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THE IMPACT OF CLIMATE CHANGE ON SOIL WATER BALANCE AND AGRICULTURAL PRODUCTION SUSTAINABILITY IN MEDITERRANEAN PART OF BOSNIA AND HERZEGOVINA

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Abstract. The world agriculture uses about 70% of the world water resources in irrigation. The concern over the sustainability of water use as demand for agricultural, industrial, and domestic uses continues to increase. Conflicts between particular sectors result in tensions, which sometimes lead to "water wars" in different parts of the world. It is the reason why many national and international organizations are putting the water quantity and quality questions on the top of the world's open questions/problems. The main aim of this paper is to present soil water balance of the Mediterranean region of Bosnia and Herzegovina, prepared for a long-term time series for two locations (Trebinje and Mostar) annually and during the vegetation period. The mean long-term data has been used as a base for future predicted calculation. The predicted PET was based on an increase in air temperature by 2°C and predicted decrease in precipitation by 25%. With so predicted calculated data of monthly PET and monthly precipitation the predicted soil water balance was done.

Keywords: agriculture, adaptation to climate change, climate change, soil water balance

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INTRODUCTION

Mediterranean Dinaric karst covers 30% of the territory of Bosnia and Herzegovina (B&H) and the condition of ecological balance in the area of the Mediterranean karst is complicated by the climate change phenomenon (Custovic and Ljusa, 2015). As IPCC reported (2018), risks associated with increases in drought frequency and magnitude are projected to be substantially larger at 2°C than at 1.5°C in the Mediterranean region (including southern Europe, northern Africa and the Near East) and southern Africa (medium confidence). Although scenarios of climate change introduce high levels of uncertainty (Yassoglou *et al*., 2003), Southern and Eastern Mediterranean countries share long-standing environmental issues and one of them is water scarcity and quality (Dudeen 2006). Predicted climate changes will have a direct impact on Mediterranean agriculture, particularly on water resources and irrigation requirements, crop growth conditions, crop productivity and crop distribution, agricultural pests and diseases, and the conditions for livestock production (Skuras and Psaltopoulos 2012). The IPCC (2007) in its scenario predicts that the Mediterranean countries which are already largely dependent on irrigation will have 15 to 25% less soil moisture in summertime, namely in the vegetation period.

What is the situation in B&H about irrigation water in agriculture? In this paper, the results of the study which was done in three phases have been used. The water balance was done for B&H and for seven main watersheds, but in this paper only the results for the south Mediterranean part of B&H, which belongs to the Neretva and Trebisnjica catchment area, will be presented. Mediterranean part of B&H, highly vulnerable to climate change, is characterized by karst fields which are very sensitive and vulnerable ecosystems. In the area of low Herzegovina, fields are semi-enclosed or enclosed, and their hydrological regime is regulated by the capacity of sinking zones to receive surplus of rainfall in winter period. Problem of flooding and long-term waterlogging is precipitation (spring rainfall), which further aggravates the situation. Droughts are a frequent occurrence related to the growing season when the water requirements of plants are the most needed, which influences negatively on yields and agricultural production. Agriculture is relatively intensive, especially along the rivers Trebisnjica and Neretva, where irrigation causes sporadic occurrence of secondary salinization.

Results of the calculation of soil water balance (Table 1) on the B&H level show that main part of the annual precipitation (51.2%) is used for evapotranspiration, it means for food and biomass production and for sustainability of the ecosystem. This part of the water we call "green water" which was marginalized in all previous calculations of planers, managers and politicians. Second, a little minor part (48.8%), is called the "surplus", "potential outflow" or "blue water". It is a part which is used for recharge of aquifers, sources, lakes and water currents. This water serves for drinking supply, industrial, recreational, irrigation and hydroelectric needs. Water planers, managers and politicians are focused only on blue water, whereas the green waters were neglected. This analysis shows that the crisis of water shortage for the future irrigation is not taken into account in agriculture of B&H. However, the crisis of soil water management does exist if we do not accept the new perceptions in strategy of soil water management. It is the large, long-term and very complicated task which was especially emphasized in this paper (Vlahinin *et al*. 2006).

