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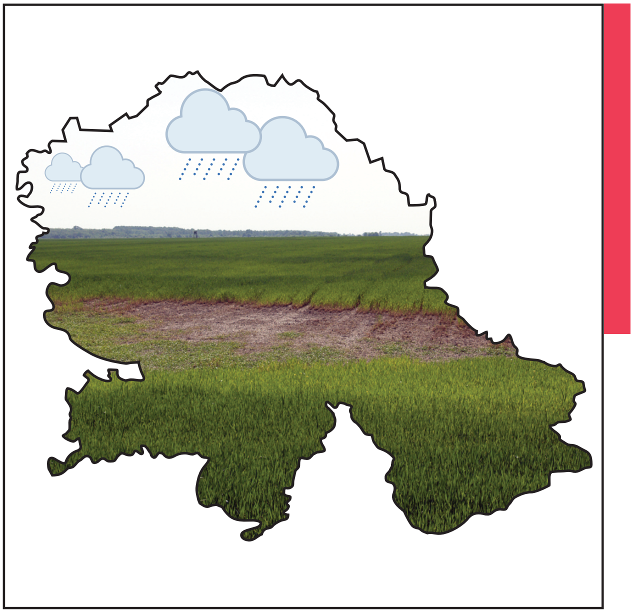
APPLICATION OF ANGOT PRECIPITATION INDEX IN THE ASSESSMENT OF RAINFALL EROSIVITY: VOJVODINA REGION CASE STUDY (NORTH SERBIA)

Tin Lukić, Tanja Micić Ponjiger, Biljana Basarin, Dušan Sakulski, Milivoj Gavrilov, Slobodan Marković, Matija Zorn, Blaž Komac, Miško Milanović, Dragoslav Pavić, Minučer Mesaroš, Nemanja Marković, Uroš Durlević, Cezar Morar, Aleksandar Petrović



Rainfall erosivity in Vojvodina (North Serbia).

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Application of Angot precipitation index in the assessment of rainfall erosivity: Vojvodina Region case study (North Serbia)

ABSTRACT: The paper aims to provide an overview of the most important parameters (the occurrence, frequency and magnitude) in Vojvodina Region (North Serbia). Monthly and annual mean precipitation values in the period 1946–2014, for the 12 selected meteorological stations were used. Relevant parameters (precipitation amounts, Angot precipitation index) were used as indicators of rainfall erosivity. Rainfall erosivity index was calculated and classified throughout precipitation susceptibility classes liable of triggering soil erosion. Precipitation trends were obtained and analysed by three different statistical approaches. Results indicate that various susceptibility classes are identified within the observed period, with a higher presence of very severe rainfall erosion in June and July. This study could have implications for mitigation strategies oriented towards reduction of soil erosion by water.

KEY WORDS: climate change, precipitation, rainfall erosivity, soil erosion, Angot precipitation index, Vojvodina, Serbia.

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Uporaba padavinski indeksa Angot za oceno erozivnosti padavin: na primeru Vojvodine (severna Srbija)

POVZETEK: Prispevek podaja pregled najpomembnejših padavinskih parametrov (pojavnost, pogostost in velikost) v Vojvodini (severna Srbija). Za 12 izbranih meteoroloških postaj so bile uporabljene mesečne in letne povprečne vrednosti padavin v obdobju 1946–2014. Kot kazalnike erozivnosti padavin smo uporabili ustrezne padavinske parametre (količina padavin, padavinski indeks Angot). Izračunali smo indeks erozivnosti padavin in ga razvrstili v razrede glede na možnost pojavljanja erozije prsti. Trende smo preučili s tremi različnimi statističnimi pristopi. V preučevanem obdobju smo prepoznali različne razrede indeksa, z zelo močno padavin erozijo junija in julija. Raziskava je dober temelj za oblikovanje strategij, usmerjenih v zmanjšanje vodne erozije prsti.

KLJUČNE BESEDE: podnebne spremembe, padavine, erozivnost padavin, erozija prsti, padavinski indeks Angot, Vojvodina, Srbija

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1 Introduction

One of the most prominent causes of land degradation is water erosion (Boardman and Poesen 2006; Bosco et al. 2015). »Erosion is a geomorphic process that detaches and removes material (soil, rock debris, and associated organic matter) from its primary location by some natural erosive agents or through human or animal activity« (Zorn and Komac 2013a, 288). Soil erosion is an important process connected to several erosive agents, such as water, wind, ice, and snow (Morgan 2005; Blinkov 2015a; Blinkov 2015b). Panagos et al. (2015a; 2015b) pointed out that in Europe, soil erosion by water accounts for the greatest soil loss compared to other erosion processes (e.g., Boardman and Poesen 2006). Water erosion may be accelerated by human activity, but human activity may also prevent runoffs and soil removal by building retention ponds (Ferk et al. 2020) or terraces (Šmid Hribar et al. 2017).

Water erosion has many on-site and off-site effects (Santos Telles, de Fátima Guimarães and Falci Dechen 2011), whereby off-site effects may have greater social, economic and environmental concern (Boardman et al. 2019). Soil erosion affects land resources and increases the risk posed by the blockage of rivers and causes degradation of water quality through pesticides, fertilizers and nutrients carried with the sediment (Lukić et al. 2019). Although soils represent a vital resource, research on soil erosion has not gained as much attention as degradation of water and air quality (Blinkov 2015a). The reason can be found in much more complex and extensive natural factors that led to this type of erosion, which are almost impossible to explain with a model that would consist of every variable and factor included in the process. Nevertheless, land degradation is recognized as a major environmental threat in many parts of Europe (e.g., de Luis, González-Hidalgo and Longares 2010; de Luis et al. 2011; Blinkov 2015a; Blinkov 2015b; Lukić et al. 2013, 2016, 2018, 2019; Zorn and Komac 2013b).

Soil erosion may be quantified using field measurement (Stroosnijder 2005) or erosion models (Borrelli et al. 2021). Globally the most widely used erosion models belong to *Universal Soil Loss Equation* family (*USLE/RUSLE* (Wischmeier and Smith 1978; Renard et al. 1997)), whereas on the territory of former Yugoslavia and in some neighbouring countries the Gavrilović equation has predominated (Gavrilović 1972; Hrvatin et al. 2019). Besides these, there are more than 600 other models that can be divided into two basic groups: those extracted from the *USLE* and *RUSLE* equations, while others employ qualitative approaches (Auerswald et al. 2014).

Precipitation is the most important natural agent with regard to water soil erosion, hence representing one of the determining factors in the *USLE* equation (Wischmeier and Smith 1978; Morgan 2005; Mello et al. 2013). The capability of rainfall to cause soil loss is called rainfall erosivity (Nearing et al. 2017; Panagos et al. 2017) and represents a climatological component in the overall erosion processes by water (da Silva 2004; Yu 1998). It is fundamental for the understanding of the climatic vulnerability regarding soil erosion in a given region (Panagos et al. 2015a). Several measures of rainfall erosivity have been proposed (Yu and Neil 2000; Morgan 2005):

- *R*-factor in the *USLE/RUSLE* (Wischmeier and Smith 1978; Renard et al. 1997),
- Fournier's Index (Fournier 1960),
- Modified Fournier Index (Arnoldus 1980),
- Lal's AI_m index (Lal 1976),
- Hudson's $KE > 1$ Index (Hudson 1976), and
- Onchev's Universal Erosivity Index (Onchev 1985).

