

Precipitation, Humidity and Cloudiness in Podgorica (Montenegro) during the Period 1951-2018

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Received: October 14, 2019 | Revised: December 23, 2019 | Accepted: December 24, 2019

DOI: 10.5937/gp23-23582

Abstract

This paper presents the results of a trend analysis of three climate elements: precipitation, cloudiness and humidity. Almost the entire period of instrumental measurements (precipitation and humidity) and visual observations (cloudiness) are covered. In the observed 68-year period (1951-2018), the trend of annual and seasonal precipitation amounts is insignificant. Though, there is a significant decrease in the number of days with precipitation ≥ 1 mm, which implies a movement towards more arid conditions. On the other hand, the number of days with extreme rainfall ≥ 40 and 50 mm is increasing. In Podgorica, the annual statistics of days with snow cover decreases as well. There is also a decrease in the relative humidity and cloudiness, and with both elements the trend is insignificant only in the autumn season. The results of the trend calculation show that the number of gloomy days is more intensively reduced than the number of increasing bright days. In general, the results of the research show that the climate of Podgorica tends to be more arid with more extreme weather events. The climate variations happening in this city are, to small amount, caused by the urbanization process. Podgorica has the character of an urban heat island in a cooler environment, with an average annual intensity of about 0.7°C and the highest in winter (about 0.8°C). The most symptomatic indicator of urbanization is temperature, but anthropogenic heat production in the city (asphalt, constructions, increase of aerosols, etc.) also affects other climate elements. Compared to the non-urban environment, Podgorica has a higher annual rainfall of 100 mm and a lower humidity of 3%, while this difference is not noticeable in the overall cloudiness.

Keywords: precipitation; humidity; cloudiness; trend; Podgorica; Montenegro

Introduction

Podgorica as well as much of Montenegro have a slightly modified Mediterranean climate, and generally pleasant life-work environment. In the context of contemporary climate change and the recent increase in the frequency of extreme weather phenomena, there is a need for more intensive research in this area, since the area of Montenegro has not been adequately researched. The indices of temperature and precipitation extremes

in Montenegro were discussed in the papers by Burić et al. (2015) and Buric et al. (2011). Kutiel et al. (2015) investigated rainfall series for the space of Serbia and Montenegro. Weather extremes also occur more frequently in the whole region. A detailed description of the occurrence of a strong vortex with tornado elements in Split (Croatia) is noted in the work of Mihajlovic et al. (2016). In other parts of the Mediterranean, the propor-

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tion of extreme weather events has increased. In the period 1961-2006 much of Spain recorded a trend of rising maximum and minimum temperatures (Del Rio et al., 2012). According to research by Tosić and Unkašević (2014) for Serbia, in the period 1949-2011 the frequency of droughts in the southern part of the country is higher than in other regions.

Milosević et al. (2016) found that in Slovenia, in 1963-2012, the western parts recorded a significant decrease in annual rainfall, in summer there was a pronounced negative trend in the southwest of the country, and in the spring along the Adriatic coast. Rainfall has also been detected during the winter, with the fall season registering an increase, but the trend of changes in these two seasons is insignificant. Examining the impact of teleconnections, the authors obtained a significant relationship of precipitation with the North Atlantic Oscillation (NAO), the Mediterranean Oscillation (MO), and the Western Mediterranean Oscillation (WeMO). In the period 1963-2014, Slovenia also recorded a significant increase in maximum annual, summer and spring temperatures. Surveys for this country have shown that mean maximum temperature corresponds best with East Atlantic Oscillation (EA), Arctic Oscillation (AO) and Scandinavian Oscillation (SCAND), while in winter there is a significant correlation with NAO and the MO, in summer with East Atlantic/Western Russia Oscillation (EA/WR), and in the fall with the El Niño Southern Oscillation (ENSO) (Milosević et al., 2017).

The Carpathian region is also affected by contemporary climate change. For 1961-2010, Szabó et al. (2019) found that this region registers positive trends in average monthly temperatures, maximum temperatures, and evapotranspiration, except in the fall season. When it comes to precipitation, most of the year registers positive trends, while negative values are characteristic of the winter season. The authors point out that Western Hungary and Eastern Croatia are the most sensitive areas for climate change. Recently, heat waves

(intervals of more than 5 consecutive days with a maximum temperature higher than 5°C in relation to average daily maximums), which are potentially dangerous for the population, especially for chronic patients and the elderly, are increasingly occurring. Arsenović et al. (2019) found that during the summer of 2015 and 2016, the mortality rate in seven of the ten cities surveyed in the Czech Republic increased significantly.

Dučić et al. (2012) studied the types of atmospheric circulation as a possible cause of heavy rainfall in Crkvice in southwestern Montenegro, probably the rainiest place in Europe. Potential causes of temperature and precipitation extremes in Montenegro were studied by Burić et al. (2019), Burić et al. (2018) and Doderović and Burić (2015). Regarding Montenegro, the research of Orgin et al. (2018) should be mentioned. Measurements made by the authors in the area of the Durmitor massif have shown that the minimum winter temperatures in the high mountain depressions of Montenegro are much lower than those measured at the surrounding weather stations. Over the past few decades (1961-2015), the warming trend has been present throughout neighboring Bosnia and Herzegovina. Research shows that in this country there is a significant correlation between temperature and EA, NAO and AO, generally (Trbić et al., 2017).

