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AGRO-ECOLOGICAL CHARACTERISTICS OF KARST REGIONS IN BOSNIA & HERZEGOVINA AND CLIMATE CHANGE

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Original scientific paper

Summary

Climate change researches indicate a significant increase in air temperature at the global level, while the annual precipitation shows a trend of decreased precipitation in the Mediterranean region. However, the local climate variability should be viewed as a consequence of global change determined by local impacts (latitude and longitude; topography; the impact of sea and altitude).

In this paper agro-ecological characteristics of two individual regions namely the area of high karst with karst fields, and the area of low-Herzegovina area were analyzed. The analysis of climate change and variability covers representative weather stations of the observed regions: Livno, Mostar, and Trebinje. Short-term scenarios on climate change for these two regions for the period 2011-2040 (scenario RCP8.5, scenario A2, scenario A1B) were presented.

The analysis of data shows that in the southern parts of Bosnia and Herzegovina, a higher level of climate variability is manifested. In particular, extremely high temperatures and solar radiation during the summer months, early moving of vegetation, the extension of dry periods during the early fall, while high rainfall occurred during the late fall and winter period. It creates many problems especially in the agricultural sector, so adaptation measures have to be developed focusing especially on the development of soil water management strategy.

Key words: *karst, the Mediterranean region, climate change, agro-ecological areas, scenarios*

INTRODUCTION

The goal of every agro-climatic zoning is to determine the requirements of individual crops (plant) varieties, and types of soils in relation to agro-climate indicators to diagnose a level of their adaptability to light, temperature, precipitation, and relative humidity.

There are four agro-ecological areas in Bosnia and Herzegovina (B&H) (Čustović *et al.*, 2016): high karst area with karst fields, low-Herzegovina area (including the upper

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course of the Neretva River and karst fields), a central highland area with river valleys and lowland hilly area (including serpentine zones and flysch) (Figure 1.).

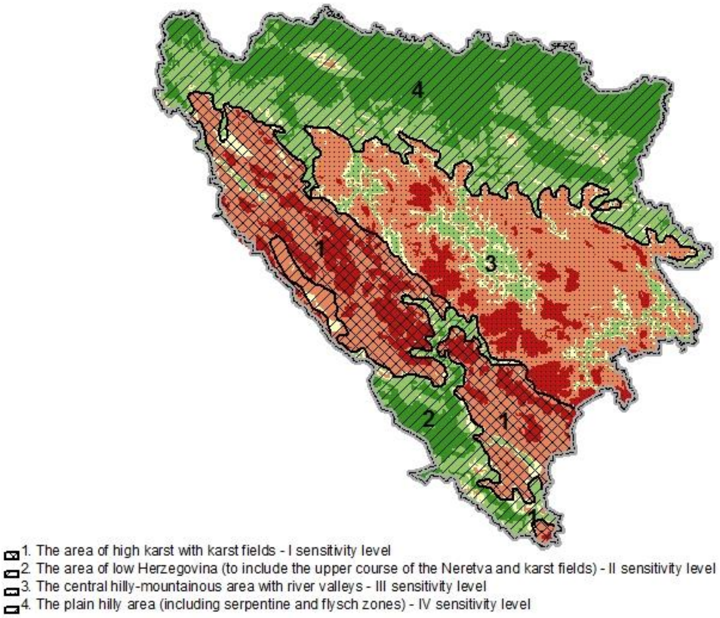

Figure 1. Agro-ecological areas in B&H
Source: H. Čustović, PAM Institute, Faculty of Agricultural and Food Science University of Sarajevo

The frequency and intensity of droughts have increased in some regions including the Mediterranean (IPCC, 2019). Average temperatures in the Mediterranean region have already risen by 1.4°C since the pre-industrial era, while summer rainfall is at risk of being reduced by 10 to 30% (JRC, 2018). Above 1.5°C, an expansion of desert terrain and vegetation would occur in the Mediterranean biome (IPCC, 2019).

The Mediterranean region is one of the regions where the strongest warming of hot extremes is projected. 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 (IPCC, 2018; 2019).

The effect of warmer temperatures on evapotranspiration, together with the decline in precipitation will make the region drier. Climate change is already affecting the region from both the physical and the economic point of view. The countries face a complicated problem: a growing risk of damages caused by meteorological, hydrological, and climate extremes and catastrophes as well as, at the same time, a high poverty rate and the necessity for economic development.

Water availability in the Mediterranean Basin will reduce as a consequence of three main factors: (i) precipitation decrease, (ii) temperature increase, and (iii) population growth (MedEEC, 2019).

