus, the main objective of this study is to determine soil water balance response to climate change in Posavina region using linear regression method, in order to analyze severity of climate change influence to soil water balance and enable better understanding of the impact of climate change on agriculture in this region.

2 Materials and Methods

2.1 Study Area and Data Availability

Study area is represented by Posavina region, the narrow area along the right (BiH) and left (Republic of Croatia) side of river Sava. Administratively this region is part of Vukovar-Srijem and Brod-Posavina County (2,030 km^2) in Croatia and Posavina canton (325 km^2) in BiH.

Because of the low density of weather stations (WS) and the insufficient data they collect, apart from the WS that are located in the very Posavina region, consideration has been given to those in its immediate vicinity. Thus, 4 weather stations (WS), two in Croatia: Slavonski Brod and Gradište; and two in BiH: Doboj and Gradačac, were selected for this study. Daily climatic data, including mean maximum and minimum air temperature (°C), sum of precipitation (mm), mean relative humidity (%), wind speed (m s^{-1}) and sunshine hours (h) for the period 1961–2018 (58 years) were collected and averaged over each month.

Basic location characteristics and number of months used are shown in Table 1.

Table 1. Location, climate characteristics and observation periods of 4 used weather stations (WS) in Croatia and BiH.

WS	Country	A (m)	°E	°N	Period	No. of months	T_{max} (°C)	T_{min} (°C)	RH_{mean} (%)	u (m s^{-1})	n (h)
Slavonski Brod	Croatia	88	17.995	45.159	1963–2018	672	16.8	5.6	78	1.7	5.2
Gradište	Croatia	97	18.704	45.159	1981–2018	456	17.0	6.8	74	2.2	6.0
Doboj	BiH	147	18.083	44.733	1961–2016	672	17.0	6.1	79	1.5	4.6
Gradačac	BiH	225	18.417	44.883	1981–2018	444	16.8	7.7	74	2.3	5.6

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 – mean wind speed; n – actual duration of sunshine.

2.2 Reference Evapotranspiration (ET_o)

Reference evapotranspiration (ET_0) was calculated using standard FAO-PM equation, given by Allen et al. [26]:

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

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

All necessary parameters required for calculation of ETo where computed following the procedure developed in FAO-56 [26].

Since reflected solar radiation (R_s) is required for R_n calculation and this parameter is not measured on WS in Croatia and BiH, it was estimated from the measured sunshine hours data (The Campbell–Stokes sunshine recorder) with the Ångström [27] equation:

$$R_s = (a_s + b_s \cdot \mathrm{n/N}) \cdot R_a \quad (2)$$

where R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1}) calculated for each day of the year and for different latitudes, from the solar constant (G_{sc} = 0.0820 MJ m^{-2} min^{-1}), the solar declination (δ) and the time of the year (J) and then by selecting the R_a for 15th day of each month converted to monthly values, n is the actual duration of sunshine (h), N is the maximum possible duration of sunshine or daylight hours (h), as is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0) and $a_s + b_s$ is the fraction of extraterrestrial radiation reaching the earth on clear days ($n = N$). In the absence of actual solar radiation (R_s) measurements, the values $a_s = 0.25$ and $b_s = 0.5$ were used as suggested by Allen and Pereira [26].

For the WS where measured solar radiation data (R_s) or sunshine hours data were missing for a certain month, solar radiation was estimated using Hargreaves' formula [28] (Eq. 3), as suggested in Allen, Pereira [26]:

$$R_s = k_{R_s}\sqrt{(T_{max} - T_{min}) \times R_a} \tag{3}$$

where R_a is extra-terrestrial radiation (MJ m^{-2} d^{-1}), T_{max} maximum air temperature (°C), T_{min} minimum air temperature (°C), k_{Rs} adjustment coefficient (°C$^{-0.5}$).

In the case of used WS, since they are located inland ("interior" location) where land mass dominates and air masses are not strongly influenced by a large water body, value of k_{Rs} = 0.13 was used [17], as suggested by Cadro, Cherni-Cadro [13] and Čadro, Uzunović [17].

Actual vapor pressure (e_a) was derived from relative humidity data [26] as:

$$e_a = \frac{e^0(T_{min})\frac{RH_{max}}{100} + e^0(T_{max})\frac{RH_{min}}{100}}{2} \tag{4}$$

where e_a is actual vapor pressure (kPa), $e^0(T_{min})$ saturation vapor pressure at daily minimum temperature (kPa), $e^0(T_{max})$ saturation vapor pressure at daily maximum temperature (kPa), RH_{max} maximum relative humidity (%), RH_{min} minimum relative humidity (%). In the absence of relative humidity data, e_a was estimated by assuming that the dew pint temperature (T_{dew}) is close to daily minimum temperature (T_{min}) [26].

