www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2021, 71(1), pp. 29–42

Original scientific paper

UDC: 911.2:551.577(497)
https://doi.org/10.2298/IJGI2101029M

Received: October 26, 2020
Reviewed: February 24, 2021
Accepted: March 12, 2021

SPATIO-TEMPORAL VARIABILITY OF PRECIPITATION OVER THE WESTERN BALKAN COUNTRIES AND ITS LINKS WITH THE ATMOSPHERIC CIRCULATION PATTERNS

Dragan Milošević[1], *Rastislav Stojsavljević*[2], *Szilárd Szabó*[3], *Uglješa Stankov*[4], *Stevan Savić*[1]*, *Luka Mitrović*[5]

[1]University of Novi Sad, Faculty of Sciences, Climatology and Hydrology Research Centre, Novi Sad, Serbia; e-mails: dragan.milosevic@dgt.uns.ac.rs; stevan.savic@dgt.uns.ac.rs
[2]University of Novi Sad, Faculty of Sciences, Department of Geography, Tourism and Hotel Management, Novi Sad, Serbia; e-mail: rastislav.stojsavljevic@dgt.uns.ac.rs
[3]University of Debrecen, Faculty of Technology and Sciences, Department of Physical Geography and Geoinformatics, Debrecen, Hungary; e-mail: szabo.szilard@science.unideb.hu
[4]University of Novi Sad, Faculty of Sciences, Center for Spatial Information of Vojvodina Province, Novi Sad, Serbia; e-mail: ugljesa.stankov@dgt.uns.ac.rs
[5]Institute of Hydrometeorology and Seismology of Montenegro, Podgorica, Montenegro; e-mail: luka.mitrovic@meteo.co.me

Abstract: Temporal and spatial variability of annual and seasonal precipitation from 71 stations located in Western Balkan (WB) countries (Serbia, Bosnia and Herzegovina, and Montenegro) and their correlations with nine atmospheric circulation patterns was examined for the period 1950–2016. Annual precipitation increased significantly throughout the WB (from 2% to 8% per decade) on 20% of stations located mainly in the mountainous western Serbia and eastern Bosnia and Herzegovina. Winter was characterized by non-significant precipitation changes in most of the studied area, with only a few stations characterized by significant precipitation increase (up to 12% per decade) in the mountainous area of WB, and a few stations characterized by significant decrease (up to –6% per decade) in the Pannonian plain. Significant precipitation increase was noticed on 15% of the stations in spring, while it was noticed on 17% of the stations in autumn. Summer precipitation decreased significantly (up to –5% per decade) on a limited area of northern Serbia (6% of the stations), while the majority of stations showed non-significant increase. The strongest influences on annual precipitation in WB region are of the Arctic Oscillation (AO) and Mediterranean Oscillation (MO), leading to the precipitation decrease during their positive phases. Winter precipitation is significantly negatively correlated with AO, East Atlantic/Western Russia oscillation (EA/WR), and North Atlantic Oscillation (NAO) and has a significant positive correlation with Western Mediterranean Oscillation (WeMO) on the majority of stations. MO has the strongest influence on summer precipitation in WB region leading to precipitation decrease, while AO has the dominant influence on precipitation in the region during autumn.

Keywords: climate change; precipitation; atmospheric circulations; Western Balkan

*Corresponding author, e-mail: stevan.savic@dgt.uns.ac.rs

Introduction

Spatial and temporal variability of precipitation becomes an increasingly important issue of climate change as the existing differences are expected to increase in the future. Climate models of the Intergovernmental Panel on Climate Change (IPCC, 2018) project robust differences in regional precipitation characteristics in frequency, intensity, and/or amount of heavy precipitation due to global warming; i.e., parallel with the fewer but intense rainfall events it also means that drought frequency and intensity also increases in several regions (Jakab et al., 2019; Kertész, 2016; Szabó et al., 2019). Accordingly, it is crucial to understand the historical variability of precipitation and try to distinguish the changes from natural pattern on different spatial scales in order to incorporate them into climate models for the future.

Spring rainfall over the Balkan region revealed significant upward trends over the period 1950–2014 in a study of Stadtherr, Coumou, Petoukhov, Petri, and Rahmstorf (2016). Luković, Bajat, Blagojević, and Kilibarda (2014) did not detect significant trends in Serbia at an annual scale in the period 1961–2009. However, seasonal trends indicated a slight decrease in winter and spring precipitation and an increase in autumn precipitation on a limited number of stations for the period 1961–2009. Significant annual precipitation decrease in northwestern and western Slovenia and during all the seasons (except autumn) was obtained in a study of de Luis et al. (2014) for a period 1951–2007. Similar results were obtained by Milošević et al. (2016) that revealed significant annual precipitation decrease (from −3% to −6% per decade) in western Slovenia and significant negative trends in southwestern Slovenia in summer (from −4% to −10% per decade) and near the Adriatic coast in spring (from −6% to −10% per decade) in the period 1963–2012. The study of Popov, Gnjato, Bajić, and Trbić (2019) investigated the spatial distribution of the seasonal and annual precipitation in Bosnia and Herzegovina using the mean monthly precipitation data from 40 meteorological stations for the period 1961–1990. They have identified three sub-regions with different precipitation regimes over the territory of Bosnia and Herzegovina: northwest sub-region, northeast, east and central part sub-region, and south sub-region. Burić, Ducić, Mihajlović, Luković, and Dragojlović (2014) obtained mainly non-significant trends in the seasonal and annual precipitation in Montenegro in the period 1951–2010. Zikov and Bakeva (2014) noticed a slight decline in the average annual precipitation in North Macedonia for the period 1925–2003. In a study of Tošić (2004), a decreasing trend in winter precipitation in Serbia and Montenegro was noticed for the period 1951–2000. The results obtained by Popov, Gnjato, and Trbić (2018) suggested a general increase in heavy precipitation over the northern region of Bosnia and Herzegovina in the period 1961–2016. Furthermore, a study of Popov, Gnjato, and Trbić (2019) obtained a downward trend in annual precipitation over the East Herzegovina region, with negative trends prevailing throughout the year, except in autumn season in the period 1961–2016.