Table 1. Parameters of average soil water balance in B&H (1960–1990)

Hydrological parameters	Mean annual in mm	In billions m^3	%
Precipitation (P)	1,120	57.3	100.0
Potential ET (PET)	660	33.7	58.9
Real ET (RET)	573	29.3	51.2
Water deficit (D)	87	4.3	7.8
Water surplus (S)	547	28.0	48.8
Relation RET/PET	0.87	0.87	
Relation S/P	0.49	0.49	
Relation S/D	6.3	6.3	

In the Mediterranean countries, the distribution of rainfall during the year is very uneven in terms of space and time and is not in harmony with requirements for evapotranspiration distribution. The main consequence is soil-water imbalance as the main limit of agricultural production. During the colder period of the year, heavy rainfall is observed when the evapotranspiration needs are very low. On the contrary, during the warm (vegetation) part of the year, there are rainfall deficiency and droughts. The impact of climate change on sustainability of agricultural production in the future, will have significant impact on yields reduction, due to reduced rainfall, increased evaporation and reduced stocks of water in the soil. In such conditions the farmer must be regularly and precisely informed about rainfall and soil water regime in rain-fed agriculture in order to select crops suitable for specific rainfall distribution.

MATERIALS AND METHODS

The main aim of this paper is to present soil water balance for the Mediterranean region of B&H, prepared for a long-term time series for two locations, namely Trebinje (60 years) and Mostar (54 years). This method assumes the soil/plant system as a hydrological medium through which evolves the water cycling transfer during the year. The soil has a certain available water storage capability depending on the soil type and depth. It is assumed that this capability is from 50 to 200 mm, but usually, an average of 100 mm (R) is used to satisfy the average conditions.

The method of soil water balance or budgeting is applied in order to find out the proportion of rain which falls on land, evaporates, runs off, percolates and infiltrates the soil. It is a widespread popular method among agronomists, ecologists, geographers, geologists, physicists, hydrologists and others concerned with water problems (Bouchet 1964, Darves-Bornoz 1957, Remenieras 1965, Rence 1992, Thornthwaite 1944, 1958, Turc 1953, 1961). The method is based on three parameters, and they are: monthly potential evapotranspiration (PET) in mm calculated by Thornthwaite, monthly precipitation (P) in mm registered in the area and the soil water available reserve (R) which is supposed to be 100 mm. By applying this method, three outcome data are: real or actual evapotranspiration (RET), soil water deficiency or drought effect (D) and soil water surplus (S) or potential outflow (runoff + percolation). Relation of RET/PET provides the coefficient of drought (drought effect) and relation of S/P provides the coefficient of potential outflow (water surplus).

The calculation begins in the month when the soil water available reserve (R) is supposed to be recharged at field capacity mostly in January or depleted mostly in August. In B&H climatic conditions, the start with January is more applicable, because we presume that in January soil water available reserve will be recharged in December of the preceding year. In months where P-PET is positive, moisture will either be added to the soil storage if it is depleted, or will be available as water surplus for stream flow and groundwater recharge if the soil is full. In months where P-PET is negative, moisture will be removed from the soil water reserve (R) or water deficit will exist with water stress on the vegetation. In this way the soil water balance has been calculated for long-term time series for two locations: Mostar and Trebinje in the Mediterranean part of B&H. The mean long-term data has been used as a base for future predicted calculation. The predicted PET was based on an expected air temperature increase by 2°C and a predicted decrease in precipitation by 25%. With so predicted calculated data of monthly PET and monthly precipitation, the predicted soil water balance was done.

RESULTS AND DISCUSSION

Water balance data analysis

Data taken from two locations (Mostar and Trebinje) were analyzed. Since the results are very similar in trend and time, and due to limited space to present all results, only the main parameters of water balance for Mostar will be presented. The main characteristic of precipitation regime in B&H is high variability in space and time (UNFCCC 2016). Mean annual precipitation in Mostar and Trebinje area is 2.1 to 2.4 times higher than in the north of country, e.g. Bijeljina area (Vlahinic *et al*. 2002). Significant differences between mean, once in ten years, maximal and minimal annual precipitation are recorded in both locations.

Analysis of annual temperature

Temperature conditions for Mostar are shown by analyzing the annual mean air temperature and results clearly indicate the present warming up. Results of the long-term data series (1961–2015) indicate an increase in the annual air temperature, $R^2 = 0.4843$ and in the last fifteen years (2001–2015) $R^2 = 0.1763$ (Fig. 1). The increase of mean annual air temperature was 0.3°C/10 years for the period 1961–2015. Analysis indicates the increase in temperature in all seasons, especially in summer where the temperature increase is 0.5°C/10 years.

