Spatio-Temporal Climate and Agroclimate Diversities over the Zagreb City Area

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Abstract

The Zagreb city is rich in green urban infrastructure that has an important role in climate change mitigation and adaptation. Knowledge on climate change and agroclimate has an important role in planning of green areas. Therefore, the aim is to evaluate the temporal and spatial diversities of agroclimate indicators over Zagreb city. Warming and no change in mean annual precipitation, as well as prolonged vegetation periods and reduced evapotranspiration were observed at all locations in the recent 1991-2018 compared to reference 1961-1990 period. The results indicate different intensity in climate change of observed indicators and existance of diffrences in indicators between city centre, suburb and hilly slopes thatshould be considered while planning green urban infracture.

Keywords: agroclimate indicators; climate change; precipitation; temperature; hydrothermal conditions; water balance; Zagreb

Introduction

Green urban infrastructure has important role in the context of climate change mitigation and adaptation. According to Demuzere et al (2014) green urban infrastructure contributes to the physical, psychological and social benefits, i.e. CO_2 reduction, thermal comfort and reduced energy use, health and restorative benefits, social and individual coping capacities and education. Green urban infrastructure contributes to climate change mitigation by sequestration of atmospheric carbon into the soil and plant pool via the process of photosynthesis. Additional uptake can occur via below-ground biomass and soils (Velasco and Roth, 2010). Furthermore, urban ecosystems can have a role in climate change adaptation by reducing air and surface temperature as they provide shading (Takacs et al., 2016) and enhance the evapotranspiration that results in energy use reduction and improved thermal comfort (Bajšanski et al., 2015; Ongoma et al., 2016; Milošević et al., 2017a;). The vegetation in urban areas also affects air and water quality as it

absorbs pollutants. These services are relevant to urban areas for adapting to climate change and the dynamics of human requirements (Farrugia et al., 2013). Green urban infrastructure provides a range of recreational and psychological benefits, as well as opportunities for community education how to adapt to climate change.

The Zagreb city is in the inland region of Croatia which has a temperate continental climate (Zaninović et al., 2008). During the entire year it is in circulation belt of mid-latitude where the state of the atmosphere is very variable. It is marked by a variety of weather situations with frequent and intense changes during the year. They are caused by atmospheric systems of low or high air pressure, often like vortexes with diameter hundreds and thousands of kilometres. In the cold season, stationary anticyclonic weather types with foggy weather or low cloudiness with very low flow prevail. Summer is dominated by pressure fields with small pressure gradient accompanied by weak

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wind, but with unstable stratification of the atmosphere. Turbulent air mixing is very strong, convective clouds develop and the possibility of rain shower. Fast moving cyclonic weather types (cyclones and pressure troughs) are typical for spring leading to frequent and sudden changes of weather, and exchange of rainy periods and those with no rain. Local climate is is modified by the weak maritime influence of the Mediterranean, as well as by the orography of the Alps and the Dinaric Alps. Medvednica Mountain and the mountains in the NW part of Croatia - Hrvatsko Zagorje have the immediate influence. They facilitate the intensification of short-term heavy precipitation on the windward side of the orographic obstacle. Medvednica Mountain acts as a barrier to the northwest precipitation outbreaks and may cause short-term intensification of heavy precipitation or may create precipitation shadow in the eastern part of Zagreb (Gajić-Čapka, 1982; Gajić-Čapka and Cindrić, 2008; Sokol Jurković, 2011).

According to the Köppen climate classification, the area of Zagreb has a temperate rainy climate (Cfwbx") like most of Croatia (Penzar and Penzar, 2010). Zagreb area has average air temperature of 10.9 °C , apsolute maximal temperature of 40.4 °C, apsolute minimal temperature of -27.3 °C, precipitation amount of 859.4 mm, 6 number of days with snow and 11 number of days with frost in the period 1949-2018 (DHMZ, 2019).

The city of Zagreb is rich in green spaces: parks, gardens, park-forests, orchards and vineyards in the downtown and suburbs both in the lowlands and on the slopes of Medvednica Mountain (highest peak Sljeme – 1033 m a.s.l.). As climate and consequently agroclimate are important parts of the resource base for green urban horticulture, gardening, fruit and vine growing, the information and knowledge on climate as well as climate change should be incorporated into the strategic urban plans and the maintenance of existing green spaces. Therefore, the aim of the paper is to evaluate the temporal (1961-1990 and 1991-2018) and spatial (city centre, suburb and hilly slopes) variability of meteorological (air temperature, precipitation amount) and agroclimatic (rain factor, water balance, aridity index, cardinal temperatures) indicators over the Zagreb city area.

Data and methods

According to the recommendations of the World Meteorological Organization (WMO) Guide to Climatological Practices (WMO, 2011) and the WMO Technical Regulations (WMO, 2012) as well as the recommendation of the 16th Commission for Climatology (Commission for Climatology-CCl) with WMO in 2014, a 30-year data series is further used to display the climatic conditions. In doing so, the period 1961-1990 serves as a reference climatic period, especially in the analyses of climate change. In order to display the climatic conditions, later 30-year periods beginning with the year ending with the number 1: 1971-2000 and 1981-2010 can be used. This enables the spatial comparison of simultaneous climatic conditions at different locations or regions.

The present analysis deals with the comparison of two periods: the reference period 1961-1990 and the recent available 28 - year period 1991-2018 for the selected meteorological (air temperature and precipitation) as well as agroclimatic indicators (rain factor, cardi-
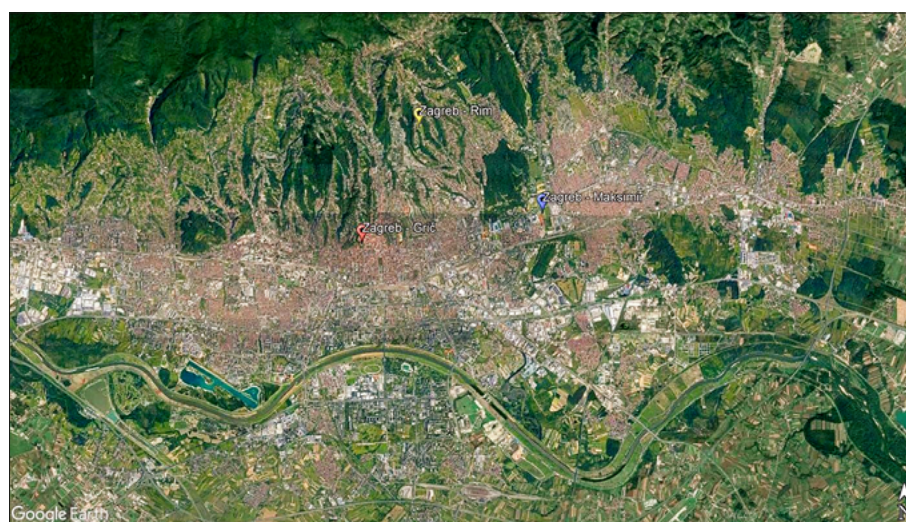