Predicted climate changes will have a direct impact on Mediterranean agriculture.

MATERIALS AND METHODS

The analysis of climate change and variability covers representative weather stations of the observed regions in B&H: Livno, Mostar, and Trebinje. The analysis examined the linear trends of annual and seasonal levels of basic meteorological parameters, air temperature, precipitation as well as the trends during the growing season in the period 1961-2014. On the recommendation of the Commission for Climatology – Technical note - WCDMP-No 72 WMO-TD No 1500, both temperature and precipitation extremes were analyzed.

Wet and dry periods were analyzed using the method of the Standardized Precipitation Index (SPI). The analysis includes all dry (SPI ≤ -1) and wet (SPI ≥ 1) values of the particular timeline (SPI 3, SPI 6, and SPI 12).

Within the analysis of the general characteristics of two individual regions (the area of high karst with karst fields, and the area of low Herzegovina region) including the climate, short-term scenarios on climate change for the period 2011-2040 (scenario RCP8.5, scenario A2, scenario A1B) will be presented. This represents an important indicator of the need to adapt agriculture by sectors.

RESULTS AND DISCUSSION

Characteristics of the area of high karst with karst fields

This is a mountainous region more than 800 m above sea level, which encompasses a significant number of high mountains extending in the Dinaric direction (NW-SE) and with pronounced relief forms and inclinations. Basic features of the Dinarids relief include deep river valleys and canyons, vast karst fields and mountain ranges whose altitude goes from 1,000 to the highest peak of Maglić at 2,386 m (Čičić, 2002, cit. Čustović *et al*., 2016).

Mountain climate dominates over this agro-ecological area but also there is a presence of pre-mountainous and Mediterranean climate. Mountainous climate is distinguished by fresh and short summers and cold and snowy winters. The average temperature in January varies from -3.5° to -6.8°C while in July it averages from 14.8° to 16.9°C. The absolute minimum temperature is from -4° to -34°C while the absolute maximum is from 30° to 36°C. Transitional seasons (spring and fall) are poorly expressed. Temperature inversions occur in basins. Temperature amplitudes range from 20° to 21°C. Autumn is warmer than spring. Precipitation is equally distributed. Annual insolation in the central mountain area amounts to 1,700-1,900 hours. Due to frequent fogs during cold periods of the year, solar radiation is lower inland than at the same altitude in the coastal region. The duration of the vegetation period with the mean temperature of 10°C on average lasts from April to September and amounts to 195 days with an average temperature sum of 3,012°C.

All soils of this area are highly sensitive and vulnerable with regard to conditions under which they are being formed and also given the pedogenic factors' character. Reasons for this lay in their shallowness or direct exposure to waters in karst underground.
Karst fields are enclosed karst valleys like a green oasis in the karstic grey. The sloped terrain of the surrounding mountains is covered mostly by very shallow soils with pasture vegetation, shrubbery, and degraded forests, which is exposed to strong erosion and denudation processes. Activities in the higher areas have a direct effect on the state of soil in karst fields and ground waters.

Observed climate change

Air temperatures

In the area of high karst with karst fields, there is an increasing trend in annual air temperature, particularly pronounced in the summer period. The following charts depict deviation of mean annual air temperatures for the total period (1961-2014) from the means for the period 1961-1990, moving means and the trend for the total period available for the stations Livno and Trebinje.

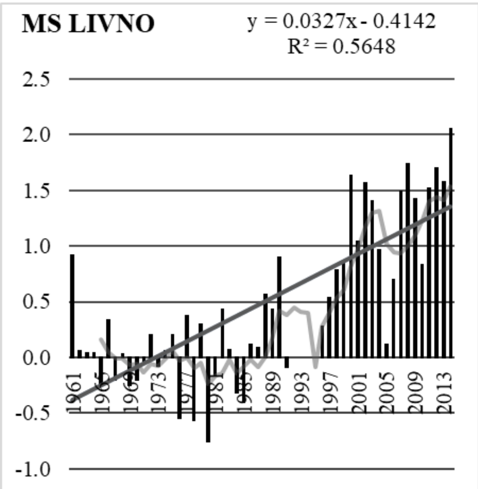

Chart 1. Deviation of mean annual air temperatures for the station Livno
Grafikon 1. Odstupanje srednjih godišnjih temperatura zraka za stanicu Livno