The Fifth Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) points out that the human impact on climate is clear, primarily in the form of increased concentrations of greenhouse gases in the atmosphere. This report, as in the previous ones, points out that changes in the intensity and frequency of extreme weather events, such as droughts, floods, extreme temperatures, heat waves, stormy weather followed by the hail, heavy short-term rains, etc., are recorded in many regions of the world. The main objective of this paper is to analyze the trend of three climate elements for almost the entire period of instrumental measurements and observations in Podgorica, during the period 1951-2018.

Research area, database and methodology

Research area

The study covers the area of Podgorica, the capital and the most populated city in Montenegro (Figure 1). Podgorica is located in a vast basin (Podgorica-Skadar basin), surrounded by several mountain ranges. The valley is open to the north and north-west through the river basins, while beyond the Skadar Lake and the Bojana River it is wider open to the south and the Adriatic Sea. Mathematical-geographical positions, as well as the proximity of the sea and relief features are the primary factors that affect the climate of Podgorica (Burić et al., 2013).

Database and methodology

For the purposes of the study, data from the main meteorological station in Podgorica were used. Continuous measurements and observations in Podgorica began in 1949. This paper analyzes almost the entire period i.e. 1951-2018. It is important to emphasize that the data sets were mostly complete - for a period of 68 years in only a few cases there were missing data from 0.01 to 3% of the total number of data. MASH v3.02 and MISH v1.02 methods, also recommended by the World Meteorological Organization (WMO),



Figure 1. Location map of Podgorica, Montenegro (meteorological station 42°26'38"N, 19°14'38"E, 44 over sea level)

have been used for homogeneity testing and interpolation of datasets, especially when dealing with daily

data (Szentimrey, 2003). The mentioned methods use Kriging interpolation algorithms and the daily value of a given climate element in grids of 100 · 100 m is estimated on the basis of all adjacent stations.

The usual mathematical and statistical methods were used in the paper - standardized deviations, percentiles, trend, moving averages, etc. The trend was calculated using the Sen Method, and its significance was tested by the Men-Kendal test. Many authors point out the advantage of using non-parametric detection tests as well as the significance of the trend of a given time series, above all Sen's slope estimates and Mann-Kendall (Mondal et al., 2012; Šumenjak & Schuster, 2011), due to the smaller number the assumptions needed to implement them. Thus, the basic advantage of Sen's method and Men-Kendal test is that it is less complex than e.g. least squares method and t-test. The trend is calculated for the period 1951-2018, and a significance of tendency was tested at the level of risk of: $p < 0.001$, $p < 0.01$, $p < 0.05$ and $p < 0.1$ (the degree of correctness of the hypothesis of 99.9%, 99%, 95% and 90%). For the purpose of the work, data were obtained from the State Institute for Hydrometeorology and Seismology of Montenegro - IHMSM.

Results

Precipitation

When it comes to the precipitation quantity, there are insignificant changes. Spring and autumn precipitation is increasing at the trend line, and it is for 8, 9 mm/decade, and 9.3 mm/decade. Summer and winter precipitation decrease - about 3.6 mm/decade (in

summer) and 2.7 mm/decade (in winter). Given that the increase in intense precipitation during transitional seasons than the overall decrease in summer and winter, annual precipitation show a tendency to grow by 2 mm / decade (Figure 2).