Rainfall erosivity presents the potential of raindrops to trigger soil erosion and its estimation is fundamental for the understanding of the climatic vulnerability of a given region (Mello et al. 2013). Thereby, respective authors (e.g., Kirkby and Neale 1987; de Luis, González-Hidalgo and Longares 2010; de Luis et al. 2011) investigated the relationship between the intensity of precipitation and its distribution in time, since there is no exact relationship between the total amount of precipitation and soil erosion. Different approaches have been developed when estimating soil erosion, namely indices based on precipitation data, and indices based on kinetic energy and precipitation intensity (e.g., Lukić et al. 2016; 2019). The most recognized indices describing kinetic energy and precipitation intensity are EI_{30} (Weischmeier and Smith, 1978), AI_{m} (Lal 1976), $KE > 1$ (Hudson 1976) and $P/\sqrt{t}$ (Onchev 1985). These parameters require daily precipitation data series over 20 years, and since there is no such data for most parts of the world, it was necessary to create a simpler approach. The most utilized indices based on available rainfall data are the Fournier Index (*FI*) and the Modified Fournier Index (*MFI*) (Morgan 2005; Arnoldus 1980) which are extracted from the *R* – rainfall erosivity factor in the *USLE* equation (Renard and Freimund 1994; Gabriels 2001; Loureiro and Coutinho 2001; Diodato and Bellocchi 2007). They were used in numerous studies with scarce precipitation databases (e.g., Lujan and Gabriels 2005; Boardman and Poesen 2006; de Luis, González-Hidalgo and Longares 2010; Ufoegbune et al. 2011; Costea 2012; Lukić et al. 2016; 2018; 2019). It was also in comparisons of several rainfall erosivity indices (e.g., Oduro-Afriyie 1996; da Silva 2004; Bayramin, Erpul and Erdogan 2006; Angulo-Martínez and Beguería 2009; Alipour et al. 2012; Mello et al. 2013; Sanchez-Moreno, Mannaerts and Jetten 2014). Fournier indices require mean monthly data averages and are based on temporal precipitation distribution obtained through Precipitation Concentration Index (*PCI*) (Arnoldus 1980). Beside articles that were based on *MFI* and *FI* parameters (e.g., Oduro-Afriyie 1996; Lujan and Gabriels 2005; Apaydin et al. 2006; Costea 2012; Yue, Shi and Fang 2014; Hernando and Romana 2015), *PCI* was also used in numerous studies concerning precipitation distribution and concentration (Martínez-Casasnovas, Ramos and Ribes-Dasi 2002; de Luis et al. 2011; Iskander, Rajib and Rahman 2014; Lukić et al. 2019).

According to Dumitrascu et al. (2017), besides soil type, topography, and land use, the amount and intensity of precipitation is an important factor in estimating the rate of soil erosion by water. The climatic factors can lead to the intensification of erosion when they register high intensities and occurrence after a prolonged drought period.

For this purpose, an indicator for the assessment of pluvial aggressiveness (Angot – *K* index) (Dragotă, Micu and Micu 2008) can be applied in assessing rainfall erosivity in Southeastern Europe – a hotspot region with the highest number of severely affected sectors (Dragotă, Micu and Micu 2008; Dragotă et al. 2014; Dumitrascu et al. 2017; Lung and Hilden 2017; Lukić et al. 2019; Milanović et al. 2019). So far, rainfall erosivity assessment in the Vojvodina Region has been carried out in the Bačka and Zemun loess plateaus (Lukić et al. 2016, 2018) and in the Pannonian Basin (Lukić et al. 2019). The study found that the amount and the intensity of precipitation are increasing. According to Marković et al. (2008; 2012; 2015), the largest part of Vojvodina is covered with loess and loess-like sediments (> 60%), which are extremely susceptible to the erosion processes due to high porosity, carbonate and clay content as abounding material (Lukić et al. 2009; Vasiljević et al. 2011; Hrnjak et al. 2014). Therefore, it is very important to point out the most vulnerable areas for mitigation and prevention (Leger 1990; Lukić et al. 2016; 2019).

The publicly available precipitation database of the Vojvodina Region record more than 70 years of continuous observations. However, the data is based on monthly values. Accordingly, the aforementioned Angot – *K* index, which was used in similar studies (in the neighbouring countries), is one of the compatible methodological approaches for assessing the potential vulnerability of the investigated area from the rainfall erosivity (e.g., Dragotă, Micu and Micu 2008; Dragotă et al. 2014; Dumitrascu et al. 2017).

So far, rainfall erosivity assessment in the Vojvodina Region has been carried out for the case study of Kula settlement (southern part of the Bačka loess plateau) and Zemun area in the vicinity of Belgrade (Zemun loess plateau), where Lukić et al. (2016; 2018) studied the relationship between recurring landslides and rainfall erosivity. In a later study, Lukić et al. (2019) showed an increase in the amount and the intensity of precipitation as well as in rainfall erosivity for most parts of the Pannonian Basin, including Vojvodina region.

In this paper climatological parameters from the Vojvodina Region (North Serbia) are processed. We used the Angot precipitation index (Dragotă, Micu and Micu 2008), which is the ratio of the daily average volume of precipitation in a month and the annual daily average precipitation volume (Constantin and Vătămanu 2015) and was previously already used in the wider study region by Dragotă et al. (2014) and Dumitraşcu et al. (2017). In order to assess the erosion vulnerability for the southern part of the Pannonian Basin, the occurrence, frequency and magnitude of some of the most significant precipitation parameters were studied.

2 Study area

The Autonomous Province of Vojvodina (21,533 km^2) is located in the southern part of the Pannonian Basin and the northern part of the Republic of Serbia (Figure 1). It is divided into three regions: Banat, Bačka, and Srem with Novi Sad as the capital (Basarin et al. 2018; Gavrilov et al. 2020).

The largest part of the region is covered with loess and loess-like sediments (> 60%). As the loess material possesses several properties which make it highly susceptible to water erosion, it is very important to point out the most vulnerable areas for mitigation and prevention (Leger 1990; Lukić et al. 2009; 2016; 2019).

The Vojvodina Region is predominantly a lowland area, and the highest parts are Fruška gora Mountain (539 m) in the northern part of the Srem Region, and the Vršačke Mountains (641 m) in the southeastern part of the Banat Region. However, the largest geomorphological structures are formed on loess and loess-like material, and present loess plateaus, terraces and microrelief forms (Marković et al. 2008; 2012; 2015; Lukić et al. 2009; Vasiljević et al. 2011; Gavrilov et al. 2020).

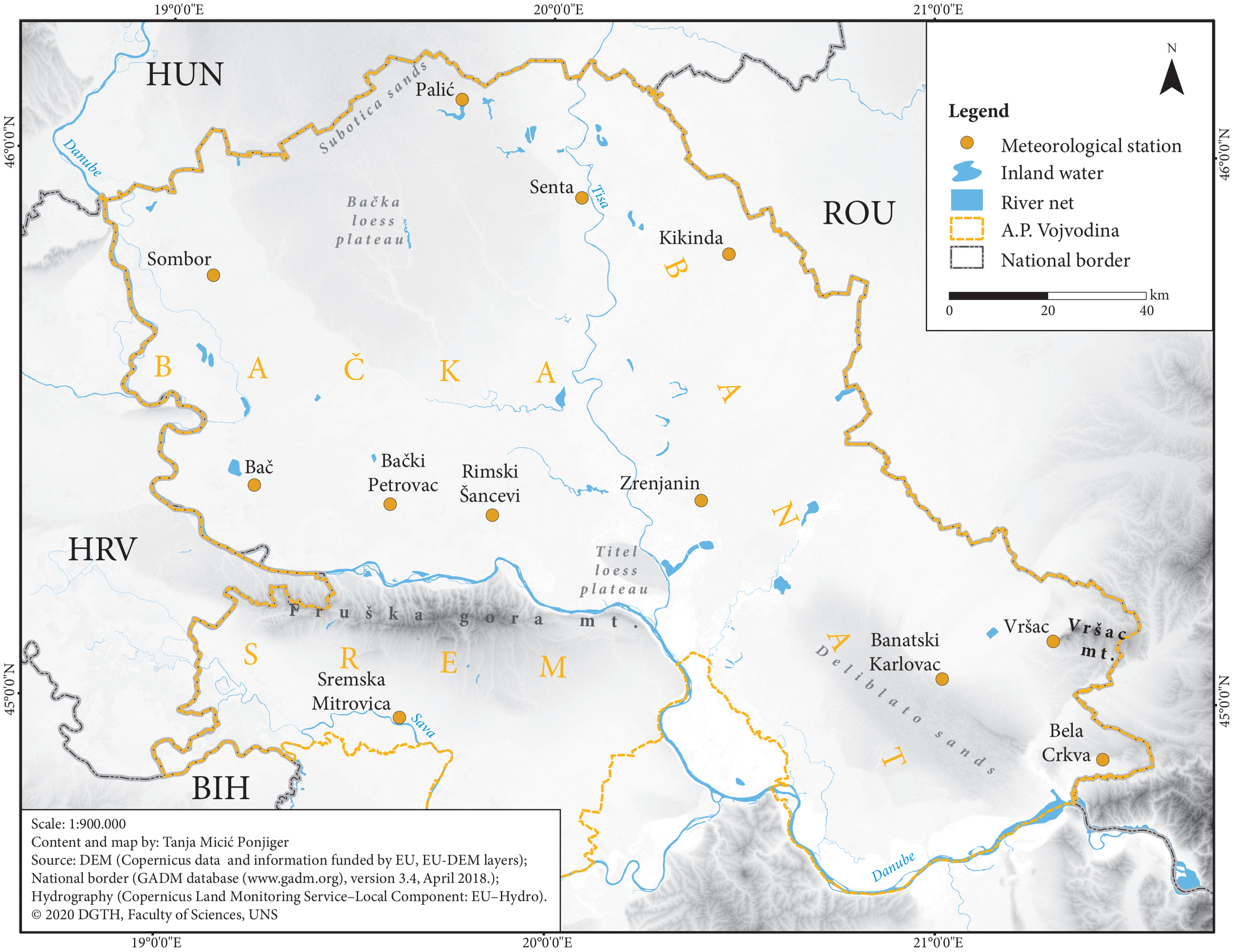
The climate of the Vojvodina Region is controlled by the geographical position in the southern part of the Pannonian Basin. According to the Köppen climate classification it is moderately continental due to the weaker impact of western air currents, and the greater impact of a Eurasian continental climate. Winter seasons are cold (average January temperatures range from < 0.0 °C to 1.0 °C), while summers are hot and humid (average July temperature of between 21.0 °C and 23.0 °C), with a huge temperature range, reaching ~70 °C and very irregular distribution of monthly rainfall (extremely rainy early summer and low precipitation in November and March) (Malinović-Milićević et al. 2018). Climate is influenced by NW cold and humid wind, and the warm and dry SE wind. Hence, the main characteristic of the rainfall regime in Vojvodina is reflected in the pronounced variability in both space and time. The average annual precipitation is 606 mm, with the highest amounts in June, and lowest in February (Gavrilov et al. 2015; 2016). During the summer the total monthly precipitation can fall within a single day. The lowest average annual rainfall of about 540 mm is recorded in the north, while the highest average precipitation values are recorded in the southwest of Vojvodina (Hrnjak et al. 2014; Tošić et al. 2014; Gavrilov et al. 2019).