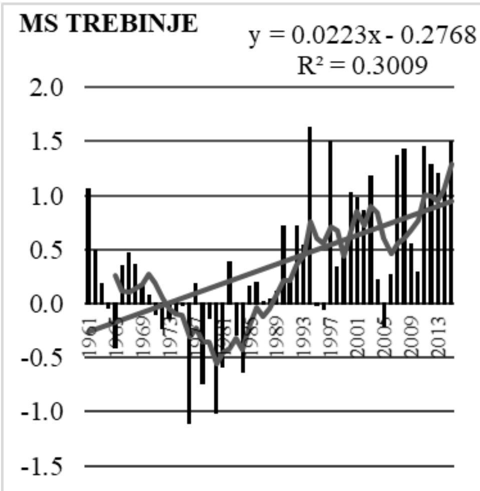

Chart 2. Deviation of mean annual air temperatures for the station Trebinje
Grafikon 2. Odstupanje srednjih godišnjih temperatura zraka za stanicu Trebinje

As can be seen from Table 1., all trends are positive, but the biggest trend is in summer which in Livno amounts to 0.5°C /10 yr and in Trebinje 0.4°C /10 yr. The smallest trends in Trebinje are in the autumn and winter, while those in the spring and summer are more significant. In Livno, the trends are bigger in all seasons except autumn. An increase in mean maximum and mean minimum temperatures were noticed.

Table 1. Seasonal values of the temperature trend for the period 1961-2014 for stations Trebinje and Livno
Tabela 1. Trendovi temperatura u sezonama za period 1961-2014 za stanice Trebinje i Livno

Trend temperature (°C)	Trebinje	Livno
Winter	0,0074	0,026
Spring	0,0217	0,0308
Summer	0,0497	0,055
Autumn	0,0068	0,0186
Year	0,0223	0,0326
Vegetation period	0,033	0,0404

Temperature extremes
The analysis of temperature extremes shows that the biggest changes occurred in the number of cold days (Tmin < 0,0°C) and the number of warm days (Tmax ≥ 25,0°C). In Livno, the number of warm days has a positive trend, it is statistically significant and the increase ranges up to 7 days per 10 years. The number of cold days has a negative trend and has been reduced by 2 days per 10 years in Livno. The number of cold nights (Tn10%) and cold days (Tx10%) has a negative trend and is getting reduced by 1 to 2 days per 10 years. The number of warm nights (Tn90%) and warm days (Tn90%) has a statistically significant positive trend, growing 3 to 5 days per 10 years.

Precipitation
Changes in the seasonal distribution of precipitation within one year compared to the „fundamental" period are reflected in a deficit of precipitation during the summer months. In this area, there is a change, i.e. an increase in precipitation during the spring and winter and a decrease during the summer. Changes in the seasonal distribution of precipitation within one year compared to the „fundamental" period are reflected in a deficit of precipitation during the summer months. In this area, there is a change, i.e. an increase in precipitation during the spring and winter and a decrease during the summer.

Dry and wet periods
In Livno, a linear trend for all drought (SPI 3 ≤ -1) values and wet (SPI ≥ 1) values have a positive trend. In a multi-year period (1961-2014), the last decade had an increased number of extreme weather events with their intensification. There is a pronounced trend of rapid alternation of extreme wet and dry situations, especially

from 2000 onwards. In addition to dry summers, the number of wet summers has also increased which indicates a high variability of precipitation over the last decade.

Climate change scenario

Given the scenario RCP8.5[4] for the period 2011-2040 at the annual level, changes of mean seasonal and annual accumulated precipitation indicate that this zone has a predominant change or increased precipitation of +5% and a predominant reduction of precipitation of -5% in the part of the zone gravitating towards Trebinje. According to the same scenario, the change in mean annual temperature shows an alternation or an increase of 1.8-2°C.

Following the scenario A2 for the period 2011-2040 at the annual level, changes of mean seasonal and annual accumulated precipitation mainly indicate positive precipitation changes of +5%. By this scenario, in the period 2011-2040, the temperature is increased by 0.8-1°C.

Given the scenario A1B for the period 2011-2040 at the annual level, changes of mean seasonal and annual accumulated precipitation indicate that the precipitation alternation varies from -5% to -20%. The change from -5% to -10% dominates the area of high Dinarides. In a part that gravitates towards Trebinje, the change is from -10% to -20%. The temperature in this scenario increases by 0.8 -1°C.