When wind speed was not available, the average regional wind speed value was used.

Monthly values of FAO-PM ET_0 were calculated using REF-ET: Reference Evapotranspiration Calculator [29].

2.3 Soil Water Balance

Monthly water balance was calculated by using Thornthwaite-Mather method [30, 31] that was modified and later described in Dingman [32]. Except data on monthly precipitation (P) and evapotranspiration (ET_o) applied water balance requires data on soil available water content ($SOIL_{max}$). The value $SOIL_{max}$ = 100 mm was used [33] since this is the most commonly used value for the types of soil that are found on the study locations.

After calculation of annual means (μ) and the standard deviation (σ) for all analyzed water balance components a statistical measure of the dispersion of data points, the coefficient of variation (CV) was calculated using equation:

$$CV = \frac{\sigma}{\mu} \tag{5}$$

To detect the trends within time series of water balance components (annual precipitation, reference evapotranspiration, actual evapotranspiration, soil moisture deficit, total runoff and snow) parametric method of linear regression was used, as shown in following equation:

$$y = a + b \times x \quad (6)$$

where x is the explanatory variable, y the dependent variable, b the slope of the line and a the intercept. The slope indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends [34, 35].

3 Results and Discussion

3.1 Descriptive Statistics

Descriptive statistics (mean and coefficient of variation) for the air temperature (T), precipitation (P), ET_0 and via water balance calculated actual evapotranspiration (AET), soil moisture deficit (SMD), total runoff (TRO) and snow for the 4 WS for the period 1961–2018 are summarized in Table 2.

Table 2. Annual statistics for the climate and water balance (WB) elements in Posavina during the period 1961–2018.

	Croatia				Bosnia and Herzegovina			
WB Element	Slavonski Brod		Gradište		Doboj		Gradačac	
	μ	CV	μ	CV	μ	CV	μ	CV
T_{mean}	11.1	0.2	11.8	0.2	11.1	0.2	12.1	0.2
P	752	34.3	680	43.2	927	52.1	835	46.3
ET_0	765	15.1	843	20.3	730	13.9	857	21.1
AET	599	16.9	575	25.2	624	15.0	644	20.4
SMD	166	25.9	268	35.6	106	21.8	213	32.0
TRO	154	17.7	106	14.5	304	34.4	192	21.9
$SNOW$	113	14.8	99	13.4	155	19.8	117	17.6

Note: T_{mean} – mean air temperature; P – Precipitation; ET_0 – reference evapotranspiration; AET – Actual evapotranspiration; SMD – Soil moisture deficit; TRO – Total runoff; CV – Coefficient of variation

Higher values of almost all climate and water balance elements are recorded in WS at the right side of the Sava River, i.e. in BiH part of Posavina. The mean annual air temperature is very similar, ranging from 11.1 °C (Slavonski Brod, Doboj) to 12.1 °C (Gradačac). Annual sum of precipitation is highest in Doboj (927 mm), or in BiH in general.

These differences in precipitation resulted in differences between water balance elements. Mean ET_o is higher in Slavonski Brod, Gradište and Gradačac, while in Doboj is lower than mean annual precipitation. As the result, at all observed WS, except Doboj, the high values of the *SMD* were obtained (166–268 mm), while in Doboj, because of high annual precipitation, higher TRO values were obtained (304 mm).

These data point to priorities when addressing climate-related issues. Under the conditions of *SMD*, the priorities are the fight against droughts, i.e. the construction of irrigation systems, while in high TRO conditions it is necessary to solve the problems of high water through the construction of embankment, water regulation and drainage system.

The highest coefficient of variation (CV) is for annual precipitation (*P*) ranging from 34.3% to 52.1%. Also, high variations are found for *SMD* (21.8%–35.6%). These results are in line with previous studies of water scarcity [36–38] and high vulnerability [21] of this region to climate extremes, which is, among other things, caused by its great importance, especially when it comes to agricultural production.

3.2 Regression Analysis

Results of the regression analysis for annual air temperature (T_{mean}), precipitation (*P*), ET_0 and via water balance calculated actual evapotranspiration (*AET*), soil moisture deficit (*SMD*), total runoff (*TRO*) and snow for the 4 WS for the period 1961–2018 are presented in Table 3.

