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DROUGHT ASSESSMENT IN VOJVODINA (SERBIA) USING K-MEANS CLUSTER ANALYSIS

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Abstract: Droughts are natural hazards that endanger the safety of population, their property and can create serious agricultural and ecological problems over the affected region. An analysis of the Standardized Precipitation Index (SPI) was performed by using the database of sixty years (1956–2016) of the monthly precipitation for the nine meteorological stations in Vojvodina region (Serbia). The SPI has been used for drought determination. The present study investigates the application of k-means clustering methods on the SPI at the 12-month timescale values to detect distinct drought clusters. For the purpose of determining the optimal number of clusters, the Gap Statistics was used. The results show that the total of four clusters (regions) can be identified in Vojvodina: three stations are listed in region 1 (Sombor, Palić, and Novi Sad), two stations in region 2 (Bač and Sremska Mitrovica), region 3 is a single-station region (Bela Crkva), while in region 4, three stations are grouped (Kikinda, Zrenjanin, and Vršac). The Mann-Kendall test has shown that only in region 1 there is a trend in SPI values ranging from arid towards more humid conditions in the 1956–2016 period. In other regions no trend was observed in the data series. These results could contribute to water resources and agricultural planning and management in Vojvodina region and also confirm the usefulness of clustering methods for drought regionalization.

Keywords: SPI; droughts; k-means; regionalization; Vojvodina

Introduction

Precipitation is one of the most important climate elements as it is affecting the available water resources, agriculture and, as such, can have severe consequences for the economy because it can lead toward water shortage as well as yield reduction (Randall et al., 2007). The Intergovernmental Panel on Climate Change [IPCC] 2007 report confirmed an increase in the precipitation over the period 1900–2005 for the regions north of the 30^{o} latitude as a result of global warming (Trenberth et al., 2007). The further sub-regional research in the variability of precipitation patterns was suggested by the same IPCC 2007 report (IPCC, 2007). This kind of research requires detailed spatial datasets that are going as far back in time as possible (Huntington, 2006). Precipitation trend

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analyses that have different spatial and temporal scales have been widely carried out over the past several decades. This is due to the attention that the global climate change has received and the indication of significant precipitation decreasing trends over North America, East Asia, equatorial regions in Africa and Oceania, while the trend is positive over Europe (IPCC, 1996; Longobardi & Villani, 2010). Over Central Europe and the Balkan Peninsula a moderate increase of precipitations is noted (Vuković & Vujadinović Mandić, 2018). From 1980s these tendencies have been more pronounced (Spinoni, Naumann, & Vogt, 2017). Several studies have been conducted in Vojvodina region (North Serbia); Tošić et al. (2014) investigated seasonal precipitation variability and Hrnjak et al. (2014) investigated aridity. There are different indicators for the evaluation of the precipitation variability that are used to provide information for analysis and further understanding of hydrological processes (Apaydin, Erpul, Bayramin, & Gabriels, 2006). Several indices have been used for this purpose and, among these, the Standardized Precipitation Index (SPI) is recommended by European Commission (2019) and World Meteorological Organization [WMO] (WMO, 2012), as it provides the most accurate information on precipitation variability and the amount over a long time period. The SPI is a widely used index for the description of meteorological drought on different timescales (Paulo & Pereira, 2006; Santos, Pulido-Calvo, & Portela, 2010). The advantage of this index is that it can be compared across regions that have noticeably different climates. Researchers have recognized the SPI as the standard index that should be applied worldwide for the purpose of quantifying and describing meteorological drought events (Sienz, Bothe, & Fraedrich, 2012; WMO & Global Water Partnership [GWP], 2016).

This paper analyses the spatial and temporal variability of the SPI by using the precipitation database of the Republic Hydrometeorological Service [RHMZ] of Serbia. The SPI is calculated for annual scales over a 60-year period (1956–2016), and, therefore, enables the comparison between two independent 30-year sub-periods (1956–1986 and 1987–2016). These data were further used for the determination of regions by applying nonhierarchical clusters that are often utilized for the identification of homogenous climatic regions (Santos et al., 2010).