Figure 1. Locations of Zagreb-Grič (ZG), Zagreb-Maksimir (ZM) and Zagreb-Rim (ZR)
meteorological stations over the Zagreb city

nal temperatures, water balance and index of aridity) for three locations over the Zagreb city area. The data used in this research are obtained from meteorological stations that are part of the regular network of Meteorological and Hydrological Service of Croatia. Meteorological stations are categorized in adequate local climate zone according to Stewart and Oke (2012) based on the authors knowledge of local climate and urbanization characteristics. Zagreb-Grič (ZG) (H = 157 m a.s.l., ϕ = 45° 48′ 52″ N, λ = 15° 58′ 19″ E) is located in the upper town of the central urban part (local climate zone 6B), Zagreb-Maksimir (ZM) (H = 123 m a.s.l., ϕ = 45° 49′ 19″ N, λ = 16° 02′ 01″ E) in the eastern suburb where the urbanization takes place (local climate zone 8D), and Zagreb-Rim (ZR) (H = 220 m a.s.l., ϕ = 45° 50′ N, λ = 16° 00′ E) on the slopes of Medvednica Mountain that extends north of the city (local climate zone 9D). The locations of the meteorological stations are presented at Figure 1.

Overview of climate and agroclimatic conditions includes the average annual variation in observed parameters: air temperature, precipitation amount, rain factor, index of aridity and beginning and the end of the vegetation period for selected cardinal temperatures. This points to the seasonal changes of mean values. The Lang's rain factor (RF) and Gračanin's monthly rain factor (RFm) are calculated according to Gračanin (1950) and interpreted as presented in Bilandžija et al. (2019.):

$$RF = \frac{Py}{Ty} \qquad RFm = \frac{Pm}{Tm}$$

where:
- *Py* - annual rainfall amount (mm)
- *Ty* - average annual temperature (°C)
- *Pm* - monthly rainfall amount (mm)
- *Tm* - average monthly temperature (°C)

Thresholds of cardinal temperatures for the beginning and the end of vegetation periods with the temperatures above 5, 10, 15 and 20°C are calculated according to Butorac (1976):
The beginning of the period with temperature above cardinal (5, 10, 15 and 20°C):

$$n = \frac{Tb - Ta}{30} \qquad x = \frac{Tc - Ta}{n}$$

The end of the period with temperature above cardinal (5, 10, 15 and 20 °C):

$$n = \frac{Tb - Tc}{30} \qquad x = \frac{Tb - Tc}{n}$$

where:
- *Ta* – temperature at the beginning/end of the period closest to the cardinal but lower than it
- *Tb* – temperature (at the beginning/end of the period) closest to the cardinal but higher than it
- *Tc* – cardinal temperature (5, 10, 15 or 20 °C)
- *x* – number of days to be added to the middle of the month with temperature a (for the beginning of the period) or with temperature b (for the end of the period)

Water balance is calculated according to Thorntwhite method (Penzar and Penzar, 2000) and drought conditions were described by monthly index of aridity created by UNEP for numerical identification of desertification (UNEP, 1992; Perčec Tadić et al., 2013):

$$IAU = \frac{P}{PET}$$

where:
- *P* - precipitation (mm)
- *PET* - potential evapotranspiration according to Thorntwhite method (mm)

Results and discussion

Air temperature
According to the data from the recent 28-year period 1991-2018 average annual cycle of mean monthly temperatures has a shape of an one-strand wave with a maximum in summer, most often in July (ZG = 23.1°C, ZM = 22.2°C, ZR = 21.1°C) and minimum in winter, in January (ZG = 2.5°C, ZM = 1.4°C, ZR = 0.0°C) (Figure 2). Continental characteristics are prevailing in the annual cycle and they are reflected in the warmer spring than autumn, with a small differences, spring beeing warmer than autumn (ZG = 0.1°C, ZM = 0.1°C, ZR = 0.2°C). Average annual cycle of mean monthly temperatures at Zagreb-Grič (ZG) in the upper town of the central urban area is 0.7°C to 1.4°C warmer than monthly means at Zagreb-Maksimir (ZM) in the eastern suburb, open to the lowland towards the Sava River valley. On average annual and seasonal temperatures are about 1°C higher at ZG than ZM. The temperature differences between city centre (ZG) and hilly slopes (ZR) are less than 1°C, the slopes being colder on average. These differences are small. The suburb meteorological station ZM is open to the low-

land towards east and exposed to the cold air penetrations and radiation cooling in winter. Consequently, it shows on average the lowest seasonal and annual temperature values compared to the other two observed locations, ZG and ZR, which sites are equally exposed on hilly slopes.

According to the standard deviation values, temperature conditions are more stable from April to October (minimum in June and July, sd = 1.3°C at ZG, sd = 1.2°C at ZM and sd = 1.1°C at ZR) than in the cold part of the year from November to March (maximum in February, sd = 2.7°C at ZG and sd = 2.8°C at ZM and ZR). Interannual variability in annual as well as seasonal average temperatures is equal at all three locations (Table 1).

During the recent period 1991-2018 mean annual temperature cycles experienced warming in all months. Mean monthly values were above normal (reference monthly mean temperature increased by one standard deviation) for summer months at all three observed locations (ZG - June: 1.8°C, July: 1.8°C and August: 2.1°C; ZM - June: 2.1°C, July: 2.1°C and August: 2.4°C; ZR - June: 1.5°C, July: 1.4°C and August: 1.7°C) and also for April and May in the city centre (ZG – for both months 1.4°C) and suburb (ZM - for both months 1.6°C). Consequently mean summer temperatures and mean growing period temperatures as well as mean annual temperatures were above normal values at all locations. On average spring at ZG and autumn at ZM were also significantly warmer (Figure 2 and Table 1).

Warming was most pronounced at the suburb location (ZM) and it can be assumed that this was due to the expanded urbanisation (seasonally: 1.1°C to 2.2°C; in vegetation period 1.8°C and annually 1.6°C) (Table 1). In the city center (ZG) it became warmer on average for seasons 0.9°C to 1.9°C, in vegetation period 1.5°C and annually 1.4°C. The weakest warming was detected at the city slopes at the foot of the Medvednica Mountain (ZR): seasonally 0.4°C to 1.5°C, in vegetation period 1.1°C and annually 1.0°C.

Considering the ten warmest years from the entire period 1961-2018 (58 years), 9 of them were recorded in the 21st century at ZG and ZR and all of them at ZM. Of the ten warmest growing seasons all of them are recorded in the 21st century.