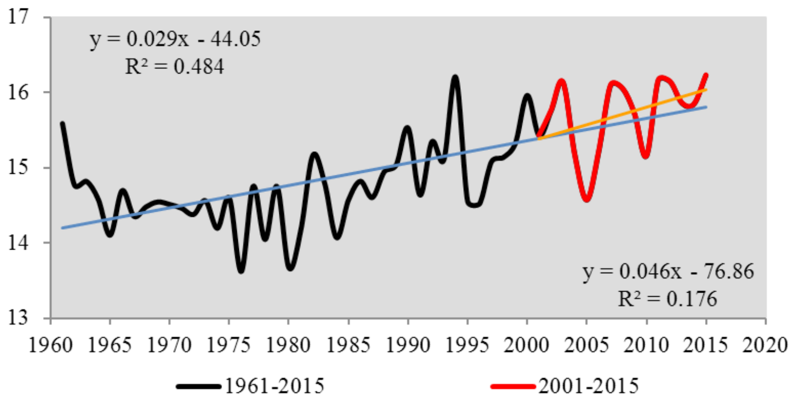

Fig. 1. Mostar – average air temperature (T) (C°)

Analysis of annual precipitation

By analyzing the data of the long-term time series (Mostar – 54 years and Trebinje – 60 years), it was noticed that precipitation were somewhat smaller compared to the long-term period 1961–1990, and that there was a noticeable increase in precipitation in the autumn time in the period 2001–2015. Trend of the occurrence in the period from 1961 to 2015 ranged within $R^2 = 0.0119$, while in the period from 2001 to 2015, it was $R^2 = 0.2051$ (Fig. 2). This phenomenon can be explained by the fact that increased temperature, and thus the PET, induces more abundant precipitation, but its distribution and intensity are not subject to this principle.

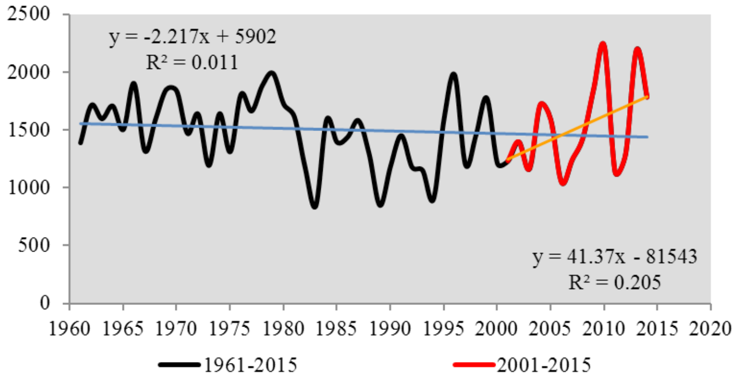

Fig. 2. Mostar – average of precipitation (P) (mm)

Analysis of annual water balance parameters (PET, AET, S and D) of water in soil

The trend of annual potential evapotranspiration (Fig. 3) is very similar to the temperature trend which is explained by close relation between air temperature and potential evapotranspiration. Should temperature continue to rise, potential evapotranspiration will increase as well. If precipitation remains unchanged, one should expect an increase in water deficiency. The analysis of trends of some parameters of the soil water balance and reserves of easily accessible water (R) of 100 mm is shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6. A general statement would indicate that the impact of climate change on water resources is reflected not so much in the overall annual amounts as in the distribution of precipitation. In the period 1961–2015, linear trends indicate stagnation or a very mild decrease of precipitation.

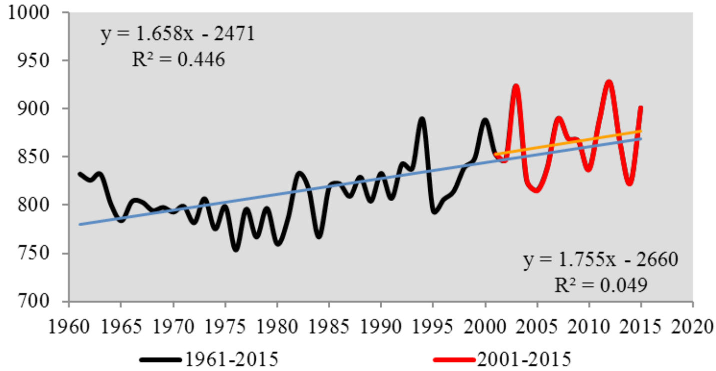

Fig. 3. Mostar – potential evapotranspiration (PET) (mm)