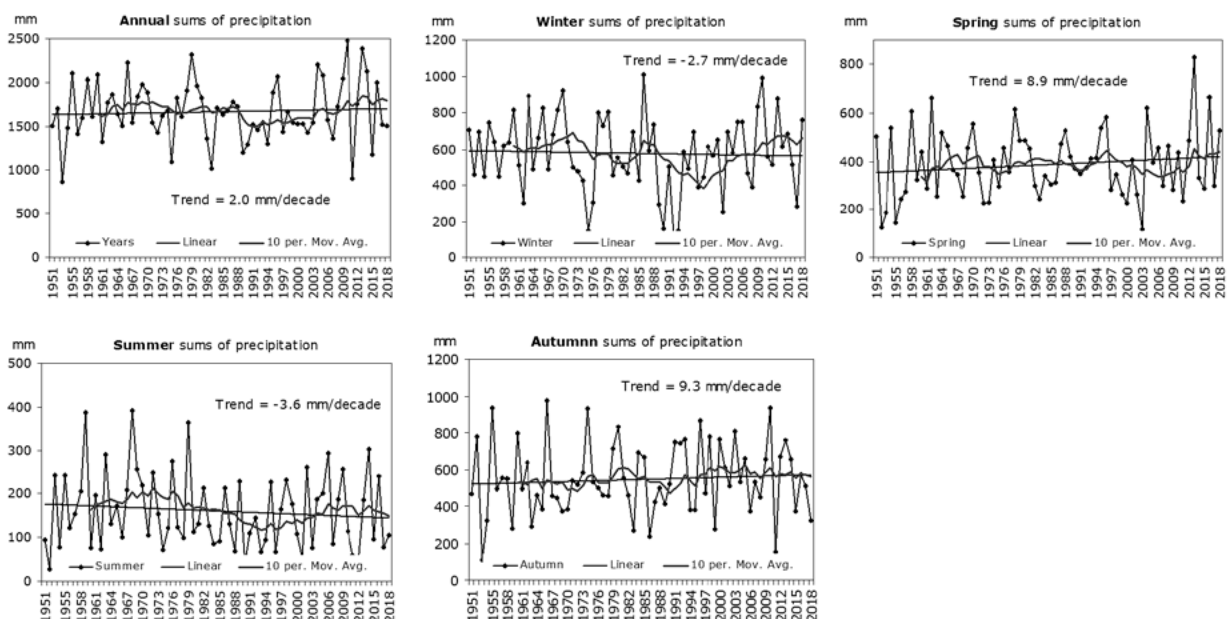


Figure 2. Trend of the annual and seasonal precipitation sums, Podgorica 1951-2018.

Precipitation is primarily influenced by variations in atmospheric oscillation, and their amount and intensity is affected by the dissociation of relief (orographic precipitation), as well as by air convection (convective precipitation in the warmer part of the year). It is clear that there is an interaction between the elements of the climate system, but it is difficult to determine the individual impact or effect of a change on one factor due to feedback effect. In other words, it is difficult to determine why with the total annual and seasonal rainfall in Podgorica, generally and in the territory of Montenegro (Burić et al., 2011), nothing significant occurs during the period of instrumental observations. The results for Podgorica suggest that the impact of global warming, or a possible anthropogenic greenhouse effect on precipitation, is still unclear.

Standardized deviations (Figure 3, above) show no significance with annual precipitation in Podgorica. Specifically, over a 68-year period, as many as 67.6% of annual rainfall cases were within the normal range. At three years, they were rated as very arid (1953, 2011 and 1983) and very wet or rainy (1979, 2013 and 2010). The percentile method is "more sensitive", however, after three years, they are classified as extremely dry or extremely wet (Figure 3, down).

Variations in the number of days with precipitation of less than 10, 20 and 30 mm are insignificant.

However, the number of days with precipitation ≥ 1 mm (trend = -2.3 days/decade) is significantly reduced, which implies more arid conditions. Secondly, it is worrying that the number of days with extreme rainfall ≥ 40 and 50 mm increases (Figure 4) at a rate of 0.5 and 0.3 days per decade, but it is significant only at 90% of acceptance of the hypothesis.

Since snow is a rare event in Podgorica, it is most appropriate to calculate the trend of the number of days with snow cover. In the observed 68-year period, the annual number of days with snow cover decreases by 0.4 days every 10 years (-0.4 days/decade), but this trend value is insignificant. It should be emphasized that the results of the trend of the number of days with snow cover should be accepted with reserve, since a significant part of the period was without snow - in the period 1951-2018 just over 1/3 years (24 years) not a single day with snow cover formed. However, there is a downward trend in the number of days with snow cover, and this is confirmed by the sliding 10-year averages (Figure 5). When looking at the sliding 10-year average, it can be clearly observed that the decade 1954-1963 had the highest number of days with snow cover (75 days in total) and the decade 1990-1999 the lowest (total only 12 days in 10 years). It is further noted that all ten-year periods with increments of +1, from 1986 until the end of 2004, had less than a total of 20 days per decade with snow.