The area of Low Herzegovina (including the upper course of the Neretva and karst fields)

Characteristics of area

The area of low Herzegovina is known as low, Mediterranean Herzegovina, and it encompasses the upper course of the Neretva river, the hinterland reaching Posušje, Stolac, Bileća and Livanjsko field which is the world largest karst field and is located at the transition zone towards the high karst. The entire area is crisscrossed by hillocks, hills, and other relief forms at an altitude ranging between 500 and 700 m.a.s.l. It accounts for about 10% of the total area of B&H and is surrounded by mountains such as Trtla, Viduša, Ivan, etc., and karst fields on the upper terraces such as Mostarsko blato, Bekijsko polje, Kočerinsko, Dabarsko, and many other smaller fields and plateaus. In the canyon of the Neretva River, represented are the sediment alluvial and colluvial-diluvial deposits in the Bijelo and Bišće fields, Hutovo Blato, as well as some smaller fields in the delta of the Neretva to Metković. In the very south of B&H, in the valley of the Trebišnjica River, there are Trebinjsko and Popovo fields. This area, just like the above mentioned one, is characterized by pronounced karstic erosion along with other karst phenomena. Fields are semi-enclosed or enclosed, and their hydrological regime is regulated by the capacity of sinking zones to receive surplus rainfall in the fall and winter period.

This agro-ecological area is dominated by two types of climate: the Mediterranean and the altered Mediterranean climate. A significant feature of this terrain is karst and its terraces descending from the mountain tops to the sea so that in the summer the bare

[4] A scenario of comparatively high greenhouse gas emission

karst has a visible impact on the climate elements, especially on the temperature. Low-Herzegovina area is under the direct influence of the Adriatic Sea. During the wintertime, it radiates heat collected during summer causing a significant increase in winter temperatures. The average January temperature ranges from 3 to 5°C. Summers are very hot and dry and with absolute maximum temperatures of 40-45°C. The mean annual temperature is 12-15°C while the absolute minimum can drop to -17°C. The duration of the vegetation period with a mean temperature of 10°C generally lasts 239 days with an average temperature sum of around 4,464°C. The area of Herzegovina and the highest central parts of B&H are normally exposed to humid mass from the south, their maritime pluviometric regime is pronounced and they receive up to 2,000 mm of rainfall per year. Maximum rainfall occurs mostly in late fall or early winter, i.e. November or December. Snow is almost nonexistent. The characteristic wind of the Mediterranean climate region is bora. Bora is most pronounced in the area of Mostar where the annual average wind speed is 3.3 m/s. In all periods of the year, the occurrence of storm-scale values is possible but usually, they are most frequent during colder periods of the year. Bora occurs often in the fall and spring when it is highly unfavorable for vegetation. Anticyclone storm is characterized by gusts of wind 30-37 m/s, while winds with the strength over 17.2 m/s^2 are registered 5-10 times a year. The probability of maximum wind speed occurrence of 44 m/s^2 is once in every 50 years.

The modified Mediterranean climate which transcends into the Mediterranean climate of low-Herzegovina includes characteristics of the Mediterranean climate during summer and mountain climate during winter. The transitional variations are typical during the autumn and spring period. The features of the Mediterranean climate are reflected in highly arid climate during most of the vegetation season.

This phenomenon is even more complex due to the character of arid pedo-climate on shallow soils, skeletal and porous substrates.

In this area of higher Herzegovina and southwestern mountains, the climate is approaching towards mountainous but with Mediterranean features. Air temperature decreases with increased altitude and distance from the sea. For every 10 km away from the sea, the temperature decreases 0.6° to 0.8°C. Winters are harsh with the absolute minimum temperatures of -14° to -25°C. Average January temperatures range from -1.8° to -6°C. The average of the absolute maximum temperature may rise to 40°C. There is up to 1,800 mm of rainfall in this area annually. Bora is most expresses in winter. Cloudiness is increased compared to low-Herzegovina. Insolation (solar radiation) decreases going from the Adriatic Sea towards inland and at higher altitudes. In the southern regions, there are 1,900-2,300 hours of sunshine. In Mostar, the amount is 2,285 hours per year. Often occurrence of draughts is related to the vegetation period when plants are in the biggest need of water, which harms agricultural production. On the other hand, there is a problem of floods and long periods of waterlogging lasting from autumn until spring. This makes the situation even more difficult. Agriculture is relatively intense especially along rivers Neretva and Trebišnjica which is why there is a sporadic occurrence of secondary soil salinization due to irrigation. Regional hydrology is of great importance since fields are sensitive ecological systems open to external influences.