The warming that was identified for seasonal and annual mean values over the Zagreb area is also characteristic for the entire Croatia (Zaninović and Cindrić, 2014). The more detailed study of the trend analysis in mean and extreme annual and seasonal temperatures, as well as in the indices of temperature
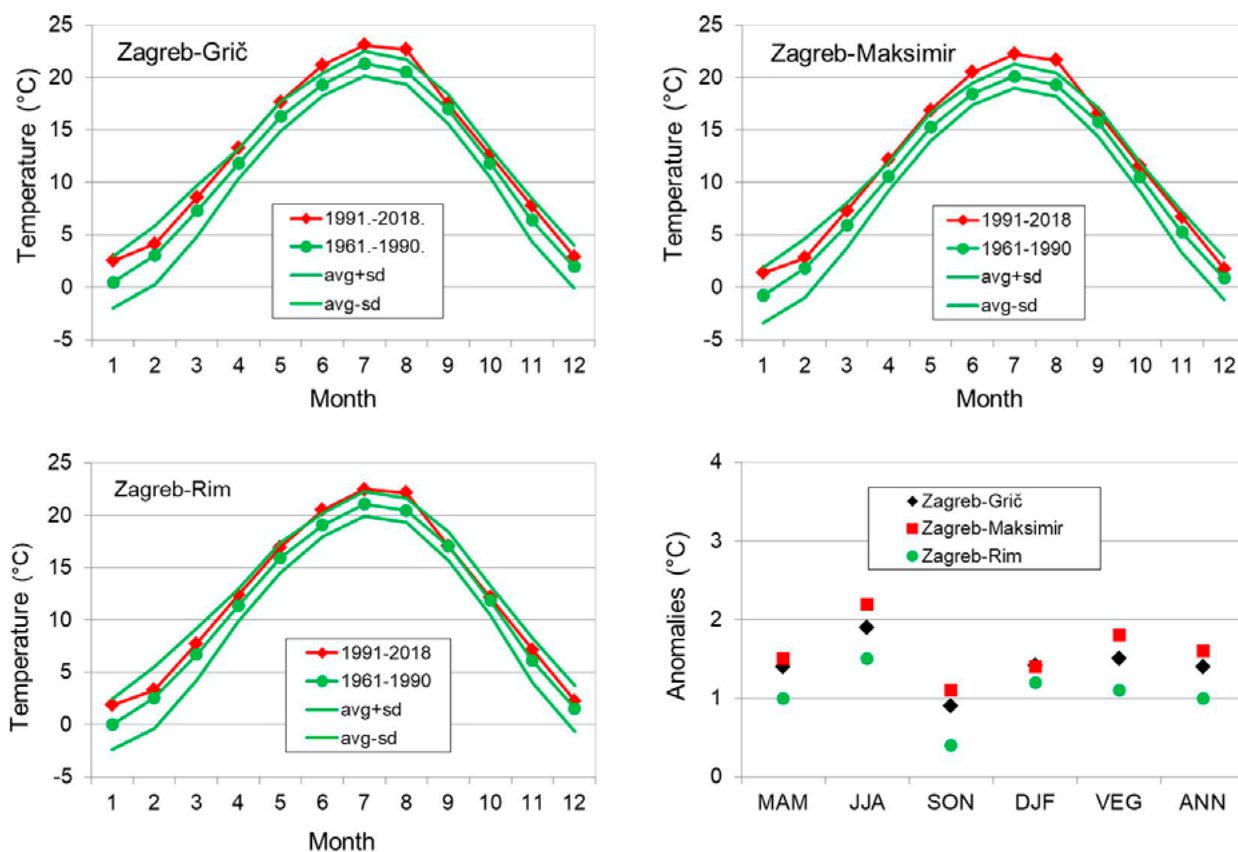

Figure 2. Average monthly air temperature values (avg) for the periods 1991-2018 and 1961-1990, and the intervals avg+sd and avg-sd for the 1961-1990 period (left and right up). Anomalies (°C) in mean seasonal, vegetation period and annual temperatures for the period 1991-2018 calculated with respect to the 1961–1990 average (right down)

Table 1. Basic statistics for seasonal. vegetation period and annual air temperature (°C) and anomalies (°C) in mean seasonal. vegetation period and annual temperatures for the period 1991-2018 calculated with respect to the 1961–1990 average

Zagreb-Grič (157 m a.s.l.) – city centre												
	1961-1990						1991-2018					
	MAM	JJA	SON	DJF	VEG	ANN	MAM	JJA	SON	DJF	VEG	ANN
avg	11.8	20.4	11.8	1.8	17.7	11.5	13.2	22.3	12.6	3.2	19.2	12.8
sd	1.1	0.6	1.0	1.8	0.6	0.6	1.0	1.1	1.0	1.6	1.0	0.8
max	13.5	21.7	13.8	4.6	19.0	12.5	15.0	24.6	14.4	6.9	21.3	14.1
min	9.9	19.1	9.7	-2.9	16.3	10.4	11.3	20.6	10.8	0.9	17.6	11.0
Zagreb-Maksimir (123 m a.s.l.) - suburb												
	1961-1990						1991-2018					
	MAM	JJA	SON	DJF	VEG	ANN	MAM	JJA	SON	DJF	VEG	ANN
avg	10.6	19.3	10.5	0.6	16.6	10.3	12.1	21.5	11.7	2.0	18.3	11.8
sd	0.9	0.6	1.0	1.8	0.6	0.5	1.0	1.0	1.0	1.5	0.9	0.8
max	12.3	20.6	12.3	3.2	17.9	11.2	13.6	24.0	13.3	5.8	20.1	13.0
min	9.0	17.9	8.7	-4.2	15.2	9.3	10.0	19.9	9.9	-0.2	16.7	10.1
Zagreb-Rim (220 m a.s.l.) - slope												
	1961-1990						1991-2018					
	MAM	JJA	SON	DJF	VEG	ANN	MAM	JJA	SON	DJF	VEG	ANN
avg	11.4	20.2	11.7	1.3	17.5	11.2	12.4	21.7	12.1	2.5	18.6	12.2
sd	1.1	0.6	1.0	1.8	0.6	0.6	1.0	1.0	1.0	1.6	0.9	0.8
max	13.3	21.5	13.9	4.4	18.8	12.3	13.9	24.1	14.1	6.1	20.6	13.3
min	9.3	18.9	9.5	-3.3	16.2	10.2	10.6	20.2	10.3	-0.2	17.2	10.4
Anomalies (1991-2018) in respect to (1961-1990)												
							MAM	JJA	SON	DJF	VEG	ANN
Zagreb-Grič							1.4	1.9	0.9	1.4	1.5	1.4
Zagreb-Maksimir							1.5	2.2	1.1	1.4	1.8	1.6
Zagreb-Rim							1.0	1.5	0.4	1.2	1.1	1.0

Abbreviations: MAM: March-May; JJA: June-August; SON: September-November; DJF: December-February; VEG: April-September; avg – average; sd-standard deviation; max-maximum; min-minimum. grey shaded-values above normal. anomalies: positive – increase

extremes for Croatia was performed for 41 meteorological stations uniformly distributed across Croatia and for the period 1961-2010. The annual air temperature increase is mainly caused by the significant positive summer trends, while the observed trends for winter and spring gave almost equal contribution to the increasing trends of mean maximum temperature. All trends of indices of warm temperature extremes are statistically significant. Warming is also evident in the observed negative trend in the indices of cold temperature extremes, but they are less expressed than the trends of warm indices.