3 Data and methods

The precipitation data for the rainfall erosivity assessment was obtained from the database of the Hydrometeorological Service of the Republic of Serbia for the period 1946–2014 for 12 meteorological stations (Meteorološki godišnjak 1946–2014) (Table 1), selected based on the completeness of the time series and spatial distribution (Figure 1). Data for the analysed period covers two thirty-year cycles, which is in accordance with the WMO standards.

Datasets for each of the stations were analysed and processed for the calculation of the mean monthly amount of precipitation. Thus, a database was created with a time series of monthly and annual precipitation values. The homogeneity of the precipitation series was confirmed by the Alexandersson (1986) test. Precipitation trends were examined using three different statistical approaches. In the first approach, a simple linear regression was used to determine the existence of a certain tendency in the data series, which gives information on the stagnation, growth or decline of the observed phenomenon (Cohen 1988; Gocić and Trajković 2013). Using

Figure 1: Map of Vojvodina (North Serbia) with meteorological stations used in this study. ➤ p. 128



Scale: 1:900.000
Content and map by: Tanja Micić Ponjiger
Source: DEM (Copernicus data and information funded by EU, EU-DEM layers);
National border (GADM database (www.gadm.org), version 3.4, April 2018.);
Hydrography (Copernicus Land Monitoring Service–Local Component: EU–Hydro).
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Table 1: Geographical coordinates and altitudes of selected meteorological stations.

Region	Meteorological stations	Latitude (N)	Longitude (E)	Altitude (m)
Banat	Banatski Karlovac	45°03′00″	21°02′12″	100
	Bela Crkva	44°54′00″	21°25′12″	90
	Vršac	45°09′00″	21°19′12″	83
	Zrenjanin	45°22′00″	20°25′00″	80
	Kikinda	45°51′00″	20°28′12″	81
	Senta	45°55′48″	20°04′48″	80
Bačka	Bač	44°54′00″	21°25′12″	90
	Bački Petrovac	45°22′12″	19°34′12″	85
	Palić	46°06′00″	19°46′12″	102
	Rimski Šančevi	45°19′48″	19°51′00″	86
	Sombor	45°46′12″	19°09′00″	87
Srem	Sremska Mitrovica	45°01′00″	19°33′00″	82

this method, the trend equation for yearly data was obtained for 69 years. The precipitation trend was also investigated using the nonparametric Mann-Kendall test, which is widely applied in environmental sciences for its simplicity and precision (Gilbert 1987; Gavrilov et al. 2011, 2013; Hrnjak et al. 2014; Lukić et al. 2017). Third, Kendall's tau (τ) (Kendall 1938, 1975) was calculated to gain a trend over a fully observed period of 69 years. Then, two hypotheses were tested:

1) Null hypothesis (H_0) – with the assertion that there is no trend in the observed time series for a defined level of significance of 95% ($\alpha = 0.05$);
2) Alternative hypothesis (H_a) – with the assertion that there is a trend in a given time series for a defined level of significance of 95% ($\alpha = 0.05$).

Statistical data processing was performed using the Wolfram Mathematica 11.3 software. Due to the presence of a positive correlation in data sets that can influence the increase in the number of false-positive trend outcomes, the Yue-Pilon method was performed (Yue et al. 2002).

Rainfall erosivity can be assessed using several methods (Costea 2012), of which we choose Angot precipitation index (*K)* (Dragotă, Micu and Micu 2008; Dragotă et al. 2014; Dumitraşcu et al. 2017). According to Dumitraşcu et al. (2017), destructive heavy rainfalls mostly depend on the intensity, duration and water quantity of the precipitation, and particular surface features, such as lithology, vegetation cover, and slope. In such conditions, heavy precipitation can trigger floods, erosion and slope failures (Lukić et al. 2016, 2018). Hence, the main components of the precipitation regime that have the strongest impact on the environment in the Vojvodina Region have been analysed using a specific erodibility *K* index. According to Dumitraşcu et al. (2017), this index has the benefit of relying on easily accessible input data (precipitation), where the quantification and ranking of precipitation aggressiveness is made using already established value classes. The Angot precipitation index (*K)* was initially aimed at determining the characteristic types of monthly and annual variation of precipitation based on regional and local comparisons. The index was quantified according to equations 1 and 2 (Dragotă, Micu and Micu 2008; Dumitraşcu et al. 2017):

$$K = \frac{p}{P} \tag{1}$$

where $p = q/n$, q being the monthly precipitation amounts, and n being the number of days/months, and

$$P = \frac{Q}{365} \tag{2}$$

where Q is the multiannual precipitation amounts.

The resulted index values were used to determine the susceptibility classes of precipitation liable for triggering soil erosion (Table 2).

Table 2: Susceptibility classes of precipitation liable to triggering soil erosion based on Angot precipitation index (K) (Dragotă, Micu and Micu 2008; Dumitraşcu et al. 2017).

Precipitation attributes	Very dry	Dry	Normal	Rainy	Very rainy
Precipitation erodibility classes	Very low	Low	Moderate	Severe	Very severe
Angot index values (*K*)	< 0.99	1.00–1.49	1.50–1.99	2.00–2.49	> 2.50

In order to examine the relationship between precipitation data, *K* and potential climate drivers, linear correlations were utilized. The selected large-scale phenomenon, North Atlantic Oscillation (*NAO*) and Multivariate ENSO Index (*MEI*) were used following the approach by Malinović-Milićević et al. (2018) and Lukić et al. (2019). *NAO* is characterized as the difference between sea-level pressure observed over Iceland and Portugal. When the values of *NAO* are negative storm tracks shift to the south, inducing more winter precipitation in the regions south of the Pyrenean-Alpine Mountains, including the Pannonian Basin (and the Vojvodina Region). On the other hand, positive values of the *NAO* lead to shifting storm tracks to the north, exposing the area south of the Pyrenean-Alpine Mountains to relatively dry conditions in the winter (Hurrell et al. 2003; Trigo et al. 2004). The station-based *NAO* time series were obtained from the Climatic Research Unit of the University of East Anglia (Internet 1).

Ocean–atmosphere interactions in the Pacific realm El Niño-Southern Oscillation (ENSO) is one of the most important climate drivers whose influence extends across the globe. *MEI* is an appropriate and a rather complex parameter, which integrates complete information of six oceanic and meteorological variables indicating the influence of southern oscillation (Pompa-García and Némiga 2015). The ENSO (*MEI*) record was obtained from the NOAA Physical Sciences Laboratory (Internet 2).