Study area

The area of Vojvodina region occupies the northern part of Serbia covering mainly a lowland area of 21,500 km^2. The climate of the region is moderate continental and it is characterized by humid springs and cold dry winters with average annual temperature of 11 ^{o}C. Temperatures during summer are between 21 °C and 23 °C and during winter around −2 °C. Annual precipitation amount is relatively low and unevenly distributed throughout the year and ranges from 550 to 600 mm with precipitation maximum during June and minimum during November and March (Malinović-Milićević, Mihailović, Radovanović, & Drešković, 2018). For the investigated period 1956–2016 the annual precipitation amount over Vojvodina ranges from 295 mm in 2000, to 919 mm in 2010.

Data and methods

For the purpose of the calculation of SPI the data from the Meteorological yearbooks (RHMZ, 1956–2016) for the period from 1956 to 2016 were used. The geographical positions of the used stations in this study are presented in Figure 1.

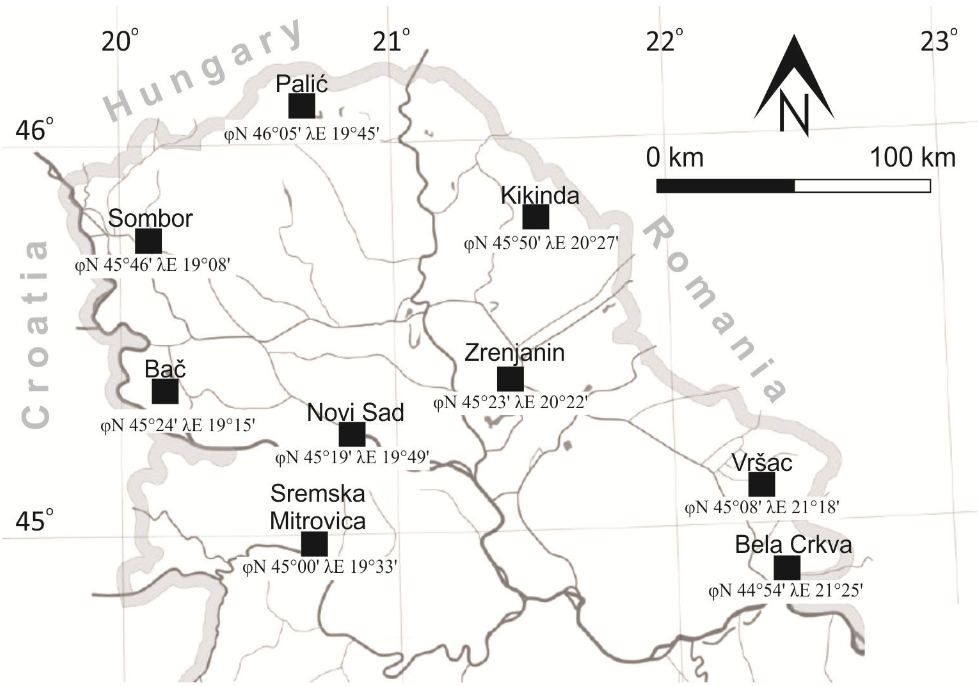

Figure 1. Geographical location of the used meteorological stations in Vojvodina region

The quality of the available data was satisfactory according to Bennett (2001), the acceptable percentage of missing data within data series is 10%. In five stations there was no missing data, at Bečej station there was 10% of missing data, in Sremska Mitrovica 5%, in Bela Crkva 3.33%, and in Bački Petrovac station 1.66%. For testing data on homogeneity we used: *Z*-test and Student's *t*-test for testing mean value at the significance level $\alpha = .05$ (Urošev, Leščešen, Štrbac, & Dolinaj, 2016).

Standardized Precipitation Index

The SPI is the best way for defining and monitoring drought events. This index was developed by McKee, Doesken, and Kleist (1993) and since then it has been adopted by a wide number of researchers (Guenang & Kamga, 2014). In 2010 WMO selected the SPI as a key meteorological drought indicator to be produced operationally by meteorological services (European Commission, 2019). Positive SPI values indicate greater than mean precipitation while negative values represent less than mean precipitation (Patel, Chopra, & Dadhwal, 2007), and the magnitude of SPI values represent the intensity of drought and wet events (Kazemzadeh & Malekian, 2016). The SPI also helps to determine the frequency of extremely wet or dry events for a selected time scale at any location for which precipitation data series are available (Gregorič & Ceglar, 2007). The fact that the index is standardized provides the ability to obtain data that is comparable for any location (Guttman, 1999; Šebenik, Brilly, & Šraj, 2017). The SPI was used for a 12-month period within each hydrological year over the period from 1956 to 2016. The hydrological year is the period between October 1st of one year and September 30th of the next year. In table 1 the classification of the SPI values and the corresponding wet and dry categories are presented.