The overall positive trends in annual air temperatures are also recorded for the area of Bosnia and Herzegovina, where the highest trend values are obtained for summer, and then for winter and spring temperatures, while autumn temperatures are subjected to small and mostly positive changes, though mainly insignificant (Trbić et al., 2017). The annual temperature increase in Bosnia and Herzegovina was in the range of 0.2–0.5°C per decade, the summer, winter and spring increase was in the range of respectively 0.5–0.6°C, 0.3–0.5°C and 0.2–0.4°C per decade (Trbić et al., 2017). Milošević et al. (2017b) obtained similar results for the Slovenia, where a significant increase in maximum temperature was observed at the annual scale (0.3-0.5°C·per decade). Considering the seasons, the warming was more intense in summer (0.4-0.7°C·per decade) and spring (0.4-0.6°C·per decade) and less intense in winter (0.2-0.6°C·per decade) and autumn (0.1-0.3°C·per decade) in Slovenia according to the authors.

Precipitation

According to the recent 28-year period 1991-2018, average annual cycle of mean monthly precipitation amounts has continental characteristics at all three locations. During the warm half-year (April to September) this area receives more precipitation than in

the cold half-year (on average 56% (ZG and ZR) namely 57% (ZM) of the annual total) (Figure 3, Table 2). Monthly maximum in annual course appears in September (ZG: 104.5 mm, ZM: 102.2 mm, ZR: 108.6 mm) and minimum in February (ZG: 49.2 mm, ZM: 45.8 mm, ZR: 51.7 mm) (Figure 3). Differences between monthly, seasonal and annual precipitation amounts at observed three locations are small but indicate the highest values on the slopes (ZR) and the lowest in the eastern suburb (ZM), which is often found in precipitation shadow for northwest precipitation penetrations. At the annual level the average amount is 2% higher in the city center than in the eastern suburb and 5% lower than on the slopes (ZR). Anomalies in monthly precipitation amounts for the recent period 1991-2018 in respect to the reference period for all three locations are similar and small and range between -16% to 9% per month except in September (29% to 30%) and in October (26% to 28%). As a consequence, average autumn amount experienced increase of 17% at ZG and ZR and 20% at ZM. Decrease (-12% to -2%) in spring, summer and growing season average precipitation, and no change or increase (up to 6%) in winter

and annual average amounts are present. Variability of seasonal and annual precipitation could be brought into relation with the large-scale atmospheric circulation. Europe climate is under the simultaneous effect of dominant North Atlantic Oscillation (NAO) and the generally weak impact of El Niño Southern Oscillation (ENSO) showing spatial and seasonal dependence (e.g. Herceg Bulić and Ivasić, 2019). At the same time for the Mediterranean region the Mediterranean oscillation (MO) and Western Mediterranean oscillation (WeMO) indices are also applied, as for example, in Milošević et al. (2016). Their results show that the influence of NAO on precipitation variability in Slovenia is smaller than the effects of atmospheric circulations belonging to the Mediterranean area (namely WeMO and MO). The trend analysis in seasonal and annual precipitation in Slovenia indicate the most expressed changes in spring (-6 to -10% per decade) and summer (-4 to -10% per decade) precipitation, which are of the same direction (decrease) as was indicated for Zagreb area (Milošević et al., 2016).

In some years there was a significant deviation in monthly amounts from the average precipitation con-
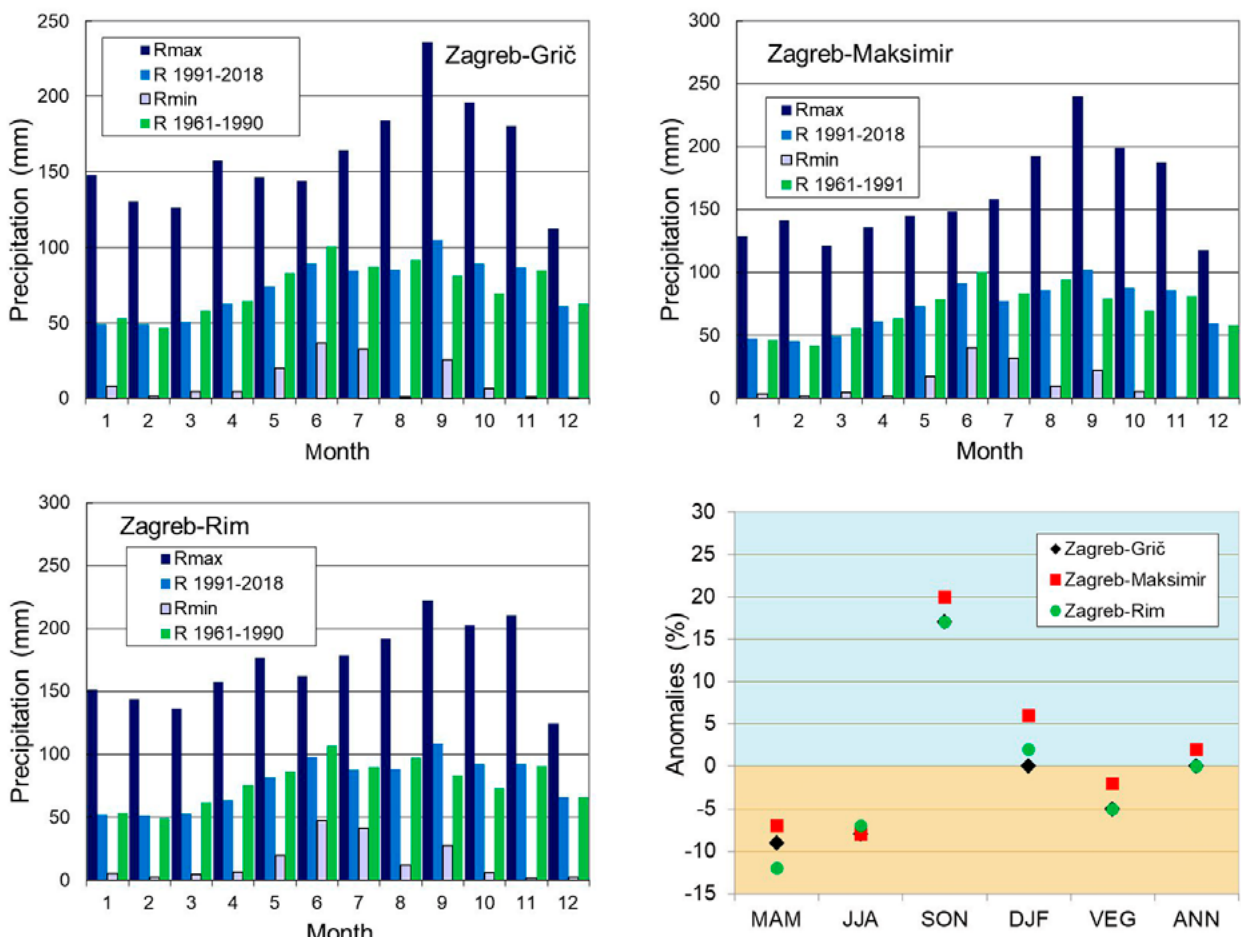