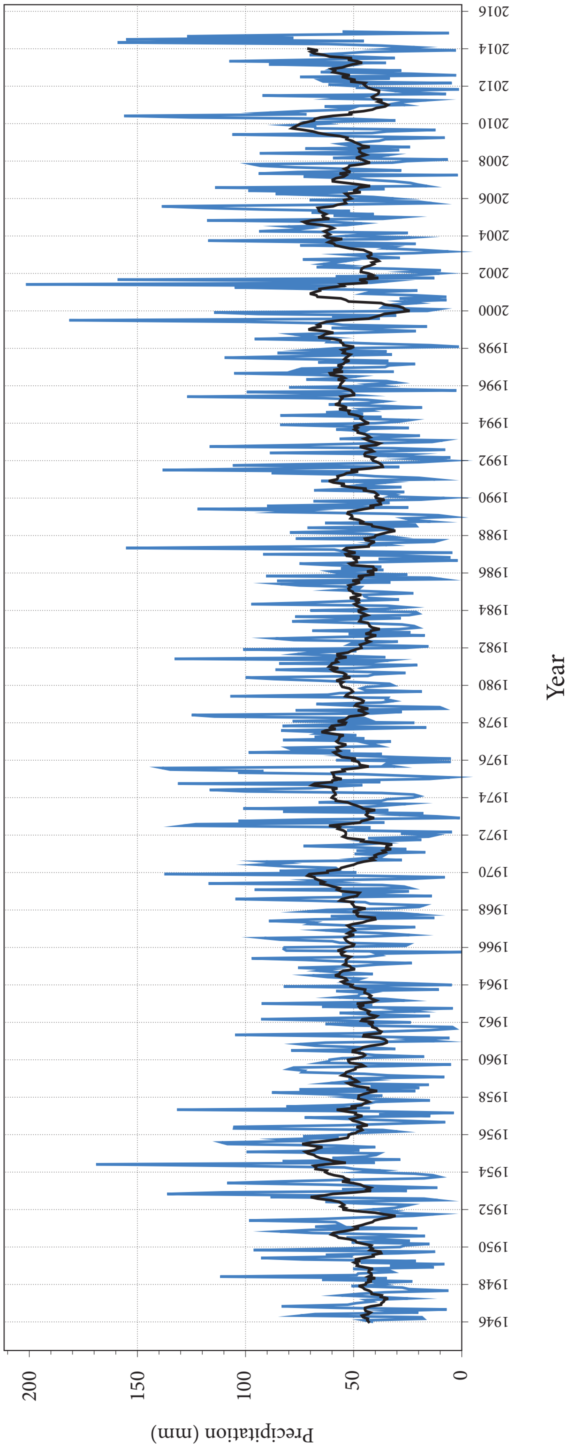
4 Results and discussion

The temporal evolution of the moving average (with a size window equal to 12 months) indicates that there are no significant variations or deviations regarding the precipitation distribution in the study area (Figure 2). This observation corresponds well with the results of Lukić et al. (2019) who pointed out that precipitation concentration values (*PCI*) in northern Serbia belong to the group of moderately distributed precipitation (a statistically significant trend was not observed). According to the authors, seasonal values of precipitation concentration for the Vojvodina Region generally display uniform values, where the winter season exhibits higher values than other seasons for all investigated stations during the period 1961–2014.

As shown by Bjelajac et al. (2016), the average annual precipitation (calculated for a period of 69 years) for 11 out of 12 stations indicate a positive linear trend, of which most pronounced trends are observed for the Bačka Region – Rimski Šančevi meteorological station ($y = 1.8309x + 550.89$). The highest average precipitation amount is recorded for the Bela Crkva meteorological station (659.1 mm) in the southeast, while the lowest values are recorded in the north and northeast (Palić station 555 mm and Kikinda station 555.5 mm) (Figure 3). According to the Mann-Kendall test, based on calculated *p* values, Sombor ($p = 0.020$) and Palić ($p = 0.021$) stations confirm the *Ha* hypothesis, i.e. there is a noticeable positive trend at the significance level $p < 0.05$. Therefore, on the annual basis, Sombor and Palić stations (for the study period) display an increase in the amount of precipitation by 1.46 mm and 1.68 mm, respectively (Figure 3). Other meteorological stations do not show statistically significant trend of precipitation variability for the study period.

The used meteorological database covers the warm period of the year (when positive values of *K* index prevail). The most favourable conditions for the occurrence of water erosion processes are distributed within April and September (when the highest rainfall amounts are recorded for all investigated stations; Figure 4). Table 3 summarizes monthly susceptibility of the Angot precipitation index classes (in%) for the selected stations during the period 1946–2014.

Figure 2: The 12-month moving average of precipitation distribution (for the study period) for the Vojvodina Region. ➤ p. 131
Figure 3: Spatial distribution of the mean annual precipitation for the study period in the study area. ➤ p. 132
Figure 4: Mean monthly multiannual precipitation amounts (mm) for the selected stations and regions. ➤ p. 133–134


Precipitation (mm)
0
50
100
150
200
Year
1946
1948
1950
1952
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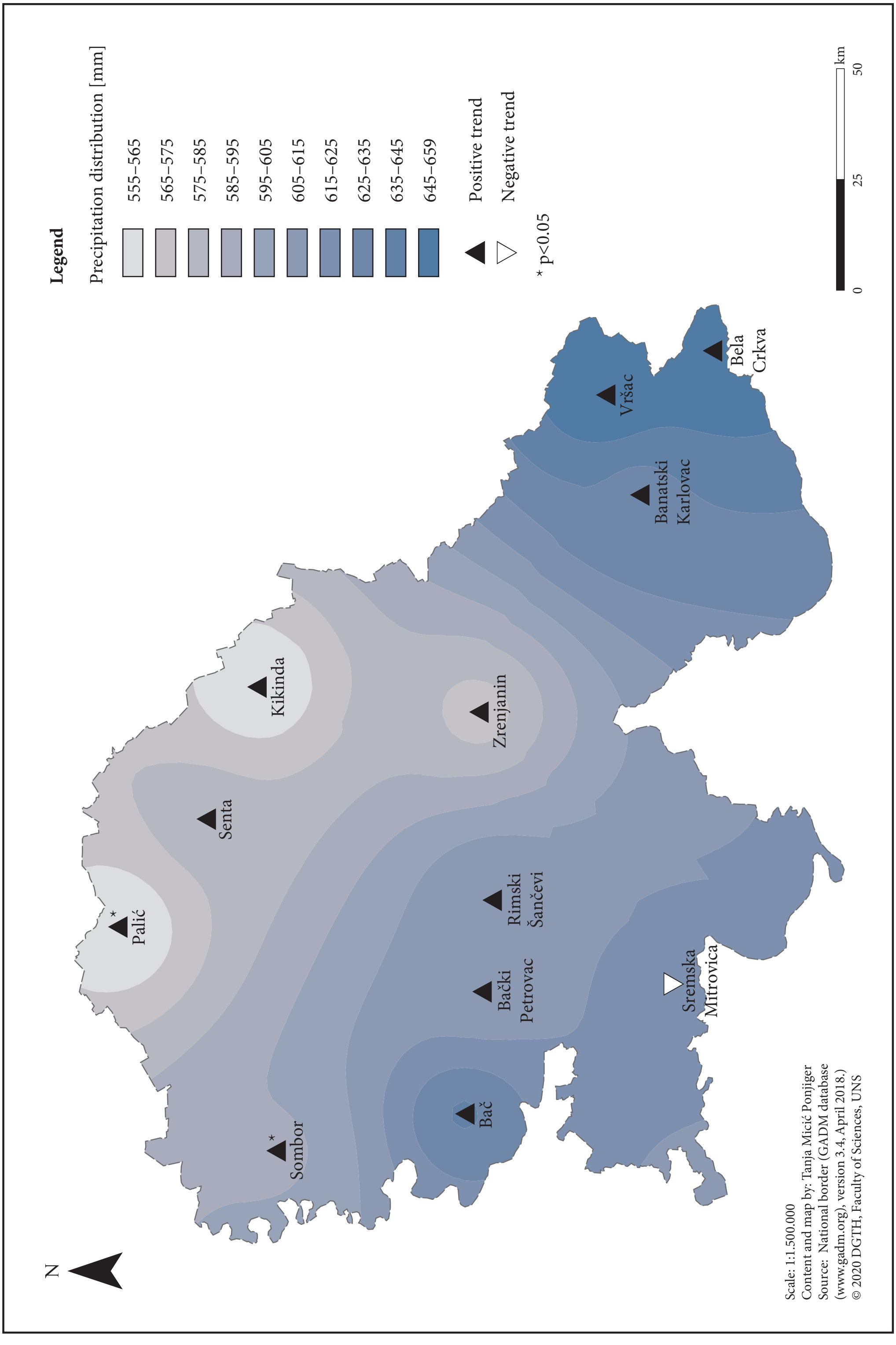