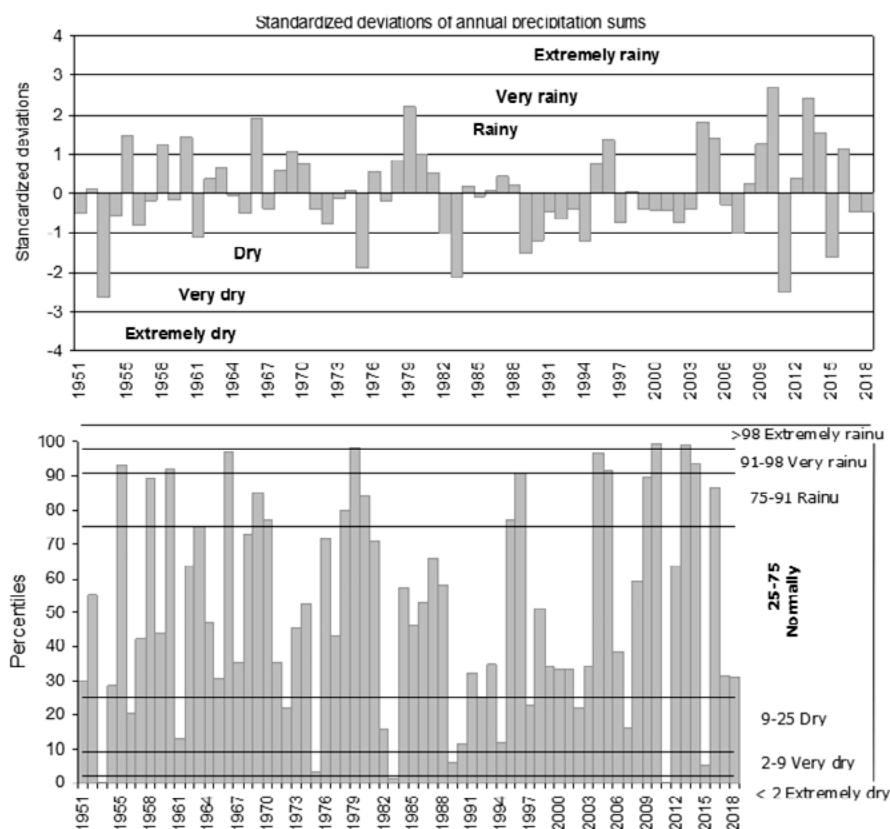


Figure 3. Standardized deviations (above) and percentage distribution (down) of annual precipitation sums, Podgorica 1951-2018.

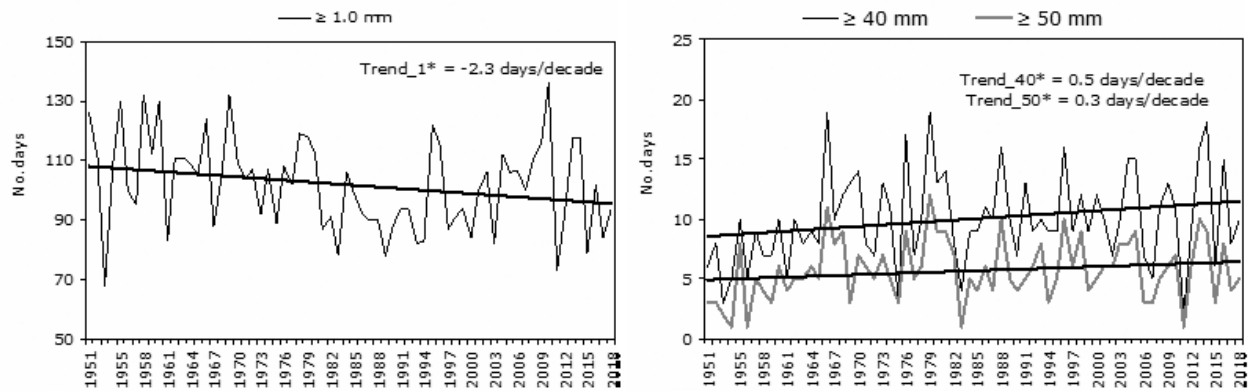
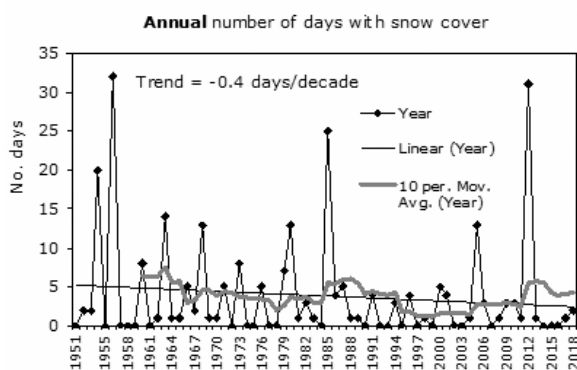


Figure 4. Trend of annual number of days with precipitation ≥ 1 (left), 40 and 50 (right) mm, Podgorica 1951-2018 (significance: * - 95%;)

According to Kostopoulou et al. (2017) a negative tendency for precipitation in Greece for the period 1971-2000 was present. Their research showed that there was a marked downward trend in precipitation during the period 1989-2000, and projections by the end of the 21st century indicate that a potential in-

An analysis of the trend and fluctuations in total annual rainfall revealed that these changes are relatively small and insignificant. To make sure that nothing and worrying happens with the annual and seasonal rainfall in Podgorica, we calculated the trend by shortening the time series (1951-2018) by 10 years. For the 1961-2018, 1971-2018 and 1981-2018 subperiods, the increase in annual and seasonal precipitation totals is generally present, but insignificant. Shortening the series by another 10 years (1991-2018), it was found that only the winter season registers significant changes in precipitation (significant risk $p < 0.05$), but the trend is positive (Figure 6). In the last observed period (2001-2018), the trend of changes in annual and seasonal precipitation in Podgorica is also insignificant. According to the IPCC (2014), there has been a global anthropogenic impact on climate since the mid-20th century. However, results for Podgorica indicate that the “signal” of the anthropogenic greenhouse effect on Podgorica’s rainfall is not evident. Moreover, the analysis of changes in total annual and seasonal rainfall did not indicate the expected aridization, both for the whole period and for individual subperiods.