Figure 3. Mean, maximum and minimum monthly precipitation amounts for the period 1991-2018, and mean monthly precipitation amounts for the period 1961-1990 (left and right up). Anomalies of mean seasonal, vegetation period and annual precipitation amounts for the period 1991-2018 calculated with respect to the 1961–1990 average (right down)

Table 2. Basic statistics for seasonal, vegetation period and annual precipitation amounts (mm) and anomalies (%) of precipitation amounts and their interannual variability for the period 1991-2018 calculated with respect to the 1961–1990 average

Zagreb-Grič (157 m a.s.l.) – city centre												
	1961-1990						1991-2018					
	MAM	JJA	SON	DJF	VEG	ANN	MAM	JJA	SON	DJF	VEG	ANN
R	206	280	236	162	508	883	187	258	274	162	485	885
sd	57	76	77	61	104	136	56	75	86	63	141	156
cv	0,28	0,27	0,33	0,38	0,20	0,15	0,30	0,29	0,31	0,39	0,29	0,18
Rmax	338	516	428	269	752	1116	291	419	462	329	736	1234
Rmin	83	157	127	53	327	607	57	129	127	71	201	521
Zagreb-Maksimir (123 m a.s.l.) - suburb												
	1961-1990						1991-2018.					
	MAM	JJA	SON	DJF	VEG	ANN	MAM	JJA	SON	DJF	VEG	ANN
R	198	278	230	146	500	853	184	255	270	155	475	867
sd	54	83	74	56	100	136	52	80	84	59	151	159
cv	0,27	0,30	0,32	0,38	0,20	0,16	0,28	0,31	0,31	0,38	0,32	0,18
Rmax	311	511	408	251	744	1092	272	422	449	280	814	1318
Rmin	76	136	106	53	309	558	57	136	115	60	185	517
Zagreb-Rim (220 m a.s.l.) - slope												
	1961-1990						1991-2018.					
	MAM	JJA	SON	DJF	VEG	ANN	MAM	JJA	SON	DJF	VEG	ANN
R	225	294	248	169	540	935	198	274	291	172	511	936
sd	75	86	82	62	115	154	62	84	90	64	165	177
cv	0,33	0,29	0,33	0,37	0,21	0,16	0,31	0,31	0,31	0,37	0,32	0,19
Rmax	457	542	446	287	839	1255	314	454	471	324	903	1446
Rmin	106	132	137	73	316	656	58	154	128	77	177	538
Precipitation amounts - Anomalies (1991-2018) in respect to (1961-1990)												
							MAM	JJA	SON	DJF	VEG	ANN
Zagreb-Grič							-9	-8	17	0	-5	0
Zagreb-Maksimir							-7	-8	20	6	-2	2
Zagreb-Rim							-12	-7	17	2	-5	0
Interannual variability - Anomalies (1991-2018) in respect to (1961-1990)												
							MAM	JJA	SON	DJF	VEG	ANN
Zagreb-Grič							8	7	-4	2	43	15
Zagreb-Maksimir							3	5	-1	-1	39	15
Zagreb-Rim							-7	5	-7	2	51	15

Abbreviations: MAM: March-May; JJA: June-August; SON: September-November; DJF: December-February; VEG: April-September; R(mm)– average; sd(mm)-standard deviation; c_v-coefficient of variation; Rmax(mm)-maximum; Rmin(mm)-minimum; anomalies (%)-negative values=decrease, positive values=increasee

ditions. These led to the large interannual variability, expressed by coefficient of variation, which have been identified for both observed periods and all three locations (Table 2). Anomalies of interannual variability for seasonal precipitation amounts for the recent period in respect to the 1961-1990 period are small and they range between -7% and 8% according to the three observed locations. There is the equal increase in interannual variability for annual precipitation amounts (15% for each location). For vegetation period precipitation amounts anomalies of interannual variability are higher and differ a bit between the locations (ZG: 43%, ZM 39% and ZR 51%).

Precipitation time series analysis for the period 1961-2018 showed that there was no clear grouping of dry or wet years or growing seasons in the 21st century.

The obtained results for precipitation anomalies between the two period in Zagreb are in accordance with

the results of trend analysis in precipitation amounts and precipitation indices over Croatia for the period 1961–2010 (Gajić-Čapka et al., 2015). They identify large spatial variability and large temporal (seasonal) variability. The results reveal that the changes in annual and seasonal amounts are predominantly weak. A significant trend is detected only for annual amounts (negative) in the mountainous region and for summer (negative) in the mountainous littoral, mountainous region and central hinterland. A significant positive trend for autumn appears in eastern mainland. Negative trends in summer are associated with a decrease in frequency of moderate wet days, in maximal 1- and 5-day precipitation and in an increase in light precipitation. A negative annual trend is mainly caused by a decrease in frequency of very wet days and their contribution to the total precipitation. A positive autumn trend is associated with more very wet days and an increase of their contribution to the total precipitation as well as an increase in maximal 1- and 5-day precipitation.

Rain factor

According to the modified Lang's rain factor, the suburb (ZM) and the city slopes at the foot of the Medvednica Mountain (ZR) became more arid and characterised by semihumid climate in recent compared to the reference period while the city centre (ZG) in both studied periods has semihumid climate at the annual level (Table 3). Similar results were obtained by Bilandžija et al. (2019) for the Đurđevac area in the north east part of Croatia that become also more arid in recent period 1991-2016 (semihumid climate) compared to the reference period 1961-1990. Comparing the monthly values of rain factors (Table 3), in the re-

cent period city centre (ZG) become more arid from February to June and more humid in October; the suburb (ZM) become more arid from May to June and more humid in November while at the city slopes (ZR) period April - June became more arid and period September - November more humid compared to the period 1961 - 1990.