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Content and map by: Tanja Micić Ponjiger
Source: National border (GADM database (www.gadm.org), version 3.4, April 2018.)
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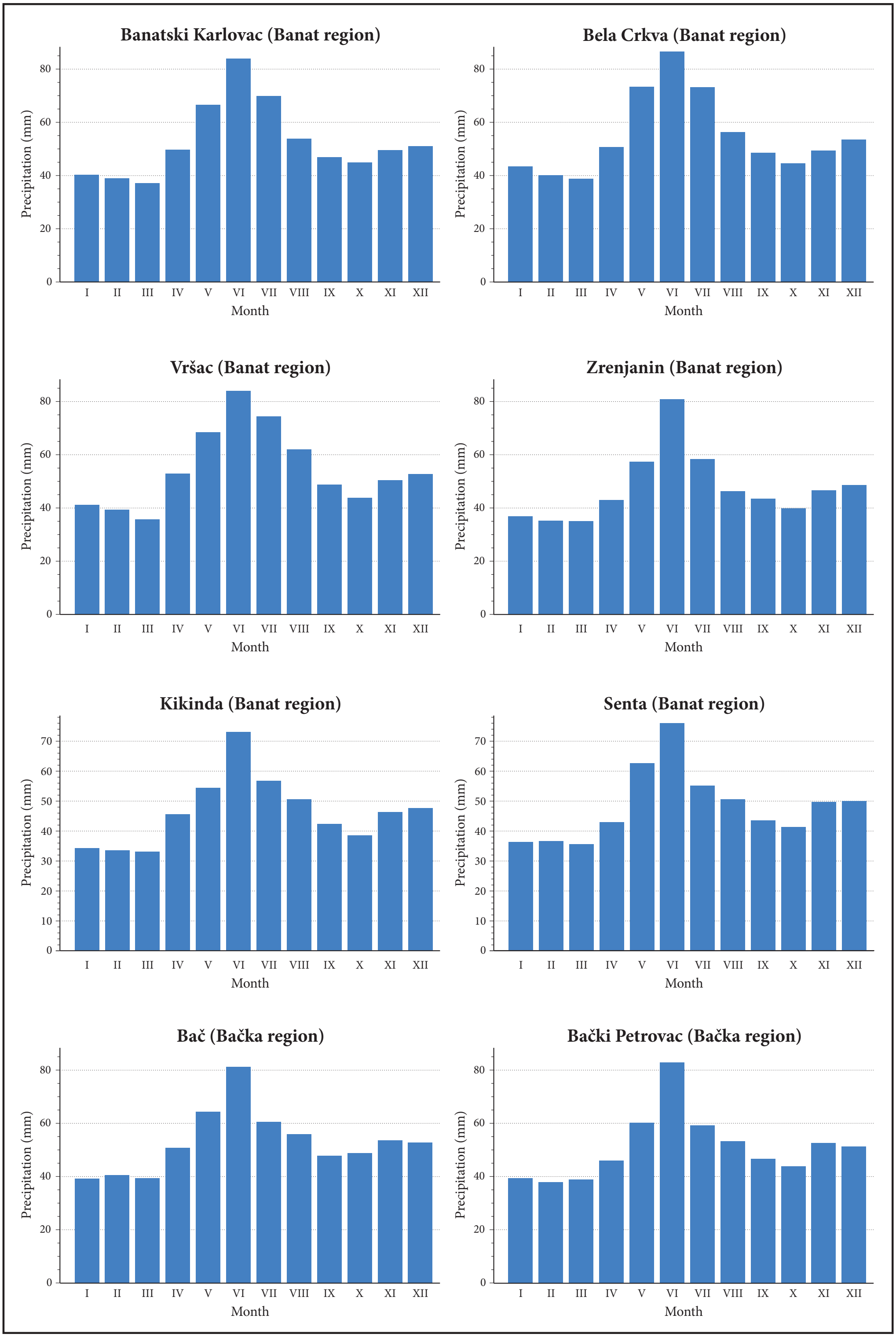
Banatski Karlovac (Banat region)
Bela Crkva (Banat region)
Vršac (Banat region)
Zrenjanin (Banat region)
Kikinda (Banat region)
Senta (Banat region)
Bač (Bačka region)
Bački Petrovac (Bačka region)
Precipitation (mm)
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30
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70
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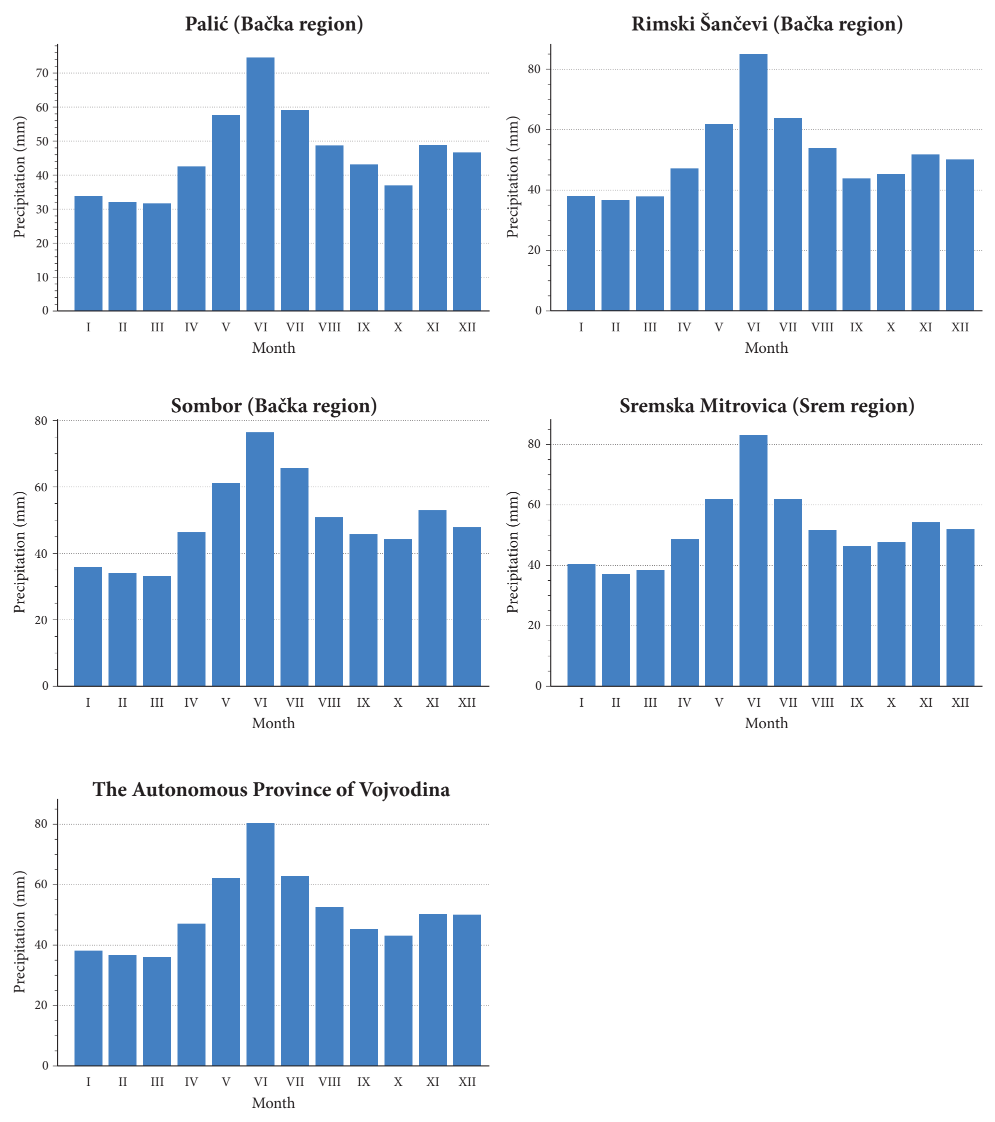
Palić (Bačka region)
Precipitation (mm)
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IX
X
XI
XII
Month
Rimski Šančevi (Bačka region)
Precipitation (mm)
0
20
40
60
80
Month
Sombor (Bačka region)
Precipitation (mm)
0
20
40
60
80
Month
Sremska Mitrovica (Srem region)
Precipitation (mm)
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40
60
80
Month
The Autonomous Province of Vojvodina
Precipitation (mm)
0
20
40
60
80
Month