Table 3. Results for the statistical tests for the annual climate and water balance elements in Posavina during the period 1961–2018.

WB Element	Croatia				Bosnia and Herzegovina			
	Slavonski Brod		Gradište		Doboj		Gradačac	
	b	**R**	**b**	**R**	**b**	**R**	**b**	**R**
T	0.037	0.503	0.057	0.534	0.032	0.465	0.048	0.452
P	-0.004	0.005	2.317	0.026	2.162	0.034	1.424	0.014
ET_0	1.451	0.183	4.640	0.483	0.462	0.022	4.019	0.542
AET	0.080	0.001	2.190	0.070	0.019	0.001	1.340	0.064
SMD	1.371	0.056	2.450	0.043	0.443	0.008	2.679	0.104
TRO	0.152	0.001	0.286	0.003	2.469	0.102	0.119	0.004
SNOW	-1.082	0.106	-0.676	0.002	-1.158	0.068	-1.664	0.133

Note: T_{mean} – mean air temperature; *P* – Precipitation; *ETo* – reference evapotranspiration; *AET* – Actual evapotranspiration; *SMD* – Soil moisture deficit; *TRO* – Total runoff; b – slope, R - Correlation coefficient

The results obtained show increasing trends in *T, P,* ET_0*, AET, SMD* and *TRO* series and decreasing trend in the amount of the *SNOW*. The increasing trends of the air temperature (*T*) are similar between 4 analyzed WS in Croatia and BiH, with values ranging from 0.032 °C year^{-1} to 0.057 °C year^{-1}. Increasing trends were also detected for the annual amount of precipitation, ranging from 1.424 mm year^{-1} (Gradačac) to

2.317 mm year^{-1} (Gradište). The exception is WS Slavonski Brod where the amount of precipitation does not change. Based on this data, the annual sum of precipitation for a period of 50 years (1969–2018) in Posavina has increased by 100 mm. The observed air temperature and precipitation change patterns in Croatia and B&H are consistent with the predominant trends in other areas of East Europe [14–16, 39–45] as well as trends observed globally [46–49].

The annual increase of ET_0 vary depending on WS. They are high in Gradište and Gradačac (4.019–4.640 mm year^{-1}), and low in Slavonski Brod and Doboj (0.462–1.451 mm year^{-1}). Similarly, the magnitude of trend for the annual *AET* is higher in Gradište and Gradačac and lower in Slavonski Brod and Doboj. *AET* has a smaller increasing trend, which will in the future cause an increasing gap between atmospheric potential for receiving water through evapotranspiration and actual evapotranspiration.

Such trends of ET_0 and *AET* point to the fact that in the future, for the intensive agricultural production in the Posavina region, it will be necessary to provide increasing amount of water, since crops will not be able to get this water from precipitation, for serious agriculture production it will be an obligation to build adequate irrigation systems.

SMD is result of difference between ET_0 and available soil moisture [50, 51]. *SMD* has increasing trend at all 4 analyzed WS, ranging from 0.443 mm year^{-1} (Doboj) to 2.672 mm year^{-1} (Gradačac). Such positive trend in *SMD* in the future will cause more severe long-lasting droughts and yield reduction. Similar results were found in other studies all over Croatia [52–54].

Annual amount of *TRO* has low increasing trend at all WS except in Doboj, which is about ten times higher, 2.469 mm year^{-1} compared to 0.286 mm year^{-1}.

The only decreasing trends was found for the amount of *SNOW*. Trend values are similar between 4 analyzed WS in Croatia and BiH, with values ranging from −0.676 mm year^{-1} to 1.664 mm year^{-1}.

The obtained results indicate an increasing amount of surface waters that can cause soil erosion, landslides, floods and cause great damage both to the areas, infrastructure and agriculture. The Doboj region suffered heavy damage during the 2014 floods [55]. In addition to Doboj, within Posavina region, the areas of Orašje, Bosanski Brod, Bosanski Šamac and Odžak are at the top of the list of Municipalities affected by floods [56].

Average annual T_{max}, T_{mean}, T_{min},, *P*, ET_0, *AET, SMD, TRO* and *SNOW* values together with their linear trend, correlation coefficient (R) and coefficient of determination (R^2) for the Posavina region and time period 1981–2018 are shown in Figs. 1, 2, 3 and 4. Period 1981−2018 was selected since all 4 WS had measurements during that period, so it was possible to determine the averages.