Water balance according to Thornthwaite method

The calculation of evapotranspiration according to Thornthwaite method (Figure 4) showed similar results for the meteorological stations in upper town city centre (ZG) and suburb (ZM). In the recent period 1991-2018, the actual evapotranspiration is lower (by 40 mm at ZG and by 41 mm at ZM), as well as the potential evapotranspiration in relation to the 1961-1990 period. Both soil water reserves (by 97 mm at ZG and 106 mm at ZM) and soil water sufficiency (by 42 mm at ZG and 54 mm at ZM) are higher compared to the reference period 1961 – 1990 (Figure 3). At the hilly slopes (ZR), the actual and potential evapotranspiration are lower (by 28 mm), while soil water reserves (by 367 mm) and soil water sufficiency (by 29 mm) are higher in the recent compared to the period 1961 – 1990 (Figure 4). The soil water deficiency in both study periods did not occur at any of the studied locations (Figure 4).

In recent period, the greatest values of actual and potential evapotranspiration, soil water reserves and water sufficiency are indicated at the hilly slopes of the city (ZR). The lowest values of actual and potential evapotranspiration are present at the suburb (ZM), and the lowest values of soil water reserves and water sufficiency in the city centre (ZG).

Table 3. Lang's and Gračanin's rain factor

Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Zagreb-Grič (157 m a.s.l.) – city centre													
1961- 1990	112,6	15,2	8,0	5,5	5,1	5,2	4,1	4,4	4,8	5,9	13,2	31,8	77,1
	ph	ph	h	sh	sh	sh	sa	sa	sa	sh	h	ph	sh
1991 – 2018	19,5	11,9	5,9	4,7	4,2	4,2	3,7	3,7	6,0	7,0	11,1	21,0	69,0
	ph	h	sh	sa	sa	sa	sa	sa	sa	h	h	ph	sh
Zagreb-Maksimir (123 m a.s.l.) - suburb													
1961- 1990		22,7	9,4	6,0	5,2	5,4	4,1	4,9	5,0	6,6	15,4	66,2	83,0
		ph	h	sh	sh	sh	sa	sa	sh	h	ph	ph	h
1991 – 2018	34,5	16,4	6,7	5,0	4,3	4,4	3,5	4,0	6,2	7,6	12,7	33,6	73,3
	ph	ph	h	sh	sa	sa	sa	sa	sh	h	h	ph	sh
Zagreb-Rim (220 m a.s.l.) - slope													
1961- 1990		19,2	9,3	6,7	5,4	5,6	4,3	4,7	4,9	6,2	14,7	42,6	83,8
		ph	h	h	sh	sh	sa	sa	sa	sh	ph	ph	h
1991 – 2018	27,5	15,6	6,8	5,1	4,8	4,8	3,9	4,0	6,4	7,6	12,9	28,9	76,8
	ph	ph	h	sh	sa	sa	sa	sa	sh	h	h	ph	sh

Abbreviations: ph-perhumid; h-humid; sh-semihumid; sa-semiarid

Zagreb-Grič (157 m a.s.l.) – city centre
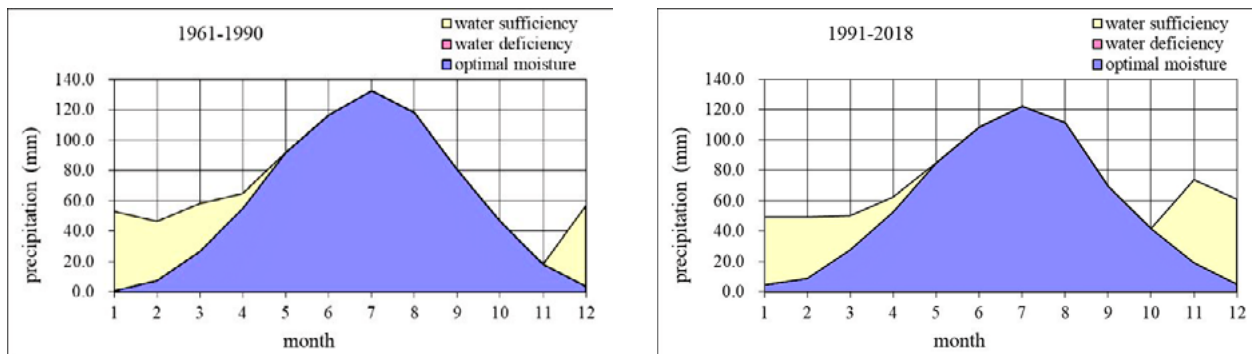
Zagreb-Maksimir (123 m a.s.l.) - suburb
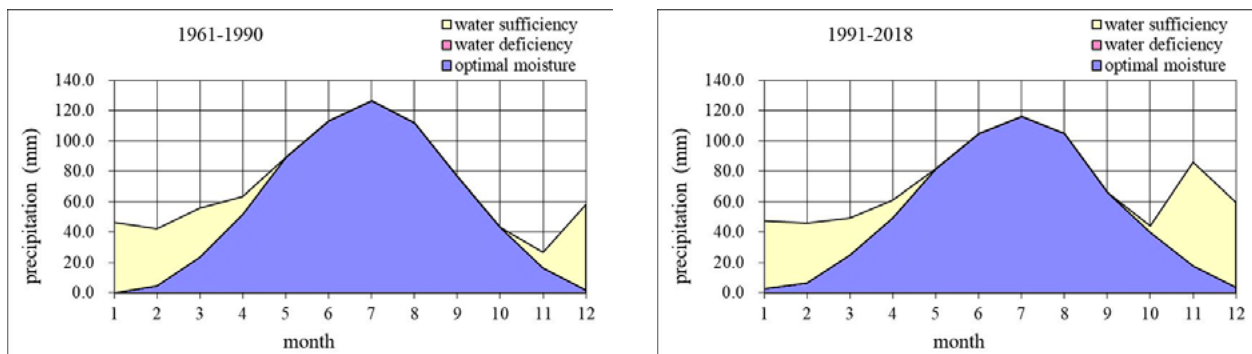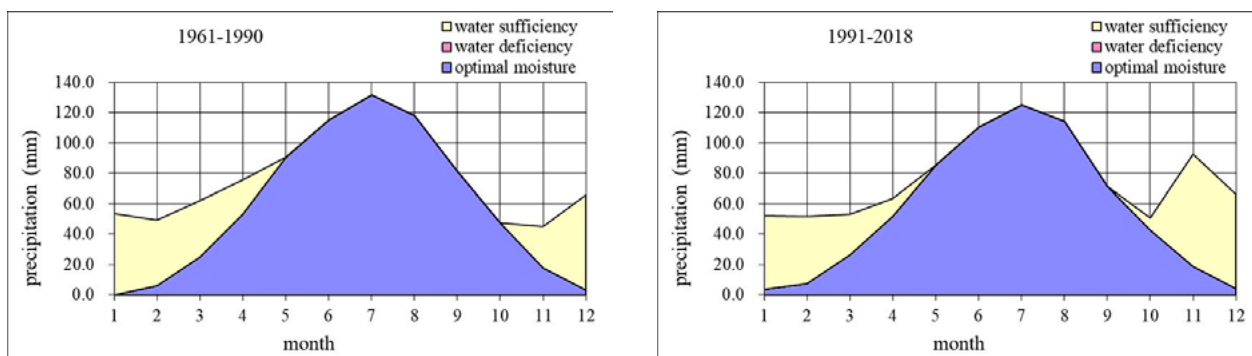