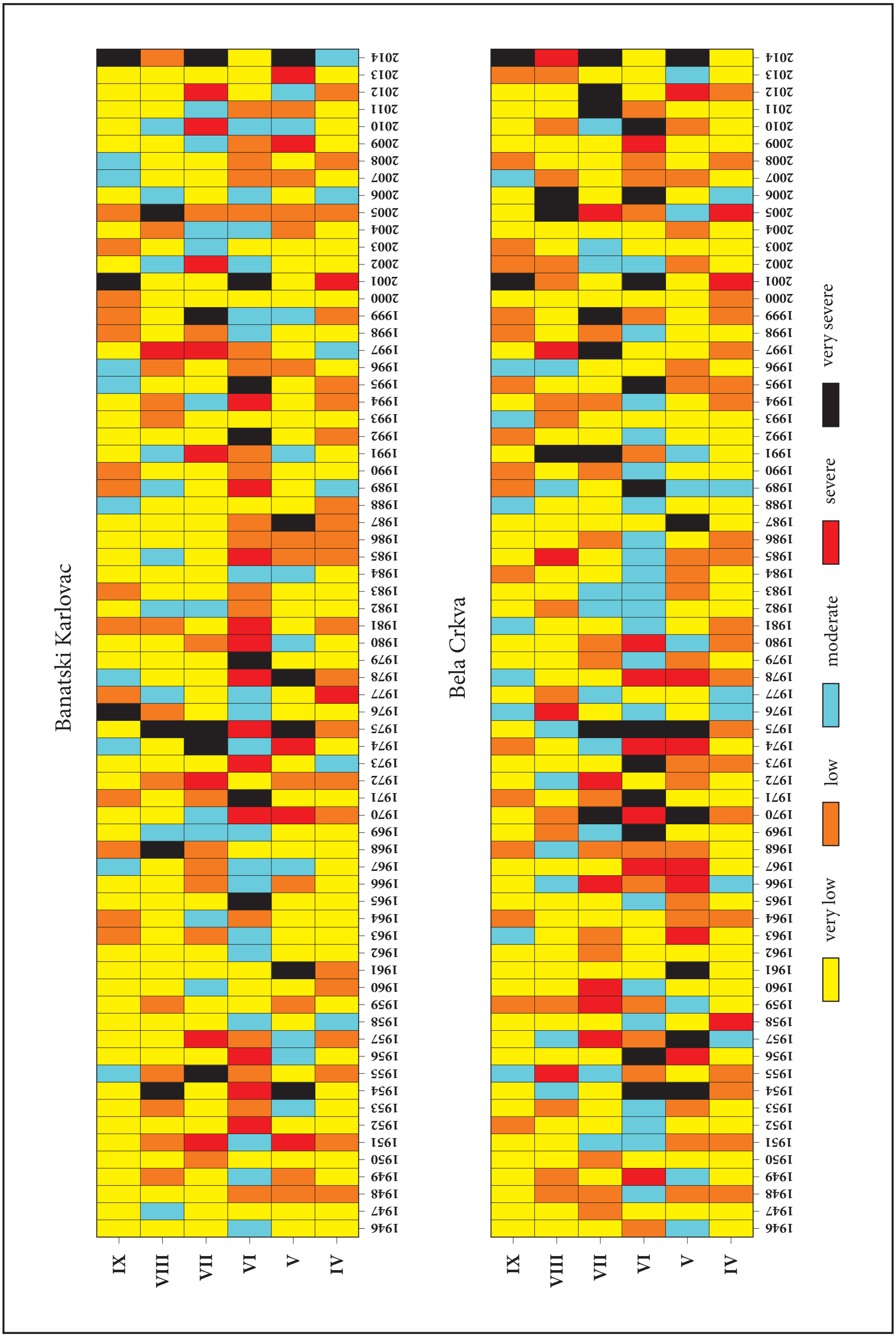
Table 3: Monthly susceptibility of Angot precipitation index classes (1946–2014).

Susceptibility class / Angot index values	Month (%)					
	April	May	June	July	August	September
Banatski Karlovac (Banat Region)						
Very low (< 1.0)	56.5	52.2	20.3	53.6	59.4	62.3
Low (1.0–1.5)	31.9	17.4	26.1	13.4	18.8	20.3
Moderate (1.6–2.0)	8.7	14.5	27.5	14.5	14.5	13.1
Severe (2.1–2.5)	2.9	7.2	17.4	11.6	1.5	0
Very severe (> 2.5)	0.0	8.7	8.7	7.2	5.8	4.4
Bela Crkva (Banat Region)						
Very low (< 1.0)	57.9	42.1	26.1	46.4	55.1	59.4
Low (1.0–1.5)	28.9	26.1	17.4	18.8	21.7	24.6
Moderate (1.6–2.0)	8.7	11.6	30.4	14.5	11.6	13.1
Severe (2.1–2.5)	4.3	10.1	10.1	8.7	7.2	0
Very severe (> 2.5)	0.0	10.1	15.9	11.6	4.3	2.9
Vršac (Banat Region)						
Very low (< 1.0)	53.6	44.9	23.2	47.8	53.6	63.8
Low (1.0–1.5)	31.9	28.9	27.5	18.8	15.9	18.8
Moderate (1.6–2.0)	10.1	14.5	20.3	13.1	14.5	8.7
Severe (2.1–2.5)	4.3	4.3	17.4	8.7	5.8	5.8
Very severe (> 2.5)	0.0	7.2	11.6	11.6	10.1	2.9
Zrenjanin (Banat Region)						
Very low (< 1.0)	59.4	53.6	17.4	53.6	66.6	62.3
Low (1.0–1.5)	28.9	17.4	26.1	18.8	14.5	23.2
Moderate (1.6–2.0)	10.1	15.9	27.5	10.1	10.1	8.7
Severe (2.1–2.5)	1.4	7.2	13.1	7.2	4.3	1.4
Very severe (> 2.5)	0.0	5.8	15.9	10.1	4.3	4.4
Kikinda (Banat Region)						
Very low (< 1.0)	56.5	49.3	30.4	47.8	53.6	56.5
Low (1.0–1.5)	28.9	18.8	23.2	21.7	23.2	28.9
Moderate (1.6–2.0)	5.8	17.4	15.9	14.5	11.6	8.7
Severe (2.1–2.5)	5.8	11.6	15.9	10.1	5.8	2.9
Very severe (> 2.5)	2.9	2.9	14.5	5.8	5.8	2.9
Senta (Banat Region)						
Very low (< 1.0)	69.6	46.4	24.6	59.4	50.7	57.9
Low (1.0–1.5)	18.8	21.7	27.5	20.3	27.5	24.6
Moderate (1.6–2.0)	8.7	15.9	24.6	8.7	13.1	11.6
Severe (2.1–2.5)	1.4	7.2	8.7	7.2	5.8	2.9
Very severe (> 2.5)	1.4	8.7	14.5	4.4	2.9	2.9
Bač (Bačka Region)						
Very low (< 1.0)	57.9	43.5	26.1	47.8	57.9	65.2
Low (1.0–1.5)	30.4	30.4	24.6	28.9	20.3	14.5
Moderate (1.6–2.0)	10.1	13.1	24.6	14.5	11.6	8.7
Severe (2.1–2.5)	0	8.7	14.5	5.8	4.3	8.7
Very severe (> 2.5)	1.4	4.3	10.1	2.9	5.8	2.9
Bački Petrovac (Bačka Region)						
Very low (< 1.0)	65.2	47.8	21.7	53.6	59.4	59.4
Low (1.0–1.5)	23.2	24.6	28.9	21.7	20.3	18.8
Moderate (1.6–2.0)	8.7	17.4	17.4	8.7	10.1	13.1
Severe (2.1–2.5)	2.9	4.3	17.4	8.7	5.8	5.8
Very severe (> 2.5)	0.0	5.8	14.5	7.2	4.4	2.9