Figures 5. Trend of annual number of days with snow cover ≥ 1 cm and 10-year moving average, Podgorica 1951-2018.

tensification of droughts in western Greece is expected. Not only in Greece but throughout the Mediterranean, in general, there was an increased frequency of drought (Hoerling et al., 2012) and a decrease in rainfall in the second half of the 20th century, with projections indicating that the trend of decreasing precipitation will continue throughout the 21st century (Narrant & Douguédroit, 2006). Projections for Catalonia (Spain) suggest a potentially significant increase in droughts frequency during the 21st century (Lopez-Bustins et al., 2013). In the territory of Serbia, in the period 1961-2010 a negative trend of precipitation during the winter, spring and summer was recorded (Arsenovic et al., 2015), while the autumn sums of precipitation were increasing (Putnikovic & Tosic, 2018).

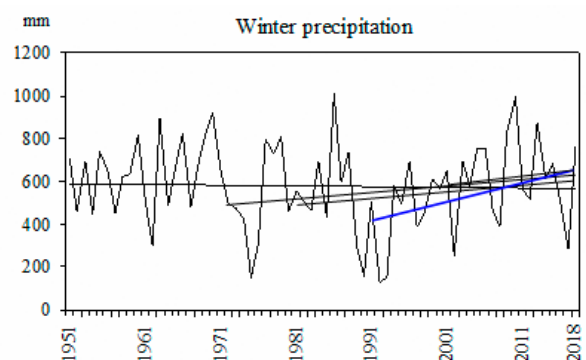


Figure 6. Trend of winter precipitation in Podgorica in different subperiods (significant only in the 1991-2018 subperiod)

Humidity

The results of the trend analysis show that the relative humidity decreases both seasonally and annually. Except for the autumn season, the trend changes are significant for other seasons as well as on an annual basis. A decrease in the mean annual relative air humidity of 0.6% per decade is significant at the 99 level of acceptance of the hypothesis (risk of accuracy 1%). During the winter, spring and summer, the negative trend is significant at the 95% level (Table 1).

Table 1. Trend of average annual and seasonal values of relative humidity in Podgorica, period 1951-2018

	Trend (%/decade)	Signific.
Year	-0.6	**
Winter	-0.8	*
Spring	-0.7	*
Summer	-0.9	*
Autumn	-0.1	In
Significance: * - 95%, ** - 99% and In - Insignificant		

In the period of instrumental measurements, Podgorica registers a significant trend of temperature rise, which may be the reason for the decrease in relative humidity. To be precise, the relative humidity decreases when the amount of water vapor in the air does not change but the temperature rises. The urbanization is one of the significant factors affecting the humidity of the air, through the change of land use, i.e. the available amount of atmospheric evaporation water. From asphalt and concrete surfaces, atmospheric water is quickly discharged through the drains into the sewer system. Less precipitation water evaporates and under the same conditions, the humidity is lower. In addition to the temperature and expansion of urbanization, variations in atmospheric circulation, as well as changes in evaporation from large waters, may also be a potential cause of changes in relative humidity, but this requires further research.

Humidity can be expressed in several sizes: relative humidity, absolute and specific humidity, water vapor voltage, dew point temperature, saturation deficit, etc. The relative humidity of the air in Podgorica was considered for the purposes of this weathering. Song et al. (2012) investigated changes in several air humidity levels in China - relative humidity, absolute humidity, specific humidity, etc. Among other things, the authors found that in most of China there is a trend of decreasing relative humidity. Using data from 15,000 meteorological stations, Dai (2006) investigated changes in humidity and temperature globally and found, among other things, that there was a trend of increasing relative humidity in the central and eastern parts of the United States, then in India and west-

ern China, while other areas registered a major decrease in the period 1975-2005. Changes in the regime of temperature and humidity in the Federal District of the Volga were reported in the paper by Perevedentsev et al. (2014), while Aleshina et al. (2018) measured the same parameters on the Black Sea coast. It should be noted that air humidity is a significant meteorological element because water vapor participates directly or indirectly in many atmospheric processes. Combined with temperature, humidity is also a significant bioclimatic element (Basarin et al., 2016; Brosy et al., 2014).