Changes in meteorological variables (e.g., precipitation) in mid-latitudes are mainly controlled by the atmospheric circulation patterns (Hurrell, 1995; Hurrell & Van Loon, 1997). They represent large and persistent patterns of pressure anomalies that influence the flow of air masses affecting climate of broad geographical regions (Hurrell, 1995), such as WB region of Europe. Only a few studies cover the correlations between precipitation in WB countries and atmospheric circulation patterns and they are mostly limited to one country or a small number of atmospheric circulation patterns. Milošević et al. (2016) showed that Western Mediterranean Oscillation (WeMO) is the most dominant atmospheric circulation pattern influencing annual and seasonal precipitation variability in Slovenia, except for winter during the period 1963–2012. In winter, Mediterranean Oscillation (MO) and North Atlantic Oscillation (NAO) are the most significant atmospheric circulation patterns influencing precipitation quantities. Furthermore, the strongest influences of NAO and Arctic Oscillation (AO) on precipitation in Serbia were noticed during cold season (January–March) in the period 1958–2007 (Pavlović Berdon, 2012). In another study of Pavlović Berdon (2013), the significant influence of East Atlantic/Western Russia (EA/WR) atmospheric circulation on winter precipitation was also observed in Serbia in the period 1950–2010. Jovanović, Reljin, and Reljin (2008) noticed that NAO and AO have dominant influence on precipitation regime in Serbia in the period 1961–2006, especially during winter. Higher correlation coefficients were obtained for AO then for NAO index suggesting that AO phenomenon has more prominent impact on the region. Tošić (2004) analysed winter and summer precipitation over Serbia and Montenegro and obtained strong correlation between one of the winter precipitation patterns and the NAO index in the period 1951–2000, which indicated that NAO could be responsible for the winter precipitation variability. Efthymiadis, Jones, Briffa, Böhm, and Maugeri (2007) noticed that the NAO is the primary mode affecting south-eastern Great Alpine Region precipitation variability which includes an area of WB (i.e., Bosnia and Herzegovina) in the period 1821–2004. Popov, Gnjato, and Trbić (2019) also noticed that the precipitation variability over the East Herzegovina is strongly dictated by NAO, EA/WR, and AO in the period 1961–2016.

In this study, precipitation variability was analyzed for three WB countries: Serbia, Bosnia and Herzegovina, and Montenegro for the period 1950–2016. We have defined three main research goals of this study: (a) to analyze temporal and spatial variability of annual and seasonal precipitation quantities in the selected WB countries; (b) to analyze seasonal and annual precipitation trends and their statistical significance in the selected WB countries; and (c) to correlate seasonal and annual precipitation quantities with seasonal and annual values of atmospheric circulation patterns indices influencing the European region. Obtained results of precipitation quantities, trends, and correlations with atmospheric circulation patterns can be of valuable contributions for the climate change scenarios, analysis and evaluation of models, as well as for the development of mitigation and adaptation plans for the WB countries.

Data and methods

Study area

The Western Balkans (WB) is a geopolitical term introduced by the governing bodies of the European Union in the early 2000s that referred to the countries in south-eastern Europe that were not EU members or candidates at the time, yet they could aspire to join the bloc (Dabrowski & Myachenkova, 2018). This area is situated in Europe, between Hungary in the north, Greece to the south, Croatia and the Adriatic Sea to the west, and Romania and Bulgaria to the east. Countries situated in this area are: Serbia, Bosnia and Herzegovina, Montenegro, Albania, and North Macedonia. The relief of WB countries is dominated by mountainous Balkan Peninsula with the Dinaric and Balkan Mountains, except for the north of Serbia which is located on the Pannonian Plain. The total research area is 153,300 km^2, i.e., 88,361 km^2 in Serbia (Pavlović, 2018), 51,129 km^2 in Bosnia and Herzegovina (Davidović, 2004), and 13,812 km^2 in Montenegro (Fabris & Žugić, 2012), with the total population of approximately 11 million (Central Intelligence Agency, 2020) (Figure 1). The climate of the area is mostly continental and temperate continental, with mountain climate in the mountainous areas and Submediterranean climatic influences on the Adriatic coast and its hinterland.

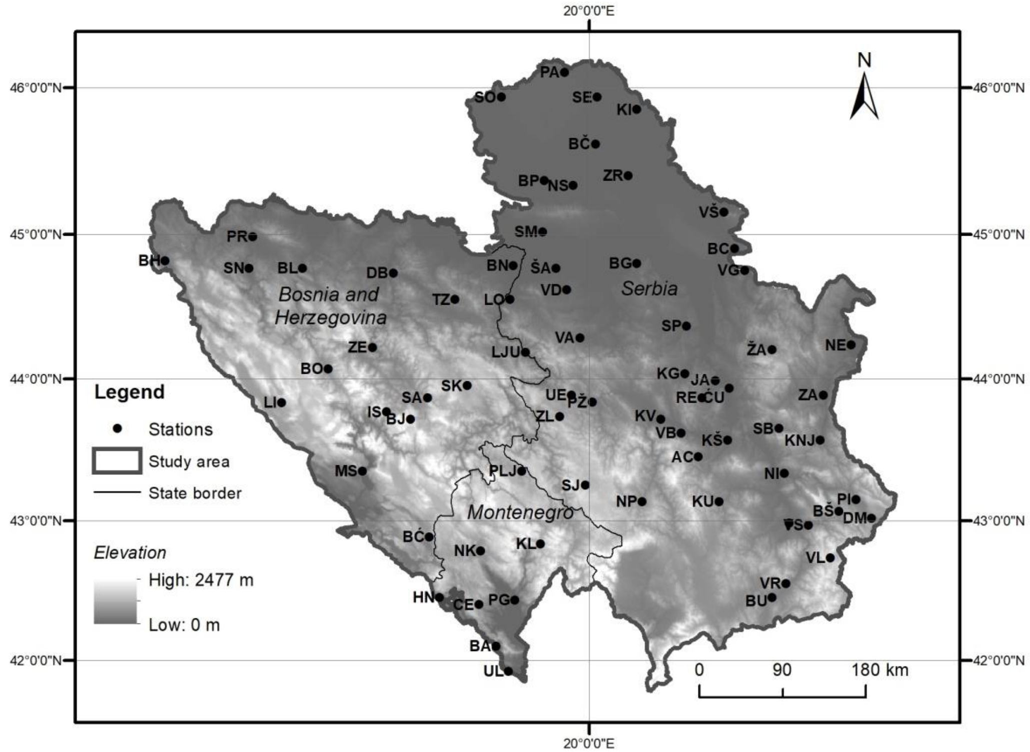

Figure 1. Location of Western Balkan countries and the distribution of 71 precipitation stations in Serbia, Bosnia and Herzegovina, and Montenegro.