Changes of precipitation are more pronounced with regard to seasons than with the annual level. The trend is different in different seasons; in most part of B&H, it is negative during the spring and summer (most pronounced in the Mediterranean part of B&H [up to 20%]), whereas in the autumn and winter periods, there is an increase in rainfall, especially in the north-western and central parts of B&H. Although no significant changes in the amount of precipitation have been recorded, the fluviometric regime, i.e. annual distribution, is disturbed to a considerable extent. Due to the increased intensity of precipitation and its increased variability as well as the increased share of heavy rains in the overall level of rainfall, the risk of soil erosion and floods is also increased. This is also confirmed by Bašić *et al*. (2016). The pronounced change of the annual distribution of precipitation along with the increased temperature constitutes one of the key factors causing more frequent and more intensive occurrences of drought, soil erosion and floods, especially in Mediterranean region of B&H – Neretva and Trebisnjica rivers basin. Average of water balance are shown in Fig. 7. Soil water deficit is present in this part of B&H from early May to the second half of September, where the deficits are highest from mid-June to mid-August.

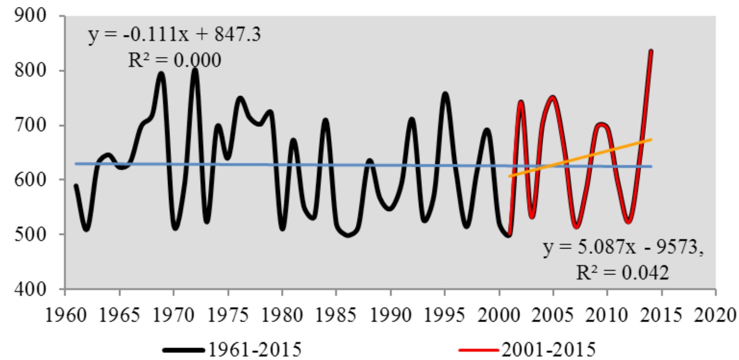

Fig. 4. Mostar – actual evapotranspiration (AET) (mm)

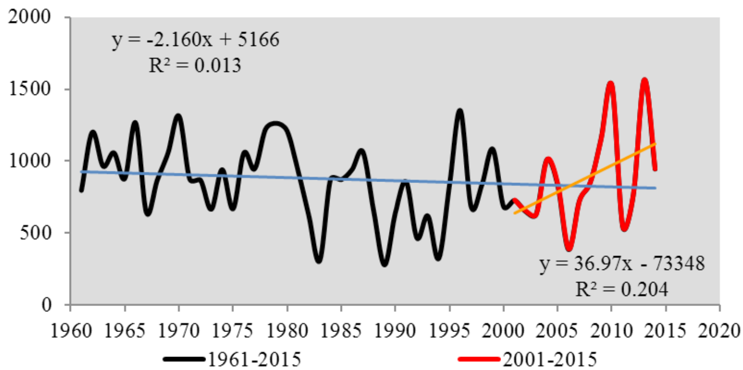

Fig. 5. Mostar – water surplus (S) (mm)

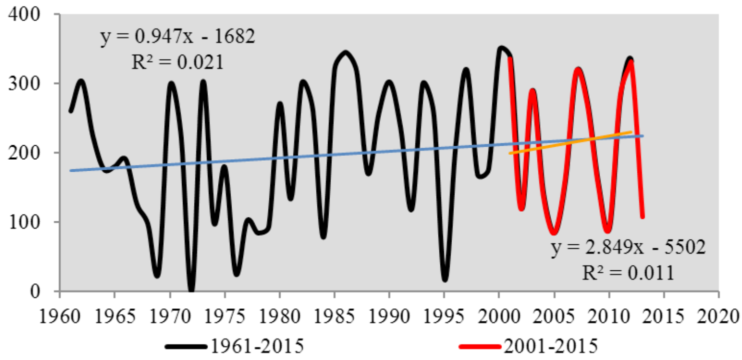

Fig. 6. Mostar – deficit of water (D) (mm)

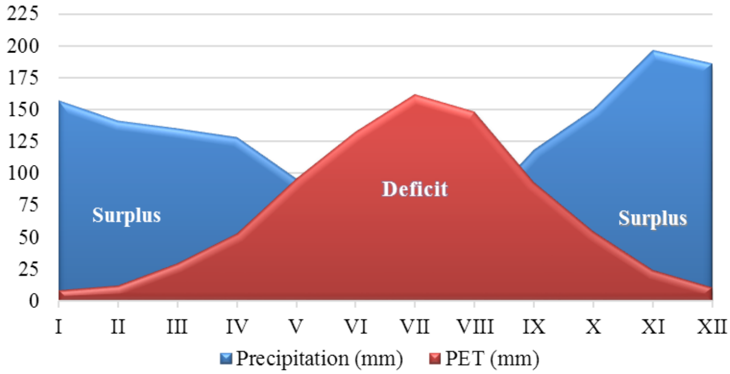

Fig. 7. Mostar – average water balance (1960–1990)