Cloudiness

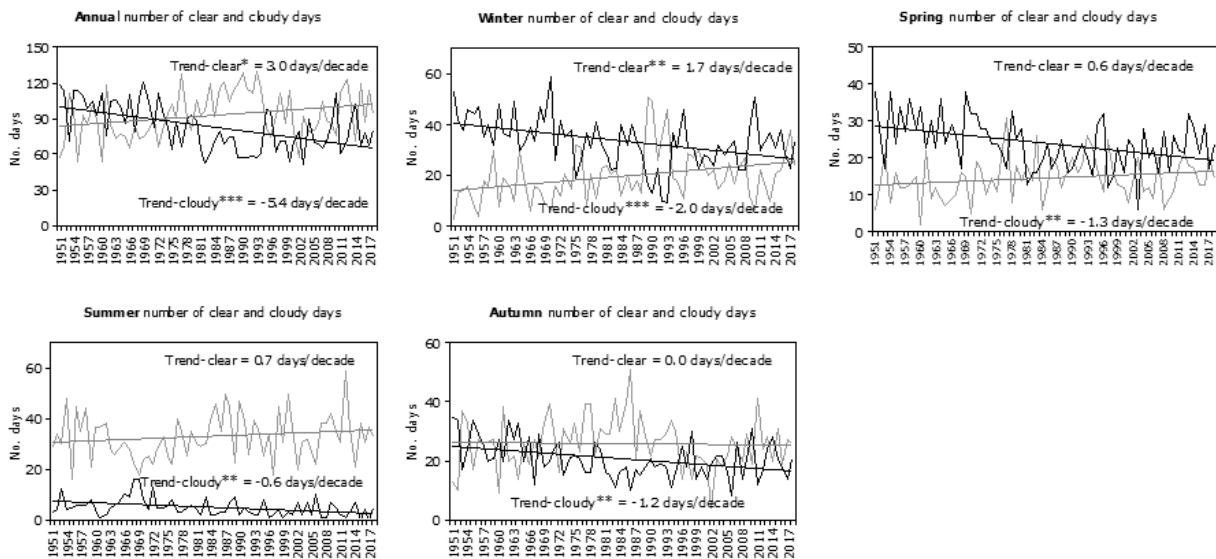
During the period 1951-2018, the mean annual cloudiness amount decreased significantly in Podgorica, at a trend rate of 1.4% per decade. Also, at 99.9% significance level there was a decrease in mean winter cloudiness (-2.6%/decade). There was a significant decrease in mean cloudiness during spring and summer, but at a lower level of hypothesis validity. Only the autumn season saw a slight decrease in the mean amount of cloudiness (Table 2).

Table 2. Trend of mean annual and seasonal cloudiness in Podgorica, period 1951-2018.

	Trend (%/decade)	Signific.
Year	-1.4	***
Winter	-2.6	***
Spring	-1.3	**
Summer	-0.8	*
Autumn	-0.6	In
Significance: * - 95%, ** - 99%, *** - 99.9% and In - Insignificant		

At the annual and seasonal level, in Podgorica, there was a generally significant trend of decreasing of the mean amount of cloudiness. That is why it is interesting to see what was happening with the number of bright and gloomy days, whether their number increased or decreased in the period 1951-2018.

The obtained results indicate that these two cloud parameters show opposite tendencies - the number of clear days increases, while the number of gloomy days decreases, both at the annual and at the season level. A significant increase in the number of bright days is present on an annual basis and during the winter, while in the other three seasons the trend is insignificant. When it comes to the number of gloomy days, the downward trend is significant over all four seasons and therefore on an annual basis. The most intense increase in the number of bright, or decrease in the number of gloomy days, is present during the winter. The results of the trend calculation show that the



Figures 7. Trend of annual and seasonal number of clear and gloomy days in Podgorica, period 1951–2018 (significance: + - 90%; * - 95%; ** - 99% and *** - 99.9%)

number of gloomy days decreased more intensively than the number of bright days increased (Figure 7). Changes in the amount of cloudiness in the territory of Montenegro have hardly been studied, and works dealing with this topic are generally rare. Potential causes for the decrease in cloudiness in Podgorica can be: increase in temperature, changes in precipitation parameters, decrease in evaporation due to expansion of urbanization, variation in atmospheric circulation, changes in evaporation from large waters (Adriatic and Mediterranean Sea), etc.

Kotsias and Lolis (2018) have considered the trend and examined the relationship between mean monthly total cloud cover and several teleconnections for the period 1979–2014 for the Mediterranean region. The authors obtained a statistically significant trend of increasing total cloudiness in the winter season only, for the northern Italy and northwestern Balkans. In the rest of the year, the greater part of the Mediterranean registers a negative trend of average monthly cloudiness, especially in the summer season. Kalimeris and Founda (2018) found that inter-decade variability in total cloudiness in Athens is strongly associat-

ed with the Atlantic Multidecadal Oscillation (AMO), but also with Mediterranean evaporation, during all seasons except winter. For the winter, they obtained a significant connection between the total cloudiness in Athens and the North Atlantic Oscillator (NAO). The authors further point out that in the summer season, the main regulators of cloud variability above Athens are the thermodynamic processes of the AMO and the Mediterranean Sea, as well as the summer NAO (SNAO).

Tang and Leng (2013) studied the relationship between cloudiness amount, precipitation, and summer temperatures in the United States for the period 1982–2009. The authors found that there was a strong negative correlation between cloudiness and mean maximum temperatures in the summer part of the year in the US, and in spring and autumn only in the mid-latitudes of the country. The relationship between cloudiness amount and precipitation was discussed in the works of Mishra (2019) and Mishra (2018), while variability in solar radiation and the association with cloudiness in the USA was discussed in the work of Hanrahan et al. (2017).