Precipitation data

Precipitation from 71 meteorological stations located in the WB countries (Figure 1) was analyzed on annual and seasonal levels in the period 1950–2016. The stations are located on the territories of three countries: 47 stations in Serbia, 16 stations in Bosnia and Herzegovina, and eight stations in Montenegro. The area of interest is situated between approximately 41°N and 46°N, and between 15°E and 23°E. Meteorological stations were selected based on the data availability and homogeneity as well as depending on the country size, climate types, and altitudes. Precipitation data was obtained from the official Hydrometeorological Institutions of Serbia, Bosnia and Herzegovina, and Montenegro and the data homogenization were performed by these institutions.

Winter, spring, summer, and autumn precipitation average sums and trends compared to the long-term means (1961–1990) were calculated for each station using standard season's definition, i.e., every season lasts for three months: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). Precipitation sums were calculated for each year in the analyzed period on annual and seasonal level. Furthermore, annual and seasonal trends of precipitation sums were calculated for each year and compared to the 30-year annual and seasonal averages (1961–1990).

Atmospheric circulation data

In this study, we used data for nine atmospheric circulation patterns represented by their index values: Arctic Oscillation index (*AOi*), East Atlantic Oscillation index *(EAi*), East Atlantic/Western Russia Oscillation index (*EA/WRi*), Oceanic Niño index (*ONi*) and the Nino3.4 index, Mediterranean Oscillation index (*MOi*), North Atlantic Oscillation index (*NAOi*), Scandinavian Oscillation (*SCANDi*), and Western Mediterannean Oscillation index (*WeMOi*). Monthly values of *AOi, EAi, EA/WRi, ONi, Nino3.4i, NAOi*, and *SCANDi* were obtained from the Climate Prediction Center (CPC) available at: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/climwx.shtml. Daily values of *MOi* were obtained from the Climatic Research Unit (CRU) available at: https://crudata.uea.ac.uk/cru/data/moi/. Monthly values of *WeMOi* were obtained from the University of Barcelona website available at: http://www.ub.edu/gc/documents/Web_WeMOi.txt. Afterwards, annual and seasonal values of the selected atmospheric circulation indices were calculated for the period 1950–2016.

Statistical methods

Based on the obtained data, simple linear regression was used to obtain trends of annual and seasonal precipitation. The statistical significance of the obtained precipitation trends was determined with Mann-Kendall non-parametric statistical test (Sneyers, 1991). For this purpose, MAKESENS calculation macro in Excel software was used, which was developed by the Finnish Meteorological Institute (Salmi, Määttä, Anttila, Ruoho-Airola, & Amnell, 2002). Precipitation changes are expressed as % per decade because of the differences in precipitation amounts between stations.

To reveal the connections between annual and seasonal precipitation and atmospheric circulation patterns, Spearman test was selected and applied in the IBM SPSS Statistics (Version 23) software. Spearman test was chosen instead of the Pearson correlation coefficient because it is based on the free probability distribution of variables (i.e., does not require normal distribution) and no linear relationship between them (Irannezhad, Marttila, & Kløve, 2014). Other reasons for selecting the Spearman test are: (i) it runs better than Linear Pearson coefficient when rainfall outlier values are present; and (ii) Linear trends can be detected using Pearson or Spearman test, yet Spearman is preferable for monotonic non-lineal relationships (Gautheir, 2001; von Storch & Zwiers, 1999). Finally, numerous published studies had successfully applied the Spearman test in their research of correlations between precipitation and teleconnections (e.g., Dong et al., 2020; Irannezhad, Liu, & Chen, 2020; Irannezhad et al., 2014; Ríos-Cornejo, Penas, Álvarez-Esteban, & del Río, 2020). The spatial distribution of the observed precipitation quantities and trends for 71 stations was plotted using ordinary Kriging method of interpolation (Oliver & Webster, 1990) with the Version 10.6 of ArcGIS (Esri, 2018).

Results

Annual and seasonal precipitation distribution in WB countries

The highest annual precipitation amounts were registered at stations located in the southwestern, coastal and mountainous parts of Montenegro (maximum of 3276 mm at station Cetinje—CE) and Bosnia and Herzegovina, influenced by the interactions between Mediterranean and continental air masses. Towards the northeast, mountain and continental climatic influences strengthen with the lowest precipitation amounts recorded in the Pannonian plain in Serbia (minimum of 559 mm at station Kikinda—KI). During winter, the highest precipitation amounts were observed at stations located in the southwest of WB, in the hinterland of the Adriatic coast at the mountainous parts of Montenegro (600–1200 mm). The precipitation was reduced in the northwestern Bosnia and Herzegovina (200–600 mm), but the lowest precipitation amounts (<200 mm) were registered in northeast Bosnia and Herzegovina and larger part of Serbia. Seasonal precipitation range was the highest during winter with a difference of approximately 1200 mm between CE and KI stations. The influences of the vicinity of the Adriatic Sea and the relief of Dinaric Alps are once more evident during spring when precipitation amounts are substantially higher in the western part of the studied region compared to its eastern part. The southwestern, coastal and mountainous part of Montenegro had the highest amount of precipitation in spring (>400 mm), followed by Bosnia and Herzegovina (200–400 mm), and Serbia (<200 mm). Summer was characterized by substantial decrease of precipitation in the southwestern, mountainous part of Montenegro where <200 mm of precipitation was recorded. The western, central, and a part of northern (Pannonian) Serbia was characterized by intermediate values of precipitation (200–400 mm). Compared to the spring, seasonal precipitation was higher in autumn in the coastal part and its mountainous hinterland with >600 mm, while in Serbia the values of <200 mm were noticed at most of the stations. Relatively even/uneven precipitation distribution throughout the year was noticed in the moderate/ Submediterranean climate.