Comparison of the mean annual previous, rank 1/10 years and predicted hydrological parameters

The previous mean annual data are the result of the long-term series of soil water budgeting recorded month by month, year by year continuously through the period of 54 years for Mostar and 60 years for Trebinje. Predicted data are calculated on the basis of precipitation decrease (25%) and air temperature increase (2.0°C) for the calculation of PET increase. The soil water available reserve (R) is not changed. The change of two hydrological parameters (precipitation-P and potential evapotranspiration-PET) input has resulted in the change of the hydrological parameters received. The results of change are given in comparative form in Table 2. Comparison of mean annual long term previous and predicted hydrological parameters shows the following changes in the hydrological structure relations of the Mediterranean region of B&H:

– potential evapotranspiration increased in both locations by about 7.7%,
– in Mostar, real evapotranspiration decreased from 627 to 583 mm (7.01%),
– in Trebinje, real evapotranspiration decreased from 625 to 575 mm (8.0%),

– in Mostar, water deficit increased from 196 to 303 mm (54.6%),

– in Trebinje, water deficit increased from 179 to 291 mm (62.6%),

– seasonal occurrence of water deficit (drought) was not changed (July and August), whereas the intensity of drought and erosion risk was changed in both locations,

– in Mostar, water surplus decreased from 871 to 696 mm (20.09%),

– in Trebinje, water surplus decreased from 1,057 to 666 (36.9%),

– drought effect coefficient (RET/PET) was changed from 0.76 to 0.66 in Mostar and in Trebinje from 0.78 to 0.66,

– coefficients of outflow (S/P) was changed from 0.58 to 0.62 in Mostar and from 0.63 to 0.53 in Trebinje,

– trend of previous annual precipitation in Trebinje shows the light increase which is in contrast to prediction, but in Mostar, it shows a slight decrease. Both trends, however, are not completely reliable because the coefficient of determination is very low and scattering of points around the trend line is very high.

Table 2. Comparison of mean annual long term previous, rank 1/10 years and predicted hydrological parameters (all parameters are in mm)

	Mostar (1961–2015)			Trebinje (1955–2015)		
Hydrological parameters	Main previous	Rank 1/10	Predicted mean	Main previous	Rank 1/10	Predicted mean
Precipitation	1,495	2,188	1,121	1,677	2,090	1,258
Precipitation in vegetation period	534			564		
Potential ET	823	856	886	804	833	866
Real ET	627	535	583	625	777	575
Water deficit	196	321	303	179	321	291
Water surplus	871	1,268	696	1,057	1,443	666

CONCLUSIONS

The science in the last fifty years has radically changed its statement about climate change (Weart 2003, cited by Bonacci 2003). In the 1950s, it was stated that it takes several thousands of years for the climate change to be established. The perceptions adopted in the 1980s and 1990s are reduced to one century, but in the new millennium, this period was reduced to a few decades. Climate change is evident in B&H which constituted the basis for this research into soil water balance and agricultural production. The predicted PET was based on an air temperature increase by 2°C and a predicted decrease in precipitation by 25%. This research of water balance of the Mediterranean region of B&H in Trebinje (1955–2015) and Mostar (1961–2015) has shown that predicted precipitation by the 25% decrease applied in this research is overestimated. The previous results concerning the trends of annual precipitation could not confirm that because in Trebinje we have found the reverse situation, i.e. the increasing trend of annual precipitation with the higher coefficient of determination than in Mostar, which is characterized by a slight decrease of annual precipitation. The previous potential evapotranspiration shows a slight decrease which is also in contrast to the prediction.

However, expected increase of the temperature and evapotranspiration in the future will increase water deficit in both locations which in consequence will cause negative effects on agriculture (crops and plantations) of the Mediterranean region of B&H. Therefore, it will be necessary to introduce more "winter crops" (wheat, rye, winter peas, oil rape) in crop rotation (rain-fed agriculture, dry farming system) and to implement new technologies and drought resistant crops, plant species and varieties as well as soil conservation practices (tillage practices, location (direction) of plots, and/or terracing, etc.). However, we have to bear in mind the fact that this information is the result of average data calculation. The variability of hydrological parameters is very high and it is possible to expect the extreme and more inconvenient results in the future.

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