Discussion

Changes in total annual and seasonal rainfall in Podgorica are insignificant, while relative humidity and cloudiness decrease. The variations of the considered parameters are related to the dynamics of the sea-atmosphere system, but also to a lesser extent with the urbanization of this city. This paper does not aim to identify the possible causes of changes in the analyzed

parameters, but to point to the general tendency of precipitation, humidity and cloudiness, and for decision makers to consider potential influences in human life and work and possible mitigation and adaptation measures.

Due to the changing surface, including artificial sources of energy and increased concentration of aero-

sols, Podgorica has characteristics of an urban climate. The climate of cities is known to differ from their non-urban environment. The effect of the city is especially noticeable on the air temperature. The construction of streets, buildings, infrastructure and other urban elements results in a change in the thermal properties of the substrate and, consequently, of the air. Without taking this opportunity to consider whether the significant rise in temperature in Podgorica was caused by natural or anthropogenic global impact, a simple analysis provided an estimate of the intensity of the heat island in this city in relation to its surroundings. The data of the nearest meteorological station in Golubovci were used for comparative analysis. The station at the airport in Golubovci started operating in 1976 has the status of a main (synoptic) meteorological station and is

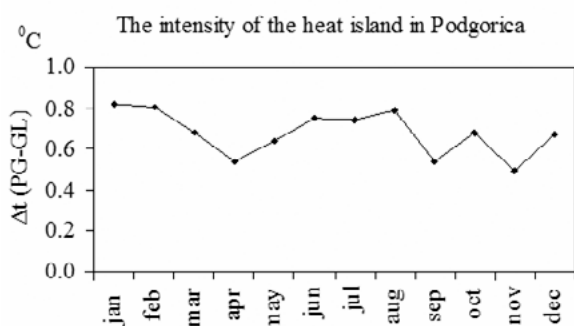


Figure 8. Annual flow of heat island intensity in Podgorica for 1977-2018.

located south of Podgorica. It is important to point out that both stations belong to the same climate area, that the height difference between them is 11 m, and that the station in Golubovci is located outside the urban area. Analyzing the difference in mean temperatures in 1977-

2018, Podgorica is warmer throughout the year than Golubovci. That the city is warmer than its surroundings is clearly evident in Figure 8. On an annual basis, the difference between the city and its surroundings is 0.7°C. At the seasonal level, the biggest difference is in winter (0.8°C), in summer it is 0.7°C, and during transitional seasons around 0.6°C. When extreme temperatures are observed, the difference is larger. The annual mean maximum temperature in Podgorica is higher by 0.8°C and the mean minimum by 0.9°C compared to Golubovci.

Compared to the non-urban environment, Podgorica has a higher annual rainfall of about 100 mm and less humidity of about 3%, while the difference in cloudiness is not noticeable. Clearly, there is a connection between temperature and precipitation, but it is not observed on an annual basis. So, on a yearly basis, there is no essential relationship between temperature and precipitation, in the sense that a warm or extremely warm year is dry or rainy, and vice versa. For example, in 2018, 2017, 2007, 2012, 2013 and 2008, the mean values were extremely warm in Podgorica, but rainfall was within normal limits. Relative to the climate norm (1961-1990), 1979 was very rainy, while the mean annual temperature that year was within normal limits. Nevertheless, we calculated the trend, regardless of the fact that the relationship between these two elements is far more complex (correlation coefficient -0.1). The bottom line is that rights have been obtained indicating a slight increase in annual precipitation and extreme warming (Figure 9). In other words, rights were obtained indicating the direction towards new climate norms for Podgorica, primarily in terms of temperature.

Many studies point out that in the era of modern climate change, the Mediterranean (including the

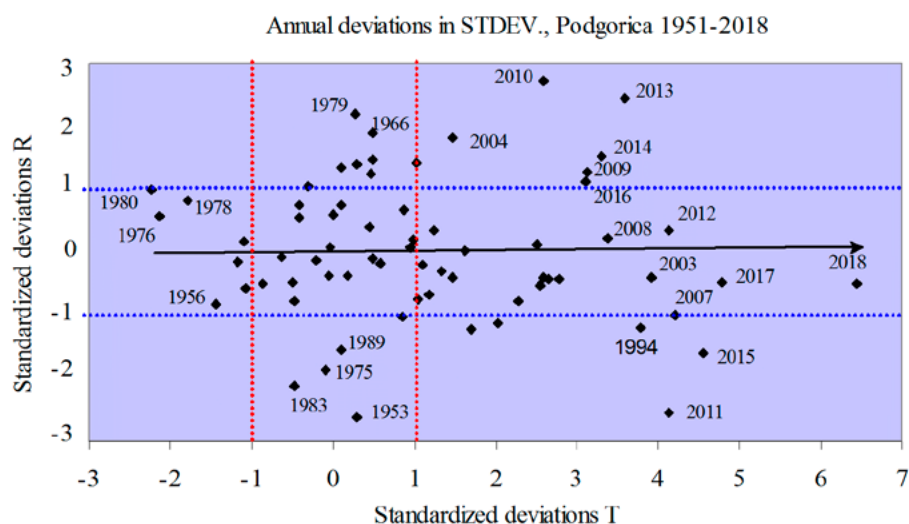


Figure 9. Standard deviations of mean annual temperature (T) and annual precipitation (R) in Podgorica for 1951-2018 (tendency towards new climatic norms!)