Annual and seasonal precipitation trends in WB countries

Regarding annual precipitation, a significant ($p < .05$) positive trend was noticed at 20% of the stations (from 2% to 8% per decade); however, the majority of the noticed positive trends were non-significant. These stations were in the mountainous western Serbia and eastern Bosnia and Herzegovina with continental and mountain climatic influences. Interestingly, station Prijedor (PR) in the valley of the river Sana in northwestern Bosnia and Herzegovina shows a statistically significant negative trend (–3% per decade) (Figure 2a, Table 1). During winter, non-significant changes were noticed over the majority of the continental parts of the WB (Table 1). Only the high-altitude meteorological stations in the studied region (>1000 m a.s.l., stations BJ, ZL, and SJ) showed significant positive trends between 4% and 12% per decade. On the contrary, stations SM, BP, and BČ located in the low Pannonian plain (<100 m a.s.l.) in northern Serbia, showed statistically significant negative trends (from –5% to –6% per decade; Figure 2b).

Table 1
The percentage of stations (%) with statistically significant and non-significant (NS) annual and seasonal precipitation trends in WB countries during the period 1950–2016

Precipitation	Annual	Winter	Spring	Summer	Autumn
Significant positive trend	20	4	15	0	17
Significant negative trend	1	4	1	6	1
Non-significant positive trend	69	45	74	67	79
Non-significant negative trend	10	47	10	27	3

During spring, increasing precipitation trends were identified in almost the whole research area with statistically significant trends at 15% of stations (Table 1). These stations were located mainly in the mountainous regions of Bosnia and Herzegovina and in the valleys of western Serbia with values between 2% and 10% per decade (Figure 2c). Contrary to spring, summer was characterized by non-significant increase of precipitation at the majority of the stations with only four stations in the northern part of the research area showing significant precipitation decrease with −1% to −5% per decade (Figure 2d). Autumn was characterized by significant precipitation increase in the lower areas of northern Serbia and in the mountainous area between the three countries (17% of stations) with positive trends between 4% and 7% per decade. Only the station HN showed significant precipitation decrease of 4% per decade in the coastal area of Montenegro (Figure 2e).

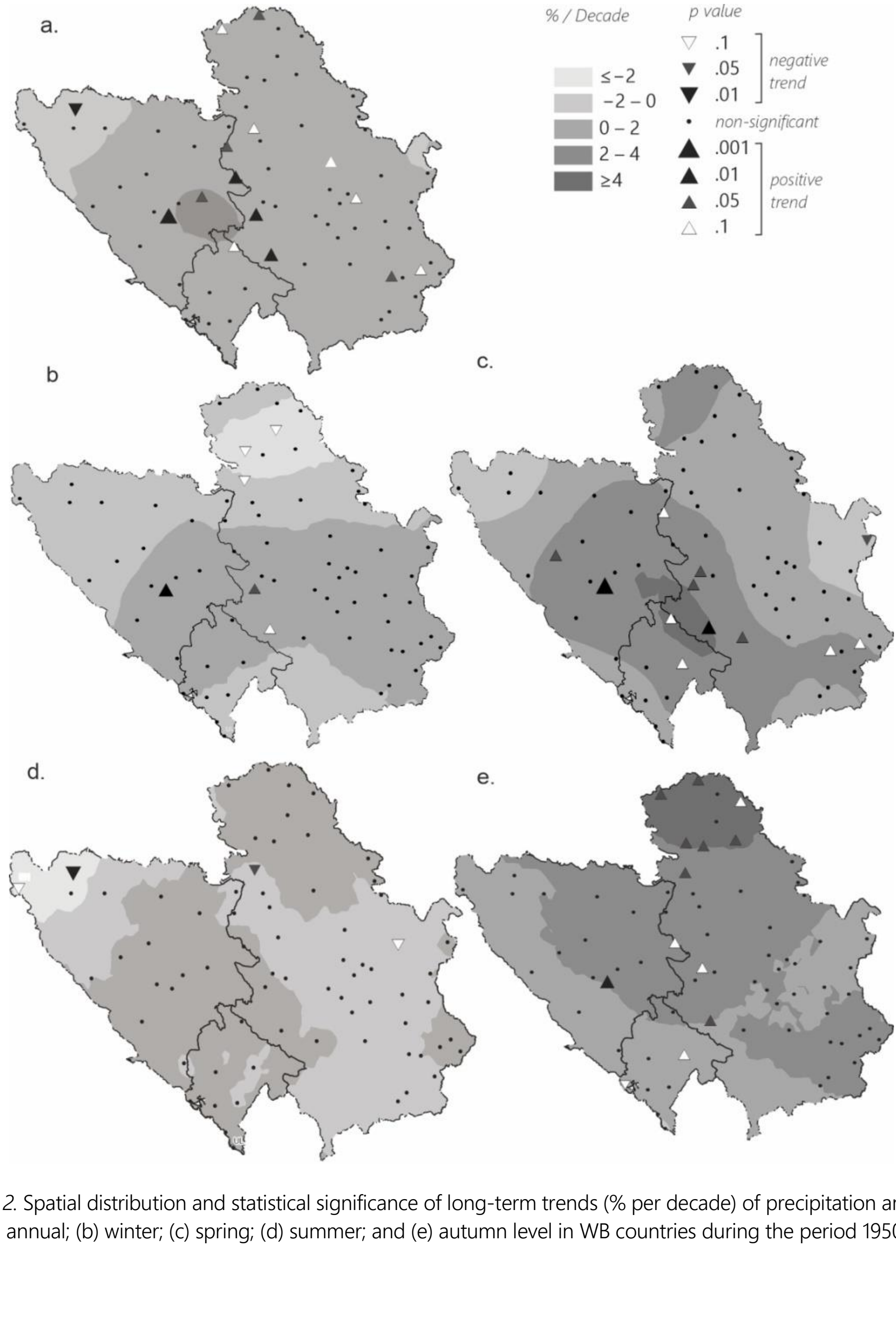

Figure 2. Spatial distribution and statistical significance of long-term trends (% per decade) of precipitation amounts on: (a) annual; (b) winter; (c) spring; (d) summer; and (e) autumn level in WB countries during the period 1950–2016.