Table 1
SPI classification

SPI value	Class	Cumulative probability	Probability of event (%)
SPI ≥ 2.00	Extreme wet	0.977–1.000	2.3
1.50 < SPI < 2.00	Severe wet	0.933–0.977	4.4
1.00 < SPI < 1.50	Moderate wet	0.841–0.933	9.2
−1.00 < SPI < 1.00	Near normal	0.159–0.841	68.2
−1.50 < SPI < −1.00	Moderate dry	0.067–0.159	9.2
−2.00 < SPI< −1.50	Severe dry	0.023–0.067	4.4
SPI < −2.00	Extreme dry	0.000–0.023	2.3

Note. Adapted from "Standardized Precipitation Index (SPI)," by European Commission, 2019 (http://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_spi.pdf). Copyright 2019 by the European Commission.

A drought event begins when SPI is continuously negative and reaches the value of −1 or less, and a drought event ends when SPI value becomes positive (McKee et al., 1993; Šebenik et al., 2017).

Regionalization method

Several methods are available for regionalization and are often used for identifying geographical regions. One of the most common approaches for defining homogeneous regions is based on different clustering techniques (Clarke, 2011). Cluster analysis method is an approach that separates the observed data into different clusters (regions). Different techniques have been used to define a geographical region (Asadi, Engelke, & Davison, 2018). Most commonly used technique is k-means method that is widely adopted in geographical research and is treated as the best suited for determining geographical regions (Hassan & Ping, 2012; Javadi, Hashemy, Mohammadi, Howard, & Neshat, 2017; Ramachandra Rao & Srinivas, 2006). The k-means method is explained in detail in Javadi et al. (2017) and Weatherill and Burton (2008).

One problem that emerges when k-means method is used is a demand to a priori choose the number of clusters in a region. To solve this problem, Gap Statistics was used (Pham, Dimov, & Nguyen, 2005). This Statistics uses the distortion of a cluster and it is determined as described by Carvalho, Melo-Gonçalves, Teixeira, and Rocha (2016). The results obtained by applying this statistics show that the optimal number of clusters for Vojvodina region is four (k = 4). When SPI values are calculated, the classification and comparison of all the events per the obtained regions will also be conducted.

Trend detection

For trend detection in the data series Mann-Kendall test was used (Gilbert, 1987). This test is widely used in environmental science (Hrnjak et al., 2014; Lukić, Leščešen, Sakulski, Basarin, & Jordaan, 2016). The advantage of this test is that it is simple, robust, and can cope with missing values. In order to obtain trends, we used a data set that is made up of yearly SPI values for each station within the research area. Kendall's tau (τ) (Kendall, 1975) was firstly calculated for the purpose of estimating a trend in the time series. Because of this, two hypotheses are tested: (I) the null hypothesis, that there is no trend in the series; and (II) the alternative hypothesis, that there is a trend in the series, for significance level α = .05. Probability was then calculated for the purpose of determining the level of confidence in the proposed hypothesis. The same procedure was applied to the calculated SPI values. For statistical analysis and trend detections R 3.5.1 software (Package "Kendall") was used.

Results and Discussion

Since all the obtained *Z*-test and Students *t*-test results are within the range of critical values ($-1.96 < Z < 1.96$; $-2.01 < t < 2.01$), it can be concluded that the series are homogeneous, independent, and stationary. The results of this analysis are presented in Table 2.

Table 2
Obtained values of Z and Student t-test statistics

Stations	*Z*	*t*
Bač	0.489	0.481
Sombor	−0.793	−0.991
Novi Sad	−1.699	−1.671
Palić	−1.132	−1.064
Kikinda	−0.033	−0.236
Zrenjanin	−0.494	−0.325
Vršac	−0.130	0.207
Bela Crkva	0.431	0.423
Sremska Mitrovica	1.170	0.961

The regionalization of the Vojvodina region by applying the cluster analysis method on the SPI data for nine meteorological stations has produced satisfactory results. When clustering algorithm is applied to the presented variables using k = 4, the investigated area is divided into four regions. Region 1 is made of three meteorological stations Sombor, Palić, and Novi Sad, region 2 is made of Bač and Sremska Mitrovica stations, region 3 is a single-station region made of Bela Crkva station and region 4 is formed of Kikinda, Zrenjanin and Vršac stations.