Zagreb-Rim (220 m a.s.l.) - slope

Figure 4. Evapotranspiration for the periods 1961-1990 (left) and 1991-2018 (right)

Due to higher soil water reserves and soil water sufficiency, the drainage of sufficient water should be considered in future planning of green urban infrastructure in order to prepare soils for receiving and managing higher quantity of precipitation and provide optimal growth conditions for green areas.

Index of aridity according to UNEP

According to the index of aridity (Table 4), the drought conditions at all three locations did not change over the time and were the same between locations. In the city centre (ZG) in the driest year of the reference period, usually humid area was semiarid in March, May, August and October while June and July were subhumid. In the wettest year of the reference period, August was the driest month and October was semiarid

compared to the reference period. In the driest year of recent period 1991-2018, August and November were arid and May semiarid, compared to the average 1961-1990. In the wettest year of the recent period, only usually humid March was subhumid.

In the driest year of reference period at the suburb, usually humid area was subhumid in September, semiarid in May and October, while June was the driest. In the wettest year of reference period August was the driest month and October was semiarid compared to reference period. In the driest year of recent period 1991-2018, July and September were subhumid, August was arid, and November hyperarid compared to the 1961-1990 average. In the wettest year of recent period, only usually humid March was subhumid.

Table 4. Index of aridity for the periods average, driest and wettest year in periods 1961-1990 and 1991-2018

Series of met. data		III	IV	V	VI	VII	VIII	IX	X	XI	P*	D*	S*
					Month							Annually, mm	
Zagreb-Grič													
1961 - 1990	Average	2,16	1,18	0,90	0,87	0,66	0,78	1,01	1,49	4,66	882,8	0	185,6
	Dry 1973	0,43	1,90	0,24	0,61	0,61	0,26	1,15	0,45	4,30	607,3	179	103,0
	Rainy 1962	7,05	1,91	0,92	0,84	1,08	0,05	1,46	0,32	16,90	1115,9	51	457,3
1991 – 2018	Average	1,83	1,19	0,87	0,82	0,69	0,76	1,51	2,12	4,46	885,3	0	228,2
	Dry 2011	1,54	0,71	0,46	0,82	0,67	0,15	0,69	2,03	0,08	520,8	138	29,8
	Rainy 2014	0,58	1,34	1,45	1,36	0,86	1,29	3,35	2,73	3,75	1233,8	0	594,5
Zagreb-Maksimir													
1961 - 1990	Average	2,36	1,23	0,88	0,88	0,66	0,85	1,04	1,61	4,96	852,3	0	194,2
	Dry 1971	5,83	0,95	0,43	0,66	0,19	1,05	0,62	0,22	4,04	558,2	152	84,3
	Rainy 1962	6,83	2,23	1,01	0,72	1,13	0,06	1,42	0,31	16,15	1092,2	40	461,2
1991 – 2018	Average	1,98	1,24	0,89	0,87	0,67	0,82	1,54	2,21	4,79	866,7	0	248,5
	Dry 2011	1,55	0,81	0,91	0,66	0,59	0,15	0,53	2,21	0,05	520,8	138	29,8
	Rainy 2014	0,60	1,38	2,08	1,55	1,50	1,29	3,00	0,60	1,38	1317,8	0	712,3
Zagreb-Rim													
1961 - 1990	Average	2,49	1,43	0,96	0,93	0,68	0,83	1,03	1,55	5,11	934,9	0	246,7
	Dry 1971	7,30	1,01	0,48	0,82	0,35	0,96	0,75	0,21	4,60	655,9	118	109,9
	Rainy 1980	3,18	7,00	1,02	0,51	0,59	0,48	0,95	3,61	12,11	1254,5	93	636,2
1991 – 2018	Average	2,02	1,23	0,96	0,89	0,70	0,78	1,52	2,17	4,92	936,1	0	275,5
	Dry 2011	1,64	0,80	0,42	0,68	0,62	0,17	0,54	2,14	0,24	537,5	173	59,6
	Rainy 2014	0,51	1,35	2,41	1,38	1,56	1,23	3,29	3,25	3,62	1446,0	0	792,4

*P – Precipitation in mm, PET - potential evapotranspiration in mm; D – water deficiency in mm, S – water surplus in mm

subhumid (0,50< AI$_U$ <0,65)	semiarid (0,20< AI$_U$ <0,50	arid (0,05< AIU<0,20)	hyperarid (<0065)

At the hilly area of Zagreb city, in the driest year of reference period usually humid area was semiarid in May, July and October and in the wettest year of past period June and July were subhumid and August was semiarid compared to reference period. August was the driest, July and September subhumid and May and November semiarid in the driest year of recent period 1991-2018. In the wettest year of recent period, only March was subhumid compared to the average of the recent period.

According to modified Lang's rain factor, the suburb (ZM) and the slopes (ZR) become more arid in recent period, primarily as a result of warming. According to evapotranspiration by Thornthwaite method and index of aridity, none of studied locations experienced water deficiency. Mentioned could be attributed to the soil water reserves and soil water sufficiency that were higher in the recent period at all three locations compared to reference period.

Szabo et al. (2019) identified the tendencies between 1960 and 2010 in the Carpathians region and revealed that monthly average temperature, maximum temperature and evapotranspiration had positive trends in all seasons except autumn, and the precipitation had a positive trend, but negative values in winter.

Furthermore, authors identified the western part of Hungary and the eastern part of Croatia as most sensitive regions for the predicted climatic changes.