Observed climate change

Air temperatures

In the area of Low-Herzegovina including the upper course of the river Neretva and karst fields, there is an upward trend in annual air temperature as well as the highest average increase in air temperature during the summer season. The following charts depict deviation of mean annual air temperatures and summer season for the total period (1961-2014) from the mean for the period 1961-1990, moving means and the trend for the total period available as well as deviations for the summer season.

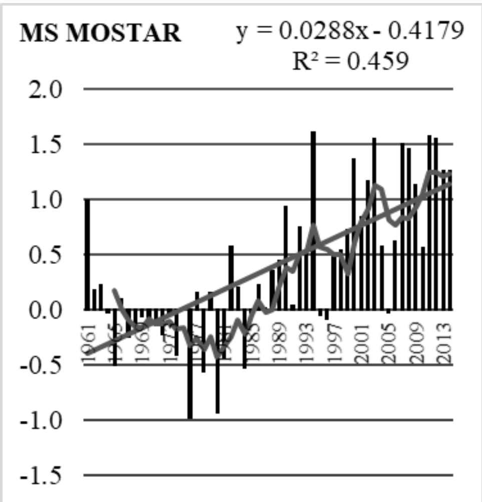

Chart 3. Deviation of mean annual air temperatures for the station Mostar
Grafikon 3. Odstupanje srednjih godišnjih temperatura zraka za stanicu Mostar

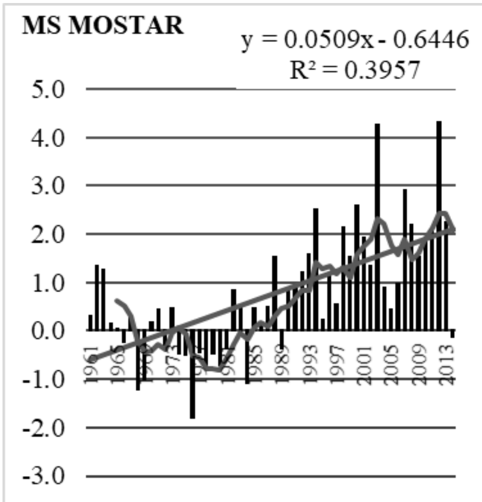

Chart 3. Deviation of mean annual air temperatures in summer season for the station Mostar
Grafikon 3. Odstupanje srednjih godišnjih temperatura zraka u ljetnom period za stanicu Mostar

Seasonal values of the trend for the period 1961-2014 are presented in the Table 2.

Table 2. Seasonal values of the trend for the period 1961-2014 for station Mostar
Tabela 2. Trendovi temperatura u sezonama za period 1961-2014 za stanicu Mostar

Trend temperature (°C) 1961-2014	Mostar
Winter	0,0227
Spring	0,033
Winter	0,0509
Autumn	0,0115
Year	0,0287
Vegetation period	0,0373

As can be seen from the table, all trends are positive, but the biggest trend is in summer which in Mostar amounts to 0.5°C / 10 yr. An increase in mean maximum and mean minimum temperatures have been observed. Analyzed were also the annual trends of temperature sums ≥ 5°C. In the south of the country, the average temperature sums ≥ 5°C amount to 3,400 – 3,700°C. The average annual temperature sums above 10°C in the south of the country range from 1,900 to 2,300°C. The linear trends in annual temperature sum for the thresholds of 5 and 10°C are positive.

Temperature extremes

The analysis of temperature extremes shows that the biggest changes occurred in the number of cold days (Tmin < 0.0°C) and the number of warm days (Tmax ≥ 25.0°C). At the meteorological stations in Mostar, the number of warm days (SU) has a positive trend, statistically significant and the increase ranges up to 3 days per 10 years. In Mostar, the number of cold days (FD) has a negative trend and gets reduced by 2 days per 10 years. The number of cold nights (Tn10%) and cold days (Tx10%) has a negative trend and is getting reduced by 1 to 2 days per 10 years. The number of warm nights (Tn90%) and warm days (Tn90%) has a statistically significant positive trend, growing 3 to 5 days per 10 years.

Precipitation

Trends of annual precipitation for a series of 1961-2014 indicate a reduction in the amount of precipitation by up to 20% in the south of the country. A negative trend in precipitation was recorded in Mostar for all seasons except autumn.

Table 3. Trends of precipitation for the period 1961-2014 for station Mostar
Tabela 3. Trendovi padavina u periodu 1961-2014 za stanicu Mostar

Trend precipitation (mm) 1961-2014	Mostar
Winter	-0,9141
Spring	-0,5159
Summer	-0,6459
Autumn	0,0517
Year	-2,0242
Vegetation period	0,5712

Changes in seasonal distribution within one year compared to the „fundamental" period are reflected in a deficit of precipitation during the summer months. Although the trend in precipitation during the vegetation period is positive, the distribution is uneven, thus in the summer months, we have a pronounced occurrence of deficit and increasingly frequent dry periods that largely determine the agricultural production.