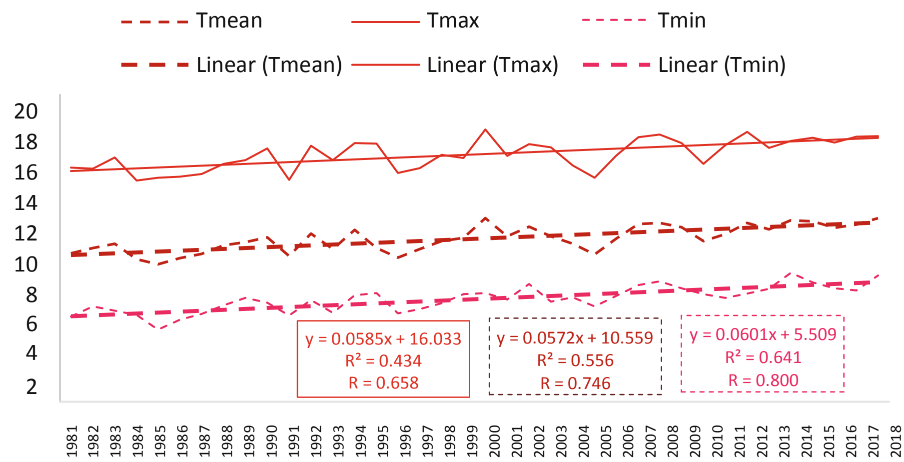

Fig. 1. Linear trend, correlation coefficient (R) and coefficient of determination (R^2) of annual maximum, mean and minimum air temperature for the Posavina region for the period 1981–2018.

The average results for the Posavina region show similar values of the trend as in the case of individual WS. There is an increasing trend in T_{max}, T_{mean} and T_{min} for this area (Fig. 1), ranging from 0.057 to 0.060 °C year^{-1}.

Also, this Posavina region is getting more precipitation, where the amount of rain increases as the amount of snow decreases (Fig. 2). It is also interesting to note that the variations in annual precipitation are higher in the period after 2000, when we had 2 extremely dry years 2000 and 2011 (P < 471 mm) and 3 extremely wet: 2001, 2010, and 2014 (P > 1100 mm).

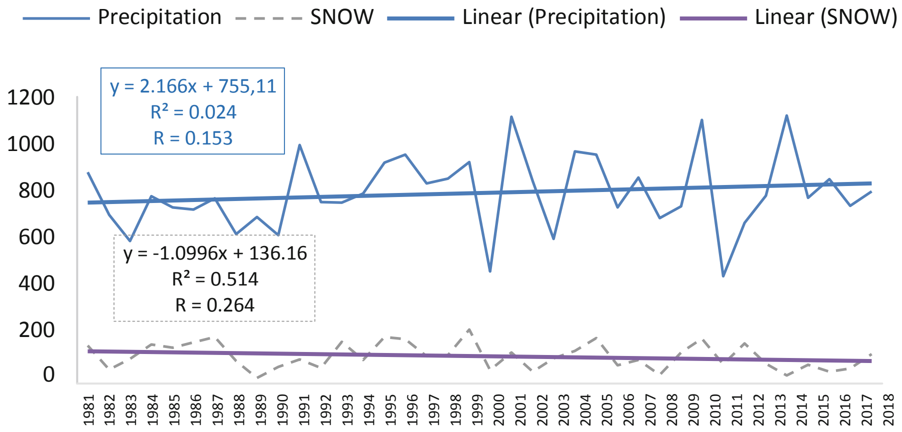

Fig. 2. Linear trend, correlation coefficient (R) and coefficient of determination (R^2) of annual precipitation (*P*) and snow amount (*SNOW*) for the Posavina region for the period 1981–2018.

Such high variations in recent years are also causing high variations in *TRO* and *SMD*, that eventually have devastating effects on Croatia and BiH economies. In Fig. 3. it is possible to notice the shift of extremely wet and dry years, i.e. larger extremes and less and less "normal" years.