Susceptibility class / Angot index values	Month (%)					
	April	May	June	July	August	September
Palić (Bačka Region)						
Very low (< 1.0)	63.8	42.1	26.1	39.1	44.9	57.9
Low (1.0–1.5)	24.6	28.9	26.1	31.9	33.3	24.6
Moderate (1.6–2.0)	5.8	13.1	15.9	15.9	15.9	8.7
Severe (2.1–2.5)	4.4	10.1	20.3	8.7	1.4	4.3
Very severe (> 2.5)	1.4	5.8	11.6	4.3	4.4	4.3
Rimski Šančevi (Bačka Region)						
Very low (< 1.0)	59.4	47.8	23.2	52.2	57.9	66.7
Low (1.0–1.5)	31.9	26.1	23.2	18.8	18.8	15.9
Moderate (1.6–2.0)	5.8	14.5	23.2	10.1	8.7	11.6
Severe (2.1–2.5)	1.4	7.2	14.5	11.6	10.1	4.3
Very severe (> 2.5)	1.4	4.3	15.9	7.2	4.3	1.4
Sombor (Bačka Region)						
Very low (< 1.0)	56.2	49.3	26.1	40.6	59.4	65.2
Low (1.0–1.5)	33.3	23.2	24.6	21.7	23.2	18.8
Moderate (1.6–2.0)	5.8	11.6	27.5	26.1	8.7	5.8
Severe (2.1–2.5)	2.9	7.2	13.1	4.3	2.9	5.8
Very severe (> 2.5)	1.4	8.7	8.7	7.2	5.8	4.3
Sremska Mitrovica (Srem Region)						
Very low (< 1.0)	52.2	49.3	21.7	44.9	60.9	63.8
Low (1.0–1.5)	37.7	23.2	27.5	34.8	18.8	18.8
Moderate (1.6–2.0)	7.2	17.4	24.6	7.2	11.6	11.6
Severe (2.1–2.5)	2.9	4.3	15.9	7.2	4.3	2.9
Very severe (> 2.5)	0.0	5.8	10.1	5.8	4.3	2.9
The Autonomous Province of Vojvodina						
Very low (< 1.0)	56.5	44.9	21.7	46.4	55.1	63.8
Low (1.0–1.5)	34.8	31.9	27.5	27.5	21.7	20.3
Moderate (1.6–2.0)	7.2	10.1	27.5	14.5	14.5	11.6
Severe (2.1–2.5)	1.4	8.7	14.5	5.8	5.8	1.4
Very severe (> 2.5)	0.0	4.3	8.7	5.8	2.9	2.9

According to the *K* index values for the Banat Region, Banatski Karlovac meteorological station records, the presence of very severe rainfall erosivity occurred in 1975 and 2014. On the other hand, the presence of moderate erosion classes is evenly distributed during the two thirty-year cycles in the study period. Bela Crkva station follows a similar pattern. After 1975, an increase of very severe precipitation classes has been observed during the studied six-month interval. The most pronounced very severe precipitation erosion classes have been observed for the Vršac station in 1995. During the study period, this station does not record the presence of severe erosion classes except in 2014 (during May, August and September). This observation corresponds with the results of Lukić et al. (2019), who pointed out that the weather station Vršac (*MFI* – 149.16) and its surroundings have the highest erosivity value for 2014. The Zrenjanin station records very severe rainfall erosivity classes in 2010 and 2014. The number of precipitation months classified as severe and very severe erosion have been increasing since 1999 (Figure 5). The weather station Kikinda does not display extreme rainfall erosivity, during the investigated period. 2001 is highlighted as a year where severe erosion occurred in April, June and September. Extreme precipitation sums (registered in 2014) for the weather station of Senta indicate the presence of very severe erosion during May, July and September. Years with the distinguished presence of very severe erosion classes (33.3% of the studied precipitation interval) are 1974, 1978, 1999, 2001 and 2004. This implies that the area surrounding Senta weather station is somewhat more prone to rainfall erosivity.

Figure 5: Mean multiannual values of *K* Index during the warm part of the year for Banat weather stations. ➤ p. 137–139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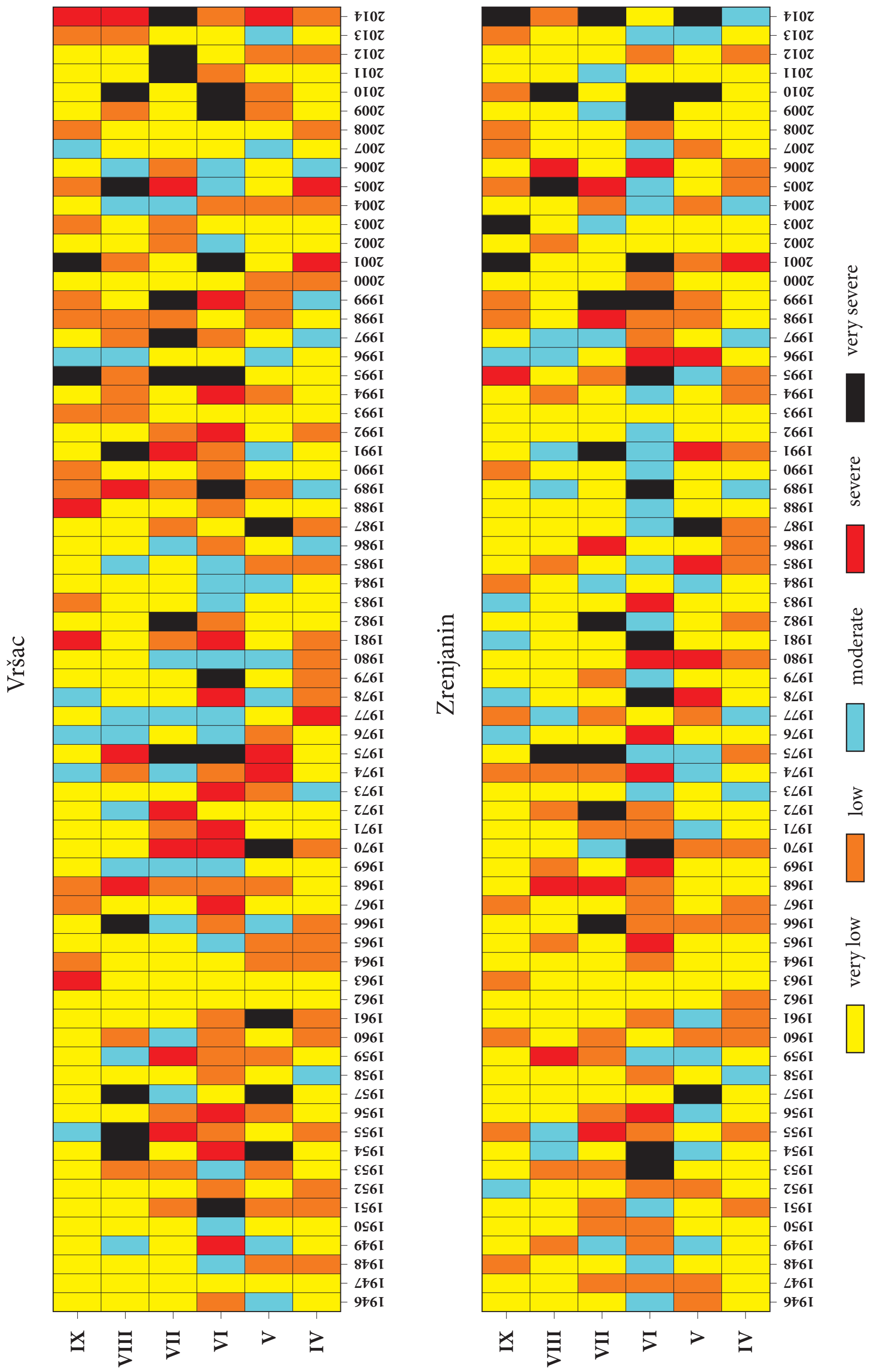
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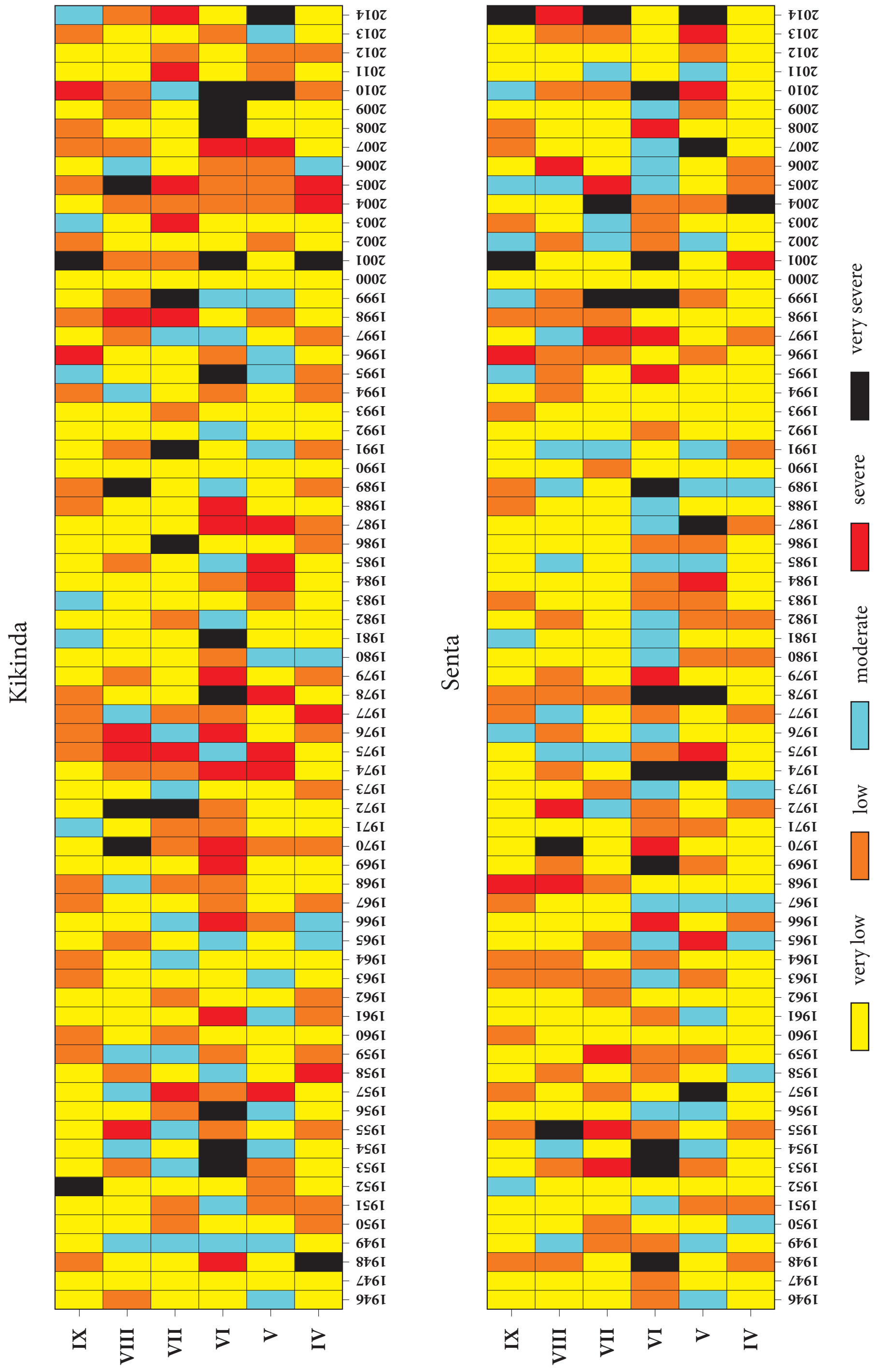
very severe
severe
moderate
low
very low