The correlations between annual and seasonal precipitation and atmospheric circulation patterns

Annual precipitation in WB countries showed significant negative correlations in the period 1950–2016 with four atmospheric circulation patterns: *AOi* (Figure 3), *MOi*, *NAOi*, and *EA/WRi* at 66%, 52%, 39%, and 27% of stations, respectively (Table 2). The spatial pattern of these correlations showed that the highest influences of AO and NAO are in the Submediterranean and mountainous area of the WB, with larger correlation coefficient values between precipitation and *AOi*. The influences of AO (Figure 3) and NAO are spatially decreasing toward the northeastern part of the research area. The influence of MO was observed throughout the research area with smaller coefficient values, while *EA/WR* influenced only a limited area in the east and south of the WB. Precipitation showed statistically significant positive correlation with SCAND at 11% of the stations in the western part of the study area (Table 2).

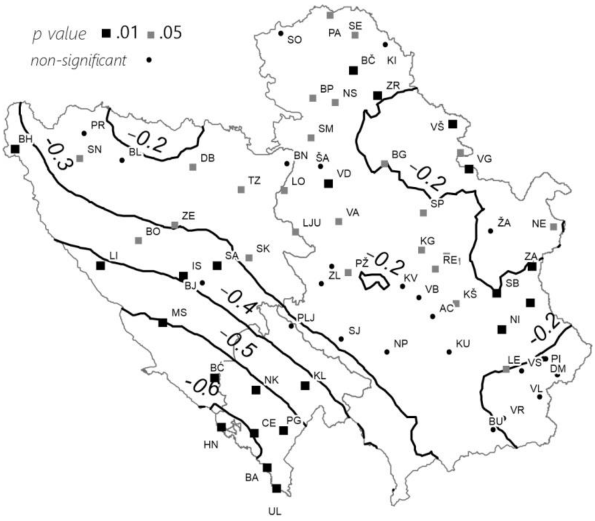

Figure 3. Spatial distribution of the Spearman's rank correlation coefficient values between annual precipitation and *AOi*. Square represents negative correlation with significance at: $p < .01$, $p < .05$, and circle represents non-significant.

Table 2
The percentage of stations (%) with statistically significant ($p < .01$, $p < .05$) and non-significant (NS) correlations between seasonal and annual mean precipitation and atmospheric circulation indices in the period 1950–2016

Atm. circulation indices	Annual			Winter			Spring			Summer			Autumn		
	NS	+	–	NS	+	–	NS	+	–	NS	+	–	NS	+	–
AOi	34	0	66	3	0	**97**	72	0	28	90	10	0	15	0	85
EAi	96	3	1	100	0	0	99	0	1	73	0	**27**	99	0	1
EA/WRi	73	0	27	7	0	**93**	92	0	8	99	1	0	39	0	61
MOi	48	0	52	62	0	38	99	1	0	15	0	**85**	96	1	3
NAOi	61	0	39	28	0	**72**	82	0	18	69	31	0	63	0	37
ONi	96	0	4	99	1	0	100	0	0	96	4	0	90	0	**10**
Nino3.4i	96	0	4	100	0	0	100	0	0	99	1	0	89	0	**11**
SCANDi	89	11	0	69	**31**	0	99	0	1	75	25	0	87	13	0
WeMOi	94	0	6	10	**90**	0	89	11	0	94	0	6	77	23	0

Note. Bolded numbers represent the highest values for each of the atmospheric circulation patterns on annual and seasonal level; + positive correlation; – negative correlation; NS – non-significant correlation.

The strongest correlations between precipitation and atmospheric circulation patterns on seasonal level were noticed in winter. Significant negative correlation was observed between precipitation and *AOi* (Figure 4), *EA/WRi*, *NAOi*, and *MOi* accounting for 97%, 93%, 72%, and 38% of the stations in the research area, respectively. On the contrary, significant positive correlation was observed between winter precipitation and *WeMOi* and *SCANDi* on 90% and 31% of the stations (Table 2). Regarding the spatial distribution of correlations, AO (Figure 4) and *EA/WR* influence was identified throughout the study area, while *NAO* and *MO* influences were the largest near the Adriatic coast, in its mountainous hinterland and in the Pannonian plain to the northeast. Positive correlations between precipitation and WeMO were revealed in the majority of the WB area with the highest coefficient values in the Pannonian and Peripanonnian area and were decreasing toward the southeast. On the contrary, positive correlations between precipitation and SCAND were noticed on a limited area with the highest correlation values near the Adriatic coast and in the Dinaric mountains in the southwest, and were decreasing towards the central area of WB countries.

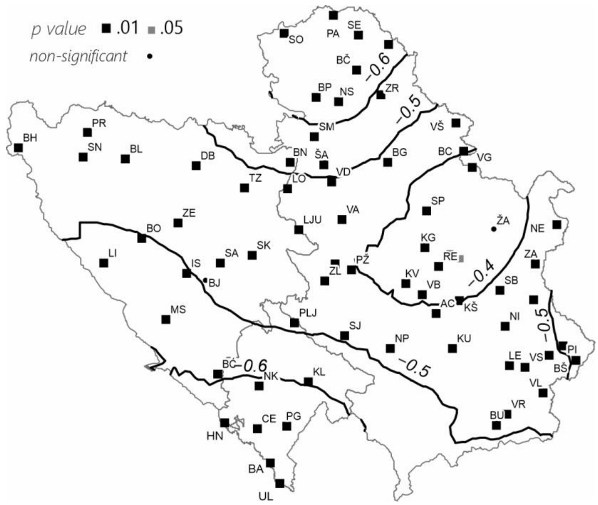

Figure 4. Spatial distribution of the Spearman's rank correlation coefficient values between winter precipitation and *AOi*. Square represents negative correlation with significance at: p < .01, p < .05, and circle represents non-significant.

The influence of atmospheric circulation patterns on precipitation amounts in WB is the weakest in spring. Areas with significant negative correlations between precipitation and *AOi*, *NAOi*, and *EA/WRi* were smaller with 28%, 18%, and 8% of the stations accounted for. WeMO had significant positive influence on precipitation at 11% of the stations (Table 2). Spatially plotted correlations suggested that AO and WeMO influences were the strongest near the Adriatic coast and its hinterland, while NAO influence was dominant in the eastern part of the research area.