In the next step, the average values of SPI for each region were used. The purpose was to present SPI values during the observed period for each region. These averaged index values are presented in Figure 2, respectively.

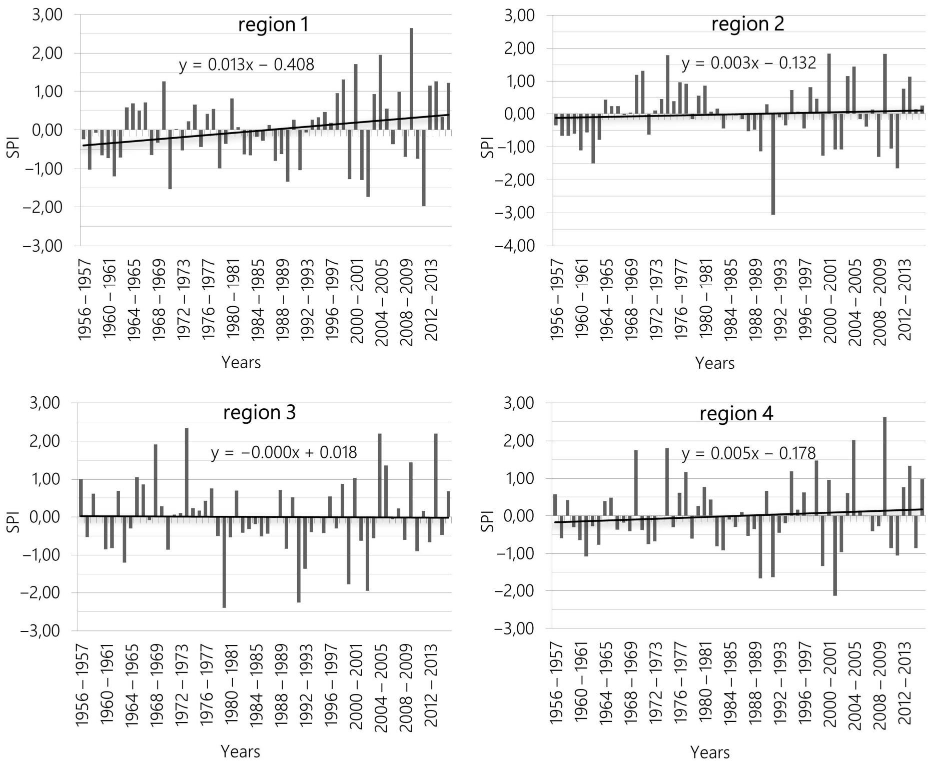

Figure 2. The SPI series in the investigated period for region 1, 2, 3, and 4

From Figure 2 it can be concluded that almost all the regions experienced at least one extreme drought event over the reference period: region 2 in 1991/1992 with SPI value of −3.06, region 3 in 1979/1980 with SPI value of −2.40, and region 4 in 2001/2002 with SPI value of −2.14. Considering region 1, extreme drought was not experienced, but during 2011/2012 the SPI value reached −1.98 (Severe dry). Extremely wet events also occurred in almost every region (except region 2); in region 1 during 2009/2010 with SPI value of 2.65, region 3 with SPI value of 2.34 in 1973/1974, and region 4 with SPI value of 2.62 in 2009/2010.

Normal conditions prevail in all the regions during the investigated period. Further, the comparison of total wet (total of Moderate, Severe, and Extreme) and dry (total of Moderate, Severe, and Extreme) events was conducted (Table 3). In region 1, dry events prevail with 9 events versus 8 wet events. Similarly, in region 2, dry events also prevail with 10 versus 8 wet events. In regions 3 and 4, that occupy the eastern part of Vojvodina, the prevailing event changes and wet events prevail with 8 wet and 6 dry in region 3. In region 4 the total of 9 wet and 6 dry events were recorded.