Balkans and South-East Europe) is one of the most sensitive regions in the world. Over the past 5-6 decades, the Mediterranean region has become warmer and drier compared to the average global state, generally. Projections for the 21st century indicate that such a situation will continue, that is, the whole region of the Mediterranean, then Southeast Europe and the Middle East will be considered as potential centers of climate change in the future - during the 21st century, the region will become warmer and drier (Adloff et al., 2015; Giorgi, 2006; Hochman et al., 2018a; Hochman et al., 2018b; IPCC, 2014; Mostafa et al., 2019). The expected rise in temperature and the likely increase in drought in the Mediterranean region are believed to have serious consequences on ecosystems and local populations (Bucchignani et al., 2018; Lelieveld et al., 2016).

The Mediterranean Sea is a significant source of humidity and heat, so variations in water temperature, evaporation and other Mediterranean features also affect the climate of Podgorica, Montenegro and the whole basin in general. Research has shown that in recent decades, the temperature of the Mediterranean Sea has been rising (Belkin 2009; Criado-Aldeanueva et al. 2008; Shaltout and Omstedt 2014), and this has an impact on the intensification of extreme rainfall events in the region, especially in its western part (Pastor et al. 2015; Turuncoglu, 2015). Seager et al. (2019) point out that atmospheric variability is the dominant source of winter rainfall variability in all regions with a Mediterranean climate. Their research shows that all climatic regions of the Mediterranean type, except in North America (California), register a trend of decreasing winter rainfall during the 20th century, and models project that aridization will continue throughout the 21st century. When it comes

to the Mediterranean region, the authors link winter precipitation reduction with dynamic processes, that is, with the development of the winter anticyclone ridge above the Mediterranean Sea.

Variations in teleconnections of the sea-atmosphere system above the Mediterranean are associated with global oscillations. Due to the increase in water temperature, evaporation from the Mediterranean waters has also intensified. Mariotti (2010) points out that since the mid-1970s there has been a significant evaporation from the surface of the Mediterranean Sea and that this has also led to an increase in salinity. Based on satellite data for the period 1985-2008, Skliris et al. (2012) found that the Eastern Mediterranean warms faster (an annual trend rate of 0.420C/decade) compared to the western part of the basin (0.370C/decade). The authors find a strong correlation between the anomalies of the SST Mediterranean and the EA and AMO indices. However, Skliris et al. have not found a statistically significant relationship between SST Mediterranean and NAO inter annual anomalies, but are at a decadal level.

Finally, it should be emphasized that in summer, Montenegro is often influenced by high air pressure fields or altitude so-called "blocking" of the synoptic situation. Secondly, the fact that in the greater part of the year, and especially in winter, there are rather dynamic atmospheric circulation conditions over Montenegro and the Balkans, which requires further analysis to determine the effect of atmospheric circulation variations on weather and climate in this country. It is also important to note that Montenegro is part of the Central Mediterranean, so that in these regions the influences of temperature and atmospheric variations that are dominant for the Western and / or Eastern Mediterranean are intertwined.

Conclusion

This paper presents the results of a trend analysis of rainfall, relative humidity and cloudiness amount for the capital of Montenegro - Podgorica. Between 1951 and 2018, trend calculations indicate that changes in the annual and seasonal rainfall exist, but are insignificant. Spring and autumn sums of precipitation are increasing along the trend line, while summer and winter are decreasing. Changes in the number of days with precipitation ≥ 10 , 20 and 30 mm are also insignificant. However, the number of days with precipitation ≥ 1 mm (trend = -1.9 days/decade) is significantly reduced, so it could be concluded that Podgorica climate tends to be more arid. On the other hand, the number of days with extreme rainfall ≥ 40 and 50 mm is increasing. In Podgorica, the annual number

of days with snow covers decreases at an insignificant rate of 0.4 days / decade. There is also a decrease in the relative humidity and cloudiness, and with both elements the trend is insignificant only in the autumn season. The results of the trend calculations show that the number of decreasing gloomy days is more intensive than the number of increasing bright days, both on an annual and seasonal level.

Previous research has shown that Podgorica climate tends to get warmer and probably with more frequent extreme temperatures (Burić et al., 2019). The results presented in this paper also show that it is moving towards more arid conditions. In any case, further research is needed, both in the field of weather and climate monitoring, and in the analy-

sis of the causes of variability in climate elements. Research into possible mitigation and adaptation to contemporary climate change is also needed. Climate change mitigation is impossible without reducing greenhouse gas emissions; we need to adjust to clean energy sources. A significant form of mitigation is the afforestation and reducing of deforestation.

tion. When it comes to adaptation, it is certain that short-term weather forecasts, or early announcements of dangerous weather events, will be of increasing importance. Such warnings should be respected in order to accustom the population to the expected extreme weather situations and thus avoid or mitigate the negative consequences.

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