Correlations between precipitation and atmospheric circulation indices were stronger in summer. A strong negative correlation between precipitation and *MOi* was noticed on the 85% of the stations (Table 2). Accordingly, it can be stated that *MOi* is the most important circulation patterns for summer precipitation in the northern part of the selected WB countries. Further significant negative correlations were noticed between precipitation and *EAi* in a smaller area at only 27% of the stations. Significant positive correlations between precipitation and *NAOi*, *SCANDi*, and *AOi* were noticed at 31%, 25%, and 10% of the stations, respectively, with a spatially heterogeneous distribution.

Autumn precipitation was significantly negatively correlated with *AOi* and *EA/WRi* at more than half of all the stations, i.e., 85% and 61%, respectively (Table 2). AO influence was the strongest near the Adriatic coast in Montenegro, in Bosnia and Herzegovina, and in the northern and southeastern Serbia. The influence of EA/WR on autumn precipitation was the strongest in Serbia, especially its northern Pannonian area, while the influence of NAO was the strongest with significant negative correlations at 37% of the stations located in Montenegro, central Bosnia and Hercegovina, and northern Serbia

(Table 2). The influence of *ONi* and *Nino3.4i* on precipitation was the strongest in autumn, yet on a limited area (10-11% of stations; Table 2) of central, mountainous Serbia and northern Montenegro. The significant positive correlation between precipitation and *WeMOi* and *SCANDi* was noticed with 23% and 13% of the stations mainly located in the Dinaric mountainous range of Montenegro and in Bosnia and Herzegovina (Table 2).

Discussion and conclusions

In this paper, we performed the analysis of precipitation quantities, distribution, and trends in order to understand the spatial and temporal characteristics and variability of annual and seasonal precipitation in WB countries of Serbia, Bosnia and Herzegovina, and Montenegro. Furthermore, precipitation was correlated with nine atmospheric circulation patterns in order to characterize their influences on precipitation variability during the period of 67 years (1950–2016).

Precipitation distribution showed diverse spatial characteristics in WB countries with annual precipitation range of >2700 mm between the area of Mediterranean climate in southwest of Montenegro and southwestern continental (non-coastal) parts of Bosnia and Herzegovina and continental climate in the northern plains of Serbia widely open to the north. The noticed precipitation decrease toward the northeast of the studied area is due to the fact that WB countries are exposed to the inflow of moisture air from the Adriatic Sea and to topographically-induced precipitation by the Dinaric Alps which represent the barrier for the moist air to reach the northeastern area of WB (Milošević et al., 2016). On the seasonal level, the highest regional differences in precipitation in WB countries occur during winter and the smallest differences occur during summer.

Annual precipitation trends in WB countries showed non-significant positive values in the majority of research area, except for 20% of the locations in the central part of the research area with significant precipitation increase from 2% to 8% per decade. Significant positive precipitation trends were noticed during spring and autumn on 15% and 17% of stations, respectively. During summer, the majority of stations had non-significant precipitation changes except for few stations in northern Serbia which had significant decrease up to –5% per decade. Winter was characterized by non-significant decrease or increase of precipitation in the majority of the studied area. Significant winter precipitation increases of up to 12% decade were registered on stations in the Dinaric Alps region. Contrary to that, few stations located in the southwestern part of the Pannonian plain (<100 m) in the north of Serbia, surrounded by the Sava and the Danube rivers, showed statistically significant negative trends of up to –6% per decade.

Precipitation in WB region showed no uniform trend when compared to previous studies. For example, non-significant precipitation changes have been found in Serbia in the past century. Seasonal trends showed increase in autumn precipitation in Serbia, similarly as in this study. However, a decrease in winter and spring precipitation was also noticed (Luković et al., 2014). Furthermore, previous study of Burić et al. (2014) also obtained mainly non-significant trends in seasonal and annual precipitation in Montenegro, while the study of Zikov and Bakeva (2014) noticed a slight decrease of average annual precipitation in North Macedonia. For Bosnia and Herzegovina, the study of Popov, Gnjato, Bajić, & Trbić (2019) recognized three sub-regions with different precipitation regimes indicating the significance of regional differences within the country of investigation. In general, the obtained trends from previous studies comply with projected precipitation decrease in the Mediterranean region (IPCC, 2007; Jacobeit, Hertig, Seubert, & Kutz, 2014) suggesting to be the most pronounced in summer (Dubrovský et al., 2014).

Annual precipitation in WB region is significantly negatively correlated with AO and MO, followed by NAO and EA/WR atmospheric circulation patterns. During the positive phases of these circulations, precipitation decrease was noticed. During NAO positive phase, low-pressure anomalies throughout the Arctic combine with high-pressure anomalies across the subtropical Atlantic leading to drier conditions over the Mediterranean region (Visbeck, Hurrell, Polvani, & Cullen, 2001), including WB area. The positive phase of MO is related to anticyclonic conditions in the western Mediterranean and with below-average rainfall rates in the entire Mediterranean basin (Marta & Begueria, 2012) including the studied region.

On a seasonal level, the largest influences of atmospheric circulations on precipitation amounts are noticed during winter. Significant negative correlations are noticed between winter precipitation and AO, EA/WR, and NAO over the majority of the research area. For Serbia, Jovanović et al. (2008) noticed that NAO and AO have a dominant influence on the winter precipitation regime in Serbia. The studies of Pavlović Berdon (2012, 2013) confirmed these findings and also noticed the strongest influences of AO, NAO, and EA/WR on precipitation in Serbia during a cold season. For Serbia and Montenegro, Tošić (2004) noticed that NAO could be responsible for the winter precipitation variability. The study of Popov, Gnjato, and Trbić (2019) recognized the strong influences of NAO, EA/WR, and AO precipitation variability over eastern Herzegovina, particularly during winter. Furthermore, in our study, winter precipitation is significantly positively correlated with WeMO and SCAND having the highest values during this season. WeMO positive phase corresponds to anticyclone over the Azores and low-pressures in the Liguria Gulf (Martin-Vide & Lopez-Bustins, 2006) resulting in a higher precipitation amounts in larger part of WB region in all the seasons, except for summer when its influence is spatially limited. A similar result was obtained for Slovenia in a study of Milošević et al. (2016). WeMO negative phase corresponds to the anticyclone north of Italy and the low-pressure centre in the Iberian south-west (Martin-Vide & Lopez-Bustins, 2006) leading to a precipitation decrease in WB region. Spring precipitation correlations with atmospheric circulations are the weakest during this season with only a limited area under a significant influence of AO and NAO. It could be that local factors such as topography of complex terrain (Bojariu & Giorgi, 2005; Fernández, Sáenz, & Zorita, 2003) can substantially influence precipitation and limit the influence of atmospheric circulations. In summer, MO has a predominant influence on the decrease of precipitation amounts in the majority of WB region. Contrary to that, AO influence is the largest during autumn season regarding precipitation in the WB region. For Montenegro, the study of Burić et al. (2014) estimated the influence of MO and WeMO on precipitation variability. Correlation estimates showed that MO has a strong influence on rainfall parameters for winter season. However, some of the rainfall parameters for spring and autumn had a better relationship with WeMO.