Table 3
Number of events per region

Event	region 1	region 2	region 3	region 4
Extreme wet	1	0	2	3
Severe wet	2	3	2	1
Moderate wet	5	5	4	5
Near normal	43	42	46	45
Moderate dry	6	8	3	2
Severe dry	3	1	2	2
Extreme dry	0	1	1	2

The SPI trends for the period 1956-2016 that are presented in Figure 2 show that there is a trend in SPI values for regions 1, 2, and 4. The hypothesis testing will prove whether this statement is true. The trend noticed in the region 1, as well as equation ($y = 0.013x - 0.408$), show a positive trend. The computed p is greater ($p = .059$) than the significance level ($\alpha = .05$). The risk to reject the null hypothesis while it is true is 5.9 %. Therefore, it can be concluded, with 94.1% certainty, that there is a trend for the observed time series from more arid towards more humid conditions in region 1. For regions 2 and 4, the hypothesis testing showed that there is no statistically significant trend in the data series for these regions as both p values are greater than the significance level ($p = .539$ for region 2 and $p = .333$ for region 4). As the computed p value is greater than the significance level, one cannot reject the null hypothesis that there is no trend in the data series. The risk to reject the null hypothesis while it is true is 53.9% and 33.3%, respectively.

The trends of SPI for two thirty-year periods (P1 is 1956–1986 and P2 is 1987–2016) for each region are presented in Figure 3. It can be noted that only in region 3 P1 a negative trend can be noticed. In all other regions a positive trend and an increase in the number of wet events were observed. The hypothesis testing will prove whether these trends have a statistically significant trend. The trend noticed in region 2 P1, as well as equation ($y = 0.038x - 0.517$), show a positive trend. The computed p is lower ($p = .044$) than the significance level ($\alpha = .05$). The risk to reject the null hypothesis while it is true is 4.43 %. Therefore, it can be concluded, with 95.57 % certainty, that there is a trend for the observed time series from more arid towards more humid conditions. For other periods, a statistically significant trend was not observed.