Thresholds of cardinal temperatures for vegetation periods with temperatures above 5, 10, 15 and 20 °C

The beginning, end and duration in days of the vegetation periods with temperatures above 5, 10, 15 and 20°C are presented in Table 5. The period with temperatures above 5°C is prolonged by 16 days in the city centre (ZG) and at the suburb (ZM), while at the hilly slopes (ZR) it is prolonged by 13 days in the recent period compared to 1961 – 1990 period. Considering the period with temperatures above 10°C, it is prolonged in the city centre (ZG) and at the suburb (ZM) by 15 days and at the city slopes (ZR) by 9 days in the period 1991 - 2018 compared to the reference period. The period with temperatures above 15 °C is prolonged by 12, 16 and 8 days respectively in the city centre (ZG), at the suburb (ZM) and at the hilly slopes (ZR). The greatest change in the duration of vegetation period with temperatures above 20 °C occurred at the suburb (ZM) where it is prolonged by 69 days, followed by city centre (ZG) where it is prolonged by 32 days, and at the city slopes (ZR) where

Table 5. Vegetation periods with cardinal temperatures of 5, 10, 15 and 20 °C

Period	Cardinal temperature, °C											
	5			10			15			20		
	B	E	L	B	E	L	B	E	L	B	E	L
Zagreb-Grič (157 m a.s.l.) – city centre												
1961-1990	28.II	24.XI	269	2.IV	25.X	206	6.V	27.IX	144	25.VI	20.VIII	56
1991-2018	20.II	2.XII	285	24.III	31.X	221	27.IV	30.IX	156	4.VI	31.VIII	88
Zagreb-Maksimir (123 m a.s.l.) - suburb												
1961-1990	9.III	17.XI	253	10.IV	18.X	191	13.V	19.IX	129	13.VII	20.VII	7
1991-2018	2.III	26.XI	269	2.IV	25.X	206	3.V	25.IX	145	10.VI	25.VIII	76
Zagreb-Rim (220 m a.s.l.) - slope												
1961-1990	4.III	22.XI	263	5.IV	25.X	203	9.V	27.IX	141	29.VI	19.VIII	51
1991-2018	25.II	28.XI	276	30.III	28.X	212	2.V	28.IX	149	10.VI	28.VIII	79

Abbreviations: B – beginning; E - end; L – length of the period in days

it is prolonged by only 8 days. The greatest average change in duration of vegetation periods experienced the suburb of Zagreb city (ZM), followed by city centre (ZG) and the lowest change experienced hilly slopes of the city (ZR).

Similar results were obtained for other locations in Croatia, as well as Europe. Longer vegetation periods with temperatures above 5, 10 and 15°C (respectively by 16, 14 and 13 days) were observed in north east part of Croatia (Đurđevac) by Bilandžija et al. (2019). At the highest meteorological station in Croatia (Zavižan, 1594m a.s.l.), longer vegetation periods in autumn are observed by Vučetić and Vučetić (2003). Earlier beginning of olive and syringa flowering in southern part of the Croatian coast (Hvar, Dubrovnik) has also been detected (Vučetić and Vučetić, 2005; Jelić and Vučetić, 2011). In neighbouring country Slovenia, vegetation periods with temperatures above 5 and 10°C prolonged between 20 and 25 days/51y under the influence of high positive trends of temperature parameters. Across biogeographical regions of Europe, the flowering phenology of plant species was examined by Templ et al. (2017) in order to identify their spatiotemporal patterns. The authors concluded that significant species-specific advancements in plant flowering onsets within the Continental (3 to 8.3 days), Alpine (2 to 3.8 days) and by the highest magnitude in the Boreal biogeographical regions (2.2 to 9.6 days per decades), while less pronounced responses were detected in the Pannonian and Mediterranean regions

Conclusions

Average annual temperature regime for three locations in the Zagreb city area show differences in the interval 0.0°C to 1.4°C for monthly, 0.3°C to 1.2°C for seasonal and 0.4°C to 1.0°C for annual averages. Zagreb-Grič (ZG) in the upper town of the central urban area is the warmest location and the coldest location is Zagreb-Maksimir (ZM) in the eastern suburb, open to the lowland towards the Sava River valley. Differences in precipitation amounts are small but indicate the highest values on the slopes (ZR) and the lowest in the eastern suburb (ZM), which is often found in precipitation shadow for northwest precipitation penetrations. The anomalies in precipitation interannual variability between the two periods are pronounced for annual amounts (15% at each location) and for vegetation period (39% to 51%).

The climate change results for annual and seasonal average temperatures and precipitation amounts, defined as the difference between the recent 1991-2018 period and the reference 1961-1990 period, are compared with the projections for the near future climate (2011-2040) for the area under consideration which are inferred from the simulated climate changes over Europe (MZOIP, 2014). The comparison with the ENSEMBLES RCM simulations indicate that the warming was in the range of projected increase (1.0°C to 1.5°C) for spring, weaker than the projected increase for autumn (1.0°C to 1.5°C) and for winter (1.5°C to 2°C), and stronger than the projected increase for summer (1.0°C to 1.5°C). According to the ENSEMBLES RCM simulations spring, summer and autumn precipitation amounts are projected to change in the interval -5% to +5%, over the observed area. Decrease in spring and summer precipitation indicated in the recent period at all three locations is stronger (-12% to -7%) than the projected change as well as increase in autumn precipitation amounts of 17% at ZG and ZR and 20% at ZM. No change (ZG) and slight increase (ZM: 6%, ZR: 2%) in winter precipitation are in the range of projected increase in

winter precipitation amount of up to 15% for a part of the observed area.

The rain factor experienced no change in the city centre (ZG) while the suburb location (ZM) and the city hilly slopes (ZR) become more arid with semihumid climate in recent period compared to the reference period 1961-1990. At all the studied locations (ZG, ZM, ZR), the actual and potential evapotranspiration is lower, the soil water reserves and soil water sufficiency are greater in the recent compared to the referent period, while soil water deficiency in both studied periods does not occur. The greatest actual and potential evapotranspiration as well as water sufficiency occur at the hilly slopes (ZR), and the greatest soil water reserves in the city centre (ZG). According to the index of aridity, the drought conditions at all three loca-

tions did not change over the time and were the same between locations. At all studied locations in the Zagreb city (ZG, ZM, ZR), the periods with temperatures above 5, 10, 15 and 20°C is prolonged between 13-16, 9-15, 12-18 and 8-69 days respectively in the recent period 1991 - 2018 compared to reference period 1961-1990. The greatest average change in duration of vegetation periods experienced the suburb (ZM) and the lowest one the hilly slopes of the city (ZR).

Indicated changes in agroclimatic conditions (warming, no change in mean annual precipitation, lower evapotranspiration, higher soil water reserves and longer vegetations periods) should be considered in the planning process of green urban infrastructure in order to mitigate and adapt to climate change in the best possible way.

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