The results obtained in the study should contribute to the better understanding of precipitation quantities, distribution, and trends in the countries of WB region. Furthermore, the most dominant atmospheric circulation patterns and their influences on annual and seasonal precipitation in this region were noticed. The strongest influences are by AO and MO on annual precipitation, AO, EA/WR, WeMO, and NAO on winter precipitation, MO on summer precipitation, and AO on autumn precipitation, while in spring the influences of atmospheric circulations were on a limited area. Accordingly, the influences of the regional patterns of climate variability (e.g., MO and WeMO) and principal modes of the atmospheric circulation variability (e.g., AO, EA/WR, NAO) on a precipitation distribution in WB were registered.

Acknowledgements

The authors acknowledge financial support of the Provincial Secretariat for Higher Education and Scientific Research, Autonomous Province of Vojvodina (Project 142-451-3143/2020-02) and the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-68/2020-14/200125). Dr. Szabó Szilárd was supported by the Higher Education Institutional Excellence Programme (NKFIH-1150-6/2019) of the Ministry of Innovation and Technology in Hungary, within the framework of the 4th thematic programme of the University of Debrecen.

References

Bojariu, R., & Giorgi, F. (2005). The North Atlantic Oscillation signal in a regional climate simulation for the European region. *Tellus A: Dynamic Meteorology and Oceanography, 57*(4), 641–653. https://doi.org/10.3402/tellusa.v57i4.14709

Burić, D., Ducić, V., Mihajlović, J., Luković, J., & Dragojlović, J. (2014). Relationship between the precipitation variability in Montenegro and the Mediterranean oscillation. *Bulletin of the Serbian Geographical Society*, *94*(4), 109–120. https://doi.org/10.2298/GSGD1404109B

Central Intelligence Agency. (2021). *The World Factbook*. Retrieved from https://www.cia.gov/the-world-factbook/countries/

Dabrowski, M., & Myachenkova, Y. (2018). *The Western Balkans on the road to the European Union* (No. 2018/04). Retrieved from https://www.bruegel.org/wp-content/uploads/2018/02/PC-04_2018.pdf

Davidović, R. (2004). *Regionalna geografija Evrope* [Regional geography of Europe]. Novi Sad, Serbia: University of Novi Sad.

de Luis, M., Čufar, K., Saz, M. A., Longares, L. A., Ceglar, A., & Kajfež-Bogataj, L. (2012). Trends in seasonal precipitation and temperature in Slovenia during 1951–2007. *Regional Environmental Change*, *14*(5), 1801–1810. https://doi.org/10.1007/s10113-012-0365-7

Dong, Y., Zhai, J., Zhao, Y., Li, H., Wang, Q., Jiang, S., . . . & Ding, Z. (2020). Teleconnection patterns of precipitation in the Three-River Headwaters region, China. *Environmental Research Letters*, *15*(10), 104050. https://doi.org/10.1088/1748-9326/aba8c0

Dubrovský, M., Hayes, M., Duce, P., Trnka, M., Svoboda, M., & Zara, P. (2013). Multi-GCM projections of future drought and climate variability indicators for the Mediterranean region. *Regional Environmental Change, 14*(5), 1907–1919. https://doi.org/10.1007/s10113-013-0562-z

Efthymiadis, D., Jones, P. D., Briffa, K. R., Böhm, R., & Maugeri, M. (2007). Influence of large-scale atmospheric circulation on climate variability in the Greater Alpine Region of Europe. *Journal of Geophysical Research, 112*(D12), D12104. https://doi.org/10.1029/2006jd008021

Esri. (2018). ArcGIS [Computer software]. Retrieved from https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

Fabris, N., & Žugić, R. (2012). Regionalisation and regional policy of Montenegro. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, *62*(1), 49–67. https://doi.org/10.2298/IJGI1201049F

Fernández, J., Sáenz, J., & Zorita, E. (2003). Analysis of wintertime atmospheric moisture transport and its variability over southern Europe in the NCEP Reanalyses. *Climate Research, 23*(3), 195–215. https://doi.org/10.3354/cr023195

Gautheir, T. D. (2001). Detecting Trends Using Spearman's Rank Correlation Coefficient. *Environmental Forensics*, *2*(4), 359–362. https://doi.org/10.1080/713848278

Hurrell, J. W. (1995). Decadal Trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. *Science, 269*(5224), 676–679. https://doi.org/10.1126/science.269.5224.676

Hurrell, J. W., & Van Loon, H. (1997). Decadal variations in climate associated with the North Atlantic Oscillation. *Climatic Change*, *36*(3), 301–326. https://doi.org/10.1023/a:1005314315270

Intergovernmental Panel on Climate Change. (2007). *The Physical Science Basis, Summary for Policymakers* (contribution of WG I to the 4th Assessment Report of the IPCC). Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (pp. 3–24). Retrieved from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf

Irannezhad, M., Liu, J., & Chen, D. (2020). Influential Climate Teleconnections for Spatiotemporal Precipitation Variability in the Lancang-Mekong River Basin From 1952 to 2015. *Journal of Geophysical Research: Atmospheres*, *125*(21), e2020JD033331. https://doi.org/10.1029/2020JD033331