Dry and wet periods

In Mostar, linear trend for all drought (SPI 3 ≤ -1) values is positive and for wet (SPI ≥ 1) values it is negative. In a multi-year period (1961-2014), the last decade had an increased number of extreme weather events with their intensification. There is a pronounced trend of rapid alternation of wet and dry extreme situations, especially from 2000 onwards. In addition to dry summers, the number of wet summers has also increased which indicates a high variability of precipitation over the last decade.

Climate change scenario

Given the scenario RCP8.5 for the period 2011-2040 at the annual level, changes of mean seasonal and mean annual accumulated precipitations indicate that this zone has a predominant precipitation increase of +5% (Neretva valley), and a predominant decrease of -5% in the part of the zone gravitating towards Trebinje. According to the same scenario, the change in mean annual temperature indicates an increase of 1.6-2°C.

Given the scenario A2 for the period 2011-2040 at the annual level, changes in mean seasonal and mean annual accumulated precipitation mostly show negative precipitation change of -5% apart from the smaller area of the upper course of the Neretva river presenting the change of +5%. According to this scenario, the change in mean annual temperature amounts to 0.8-1°C.

Because of the A1B, the change of mean seasonal and mean annual accumulated precipitation ranges from -10% to -20%. According to the scenario A1B during the period 2011-2040, the increase in the temperature will achieve 0.8-1°C.

CONCLUSIONS

Karst regions in B&H, namely the area of high karst with karst fields, and the area of low Herzegovina region, are affected by global climate change. There is an evident increase in extreme maximum temperatures in the summer months, so due to hot weather the plants suffer from drought and unless agro-technical measures (irrigation) are implemented, production becomes ever more precarious. The lack of rainfall during the summer months and increased evapotranspiration combined with high temperatures causes heat stress in plants resulting in a reduction or loss of yield.

Particular attention should be paid to the problem of erosion and, in that way, ensure the sustainable management of these soils through the implementation of good agricultural practices, rational use of forest resources, properly organized grazing and improvement of the state of pastures, as well as taking the necessary preventive measures and practices to prevent fire. Additionally, it is necessary to plan the expansion of protected areas with different levels of protection, depending on the degree of sensitivity to degradation as a result of climate change and human activities.

The need for planning and implementation of appropriate measures of adaptation to climate change is evident.

However, we need to accept a new perception and to develop a strategy for the soil water management which is a large, long-term, and very complicated task.

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AGROEKOLOŠKE KARAKTERISTIKE KARSTNIH PODRUČJA BOSNE I HERCEGOVINE I KLIMATSKE PROMJENE

Rezime

Istraživanja klimatskih promjena ukazuju na značajan porast temperature zraka na globalnom nivou, dok godišnje padavine pokazuju trend smanjenja u mediteranskoj regiji. Međutim, lokalnu klimatsku varijabilnost treba posmatrati kao posljedicu globalnih promjena određenu lokalnim uticajima (geografska širina i dužina, topografija, uticaj mora i nadmorske visine).
U ovom radu analizirane su agro-ekološke karakteristike dva područja: područje visokog krša sa kraškim poljima i područje niske Hercegovine. Analiza klimatskih promjena i varijabilnosti zasniva se na podacima reprezentativnih meteoroloških stanica u posmatranim područjima: Livno, Mostar i Trebinje. Predstavljeni su kratkoročni scenariji o klimatskim promjenama za ova dva područja za period 2011-2040. godina (scenarij RCP8.5, scenarij A2, scenarij A1B).
Analizirani podaci pokazuju jasno povećanje varijabilnosti klime u južnim dijelovima Bosne i Hercegovine. Posebno se to odnosi na izuzetno visoke temperature i sunčevo zračenje tokom ljetnih mjeseci, raniji početak vegetacije, produženje sušnih perioda tokom rane jeseni, dok su se velike kiše javljale u kasnoj jeseni i zimskom periodu. To stvara mnoge probleme posebno u poljoprivrednom sektoru, tako da se moraju razviti mjere adaptacije usmjerene posebno na razvoj strategije upravljanja vodom u tlu.

Ključne riječi: *krš, mediteransko područje, klimatske promjene, agro-ekološka područja, scenariji*