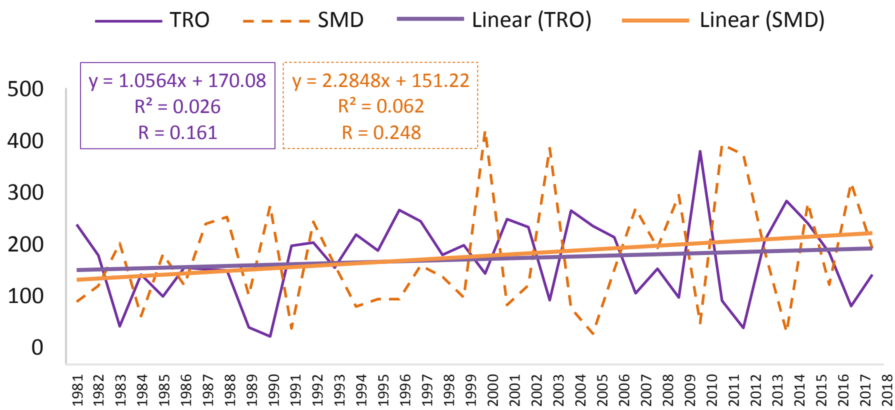

Fig. 3. Linear trend, correlation coefficient (R) and coefficient of determination (R^2) of annual total runoff (*TRO*) and soil moisture deficit (*SMD*) for the Posavina region for the period 1981–2018.

In addition, the gap between ET_0 and *AET* is also increasing (Fig. 4).

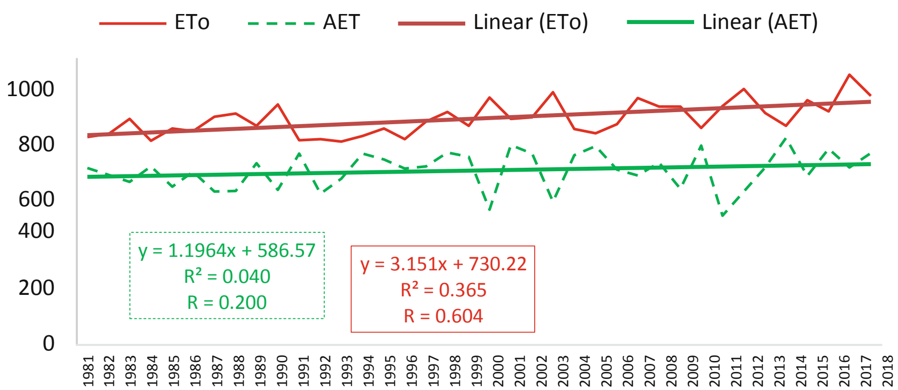

Fig. 4. Linear trend, correlation coefficient (R) and coefficient of determination (R2) of annual reference (*ET0*) and actual evapotranspiration (*AET*) for the Posavina region for the period 1981–2018.

4 Conclusion

Linear regression was applied to determine soil water balance response to climate change in Posavina region. The air temperature, precipitation, FAO-56 PM reference evapotranspiration and water balance components: actual evapotranspiration, total runoff, soil moisture deficit and amount of snow trends were analyzed.

Monthly weather data from four weather stations, two in Croatia: Slavonski Brod and Gradište; and two in BiH: Doboj and Gradačac, for the time period of 58 years (1961–2018) were used.

The results obtained showed that higher values of almost all climate and water balance elements are in BiH part of Posavina. This is especially true for annual sum of precipitation. These differences in precipitation resulted in differences between main water balance elements. Mean reference evapotranspiration is higher in Slavonski Brod, Gradište and Gradačac, while in Doboj is lower than mean annual precipitation. As the result, at all observed locations, except Doboj, the high values of the soil moisture deficit were obtained (166–268 mm), indicating need for irrigation, while in Doboj, because of high annual precipitation, higher total runoff values were obtained (304 mm) pointing to a greater need for drainage.

The results obtained show an increasing amount of surface waters that can cause soil erosion, landslides and floods while in the same time there is an increasing trend in temperature and soil moisture deficit causing the prolonged hot and dry conditions, thus droughts that can seriously affect agricultural production in Posavina.

High variations in amount of precipitation, together with increasing trend of temperature and evapotranspiration, are causing high variations and more frequent occurrence of extreme amount of total runoff and severe droughts. In addition, as the result of such climate variations, the possibility of occurrence of years with extreme rainfall in spring and extreme droughts during the summer, becomes certain.

Based on the obtained results for the Posavina region, we can say that the problems caused by climate change are only partly the result of the increase in trend of climate elements, which is primarily related to temperature increase, the bigger problem is increased variability and frequent occurrence of extreme weather events.

There is an urgent need to start with climate change adaptation measures, with coordinated actions to combat the negative impact of climate change otherwise, agriculture of the Posavina area and therefore the people engaged in it, will in the near future face significant negative consequences.

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