Irannezhad, M., Marttila, H., & Kløve, B. (2014). Long-term variations and trends in precipitation in Finland. *International Journal of Climatology*, *34*(10), 3139–3153. https://doi.org/10.1002/joc.3902

Jakab, G., Bíró, T., Kovács, Z., Papp, Á., Sarawut, N., Szalai, Z., Madarász, B., & Szabó, S. (2019). Spatial analysis of changes and anomalies of intense rainfalls in Hungary. *Hungarian Geographical Bulletin*, *68*(3), 241–253. https://doi.org/10.15201/hungeobull.68.3.3

Jacobeit, J., Hertig, E., Seubert, S., & Lutz, K. (2014). Statistical downscaling for climate change projections in the Mediterranean region: methods and results. *Regional Environmental Change*, *14*(5), 1891–1906. https://doi.org/10.1007/s10113-014-0605-0

Jovanović, G., Reljin, I., & Reljin, B. (2008). The influence of Arctic and North Atlantic Oscillation on precipitation regime in Serbia. *IOP Conference Series: Earth and Environmental Science*, *4*, 012025. https://doi.org/10.1088/1755-1307/4/1/012025

Kertész, Á. (2016). Is desertification a problem in Hungary? *Landscape & Environment*, *10*(3–4), 242–247. https://doi.org/10.21120/LE/10/3-4/18

Luković, J., Bajat, B., Blagojević, D., & Kilibarda, M. (2014). Spatial pattern of recent rainfall trends in Serbia (1961–2009). *Regional Environmental Change*, *14*(5), 1789–1799. https://doi.org/10.1007/s10113-013-0459-x

Martin-Vide, J., & Lopez-Bustins, J.-A. (2006). The Western Mediterranean Oscillation and rainfall in the Iberian Peninsula. *International Journal of Climatology*, *26*(11), 1455–1475. https://doi.org/10.1002/joc.1388

Milošević, D. D., Savić, S. M., Pantelić, M., Stankov, U., Žiberna, I., Dolinaj, D., & Leščešen, I. (2016). Variability of seasonal and annual precipitation in Slovenia and its correlation with large-scale atmospheric circulation. *Open Geosciences*, *8*(1), 593–605. https://doi.org/10.1515/geo-2016-0041

Oliver, M. A., & Webster, R. (1990). Kriging: a method of interpolation for geographical information systems. *International Journal of Geographical Information System*, *4*(3), 313–332. https://doi.org/10.1080/02693799008941549

Pavlović, M. (2018). *Geografija Srbije 1* [Geography of Serbia 1]. Belgrade, Serbia: University of Belgrade–Faculty of Geography.

Pavlović Berdon, N. (2012). The Impact of Arctic and North Atlantic Oscillation on Temperature and Precipitation Anomalies in Serbia. *Geographica Pannonica*, *16*(2), 44–55. Retrieved from http://www.dgt.uns.ac.rs/dokumentacija/pannonica/papers/volume16_2_2.pdf

Pavlović Berdon, N. (2013). The Impact of Teleconnection on Pressure, Temperature and Precipitation in Serbia. *International Journal of Remote Sensing Applications*, *3*(4), 185–192. https://doi.org/10.14355/ijrsa.2013.0304.03

Popov, T., Gnjato, S., Bajić, D., & Trbić, G. (2019). Spatial Patterns of Precipitation in Bosnia and Herzegovina. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, *69*(3), 185–195. https://doi.org/10.2298/IJGI1903185P

Popov, T., Gnjato, S., & Trbić, G. (2018). Analysis of extreme precipitation over the Peripannonian region of Bosnia Hercegovina. *Időjárás*, *122*(4), 433–452. https://doi.org/10.28974/idojaras.2018.4.5

Popov, T., Gnjato, S., & Trbić, G. (2019). Changes in precipitation over the East Herzegovina region. *Bulletin of the Serbian Geographical Society*, *99*(1), 29–44. https://doi.org/10.2298/GSGD1901029P

Ríos-Cornejo, D., Penas, Á., Álvarez-Esteban, R., & del Río, S. (2015). Links between teleconnection patterns and precipitation in Spain. *Atmospheric Research*, *156*, 14–28. https://doi.org/10.1016/j.atmosres.2014.12.012

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., & Anmell, T. (2002). *Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates-the Excel template application MAKESENS*. Helsinki, Finland: Finnish Meteorological Institute.

Szabó, S., Szopos, N. M., Bertalan-Balázs, B., László, E., Milošević, D. D., Conoscenti, C., & Lázár, I. (2019). Geospatial analysis of drought tendencies in the Carpathians as reflected in a 50-year time series. *Hungarian Geographical Bulletin*, *68*(3), 269–282. https://doi.org/10.15201/hungeobull.68.3.5

Sneyers, R. (1991). *On the statistical analysis of series of observations* (Technical Note No. 143). Retrieved from https://library.wmo.int/index.php?lvl=notice_display&id=7427

Stadtherr, L., Coumou, D., Petoukhov, V., Petri, S., & Rahmstorf, S. (2016). Record Balkan floods of 2014 linked to planetary wave resonance. *Science Advances, 2*(4), e1501428. https://doi.org/10.1126/sciadv.1501428

Tošić, I. (2004). Spatial and temporal variability of winter and summer precipitation over Serbia and Montenegro. *Theoretical and Applied Climatology*, *77*(1–2), 47–56. https://doi.org/10.1007/s00704-003-0022-7

von Storch, H., & Zwiers, F. W. (1999). *Statistical Analysis in Climate Research*. Cambridge, UK: Cambridge University Press.

Visbeck, M. H., Hurrell, J. W., Polvani, L., & Cullen, H. M. (2001). The North Atlantic Oscillation: Past, present, and future. *Proceedings of the National Academy of Sciences of the United States of America*, *98*(23), 12876–12877. https://doi.org/10.1073/pnas.231391598

Zikov, M., & Bakeva, V. (2014). Variations in precipitation in Republic of Macedonia. *Acta geographica Bosniae et Herzegovinae*, *2*, 29–34. Retrieved form https://www.geoubih.ba/publications/Acta2/Article-Mihailo%20Zikov, Verica%20Bakeva.pdf