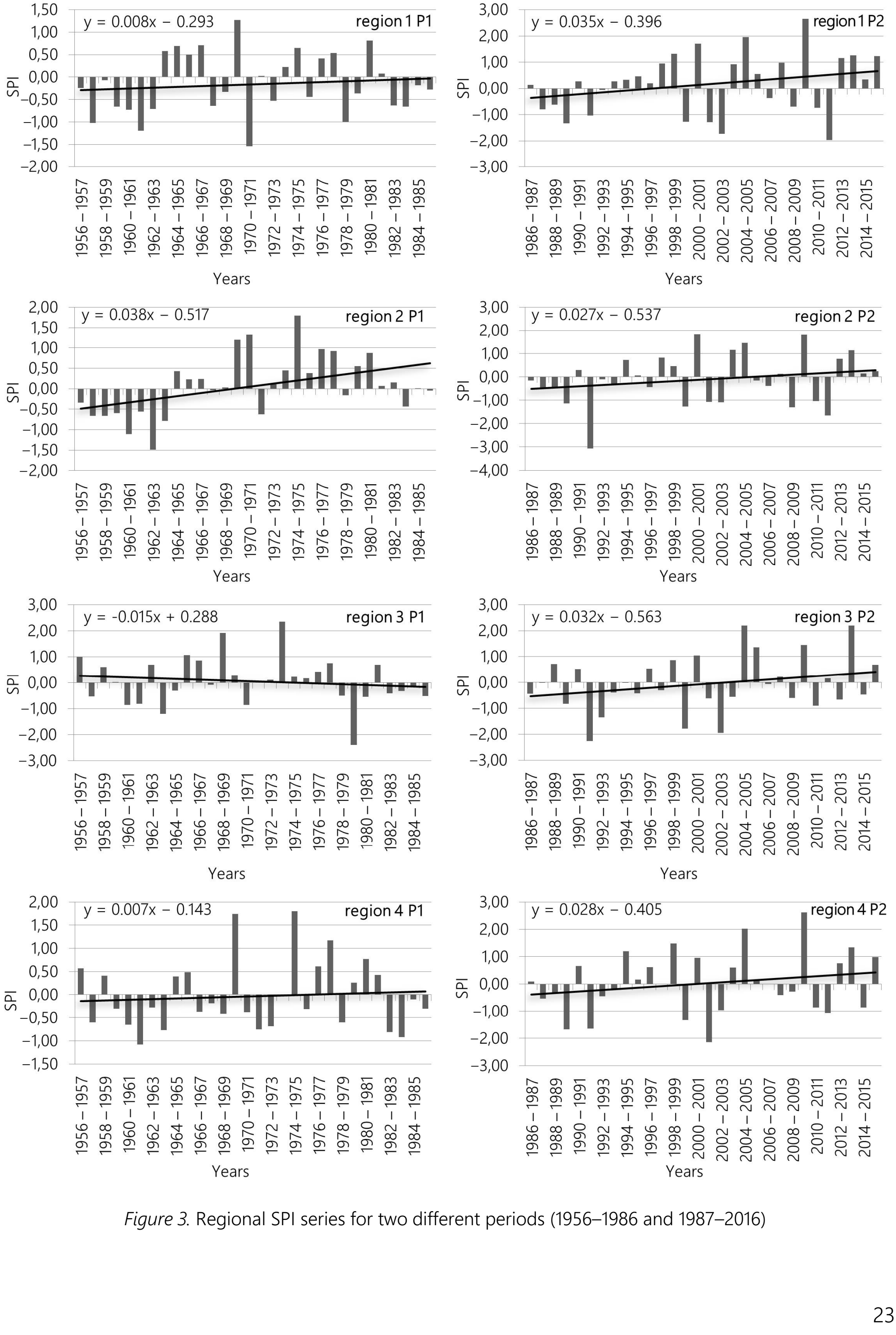

Figure 3. Regional SPI series for two different periods (1956–1986 and 1987–2016)

When the number of different events within two thirty-year periods (1956–1986 and 1987–2016) are compared (Table 4), it is notable that changes in the number of events can be observed in all the regions, i.e. all the events have increased during the second period except Near normal events that has decreased.

Table 4
Number of events in two different thirty-year periods

Event	region 1		region 2		region 3		region 4		Vojvodina	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Extreme wet	0	1	0	0	0	2	1	2	1	5
Severe wet	0	2	1	2	2	0	1	0	4	4
Moderate wet	1	4	2	3	1	3	2	3	6	13
Near normal	26	17	25	17	26	20	24	21	101	75
Moderate dry	2	4	2	6	1	2	1	1	6	13
Severe dry	1	2	0	1	0	2	2	0	1	7
Extreme dry	0	0	0	1	0	1	1	1	1	3

Note. P1 = 1956–1986 period; P2 = 1987–2016 period.

In region 1, the total number of wet events (Moderate, Severe, and Extreme) has drastically increased during 1987–2016 period. In regions 2 and 3, the same increase, but this time in dry events, can be noticed during the same period. In general, the number of different events over Vojvodina has grown during the period 1987–2016. This increase was caused by an increase in precipitation amount and precipitation oscillation over the investigated period (Malinović-Milićević et al., 2018).

Conclusion

For Vojvodina region, the changes in precipitation for the period 1956–2016 were observed by using SPI. For this entire period, the precipitation data were used from nine meteorological stations evenly distributed over the investigated region. Monthly precipitation data was used for the determination of annual SPI values. Cluster analysis shows the existence of four precipitation regions in Vojvodina. Annual SPI values for each of the four regions can be described as strongly irregular, but with a dominant near normal conditions. The Mann-Kendal test has shown, with 94.1% certainty, that over the investigated period a change from drier to more humid conditions is observed in region 1. Other regions show no statistically significant trend at the level of $\alpha = .05$. In addition to the great spatial variability across Vojvodina, the SPI shows temporal changes if it is evaluated for the two 30-year periods (1956–1986 and 1987–2016). The results indicate that, in general, on an annual scale, the number of wet events (Extreme, Moderate, and Severe) increased across Vojvodina, particularly from northwest to southeast. This increase has been caused by an increase in precipitation over the sixty-year period.

The presented regions and the precipitation trends are valuable for different water mitigation agencies, local communities, agricultural planning, civil engineering, etc. and should be taken into account. The main results of this study are that a clear positive trend from dry towards more humid conditions can be noticed in region 1. During the last three decades, at least one Extreme dry event occurred in each of the four regions. When the comparison between the two investigated periods is made 1956–1986 and 1987–2016, it is noticeable that the number of wet and dry events (except Near normal) has increased over the last three decades. Some limitations of SPI are that it does not account for evapotranspiration and the intensity of precipitation and the impact it can potentially have on water availability. The presented precipitation tendencies could have a strong influence on natural processes such as fluvial regimes, groundwater recharge, soil erosion, and the availability of water.

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