Kikinda
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severe
very severe

According to the *K* index values for the Bačka Region, the Bač weather station in the western part of Vojvodina Region, registers several years with the two-month precipitation interval presence of very severe erosion classes (2001, 2005 and 2014). The presence of low values of the *K* index corresponds well with the observations provided by Bjelajac et al. (2016). The Bački Petrovac station does not display a higher presence of severe erosion classes during the study period. The years with the presence of severe erosion classes within the 33.3% of the precipitation interval are 1975, 2005 and 2014. On the other hand, the Palić weather station in the north of the Vojvodina province generally displays an absence of periods with intensive rainfall erosivity classes. These observations fit well with the finding of Lukić et al. (2019), that Palić area records the lowest erosivity value in the Vojvodina Region during 1983 (*MFI* – 8.60). Results for the Rimski Šančevi weather station in the southern parts of Bačka Region indicate that an increase of rainfall erosivity can be seen from 1995, with the presence of three-month precipitation intervals of very severe erosion in 2001. Lukić et al. (2019) indicate that this part of the Pannonian Basin is characterized by periods of irregular precipitation concentration and an increase of *MFI* values on an annual basis. These features suggest a rather wetter conditions in this part of Vojvodina Region. The Sombor weather station generally registers weaker rainfall erosivity, with an exception of extreme rainy years (Figure 6).

According to the *K* index values for the Srem Region, the Sremska Mitrovica weather station does not identify higher three-month precipitation intervals of severe and very severe erosion classes. The years 1972, 2001 and 2014 record two-month precipitation intervals of very severe erosion. Three-month precipitation intervals of very severe erosion classes were only present during the extremely rainy 2014. The years of 1975 and 2001 record two-month precipitation intervals of the highest erosion classes. During the period 1946–2014, the highest presence of very low and low rainfall erosivity classes can be observed (Figure 7).

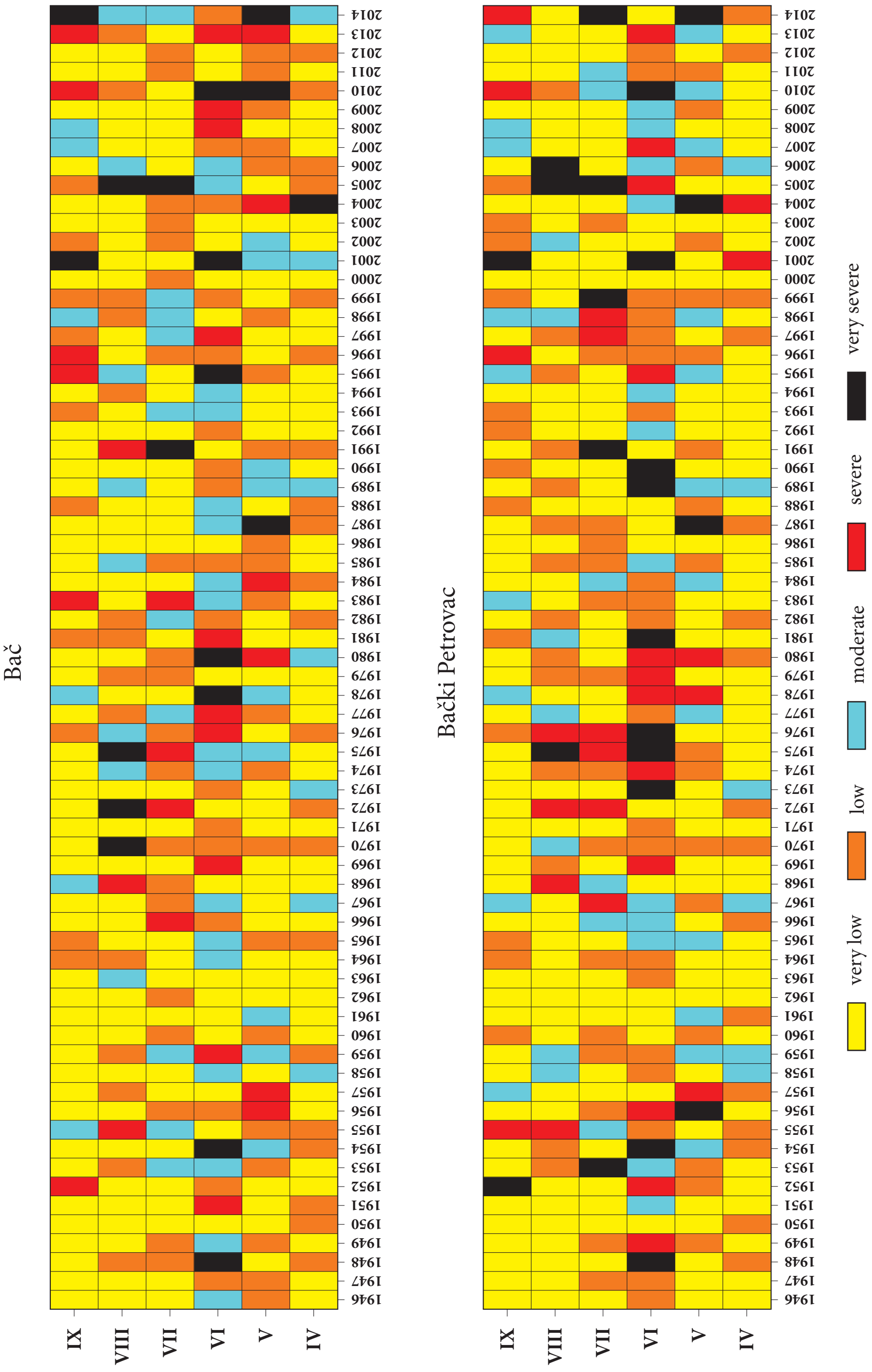
Similar approach related to the hydro-meteorological hazard assessment has been performed by Dumitraşcu et al. (2017) for the south-western part of Romania. Previously, Dragotă et al. (2014) pointed out that the Danube Floodplain displays moderate to excessive rainfall erosivity regime. Authors emphasize that due to relief configuration, reduced declivity and soil types, moderate, low and very low susceptibility classes prevail in the study area. On the other hand, Dumitraşcu et al. (2017) showed that mountainous and hilly areas display the highest susceptibility to rainfall erosivity, as it can be observed for south-eastern parts of the Vojvodina Region (Banat Region with Vršac weather station) (Figure 8). As the altitude drops, severe and very severe class values are approximately equally distributed on a multiannual basis corresponding to the findings in a neighbouring country. As observed for the Romanian plain and the Danube valley, very low and low classes dominate, especially in April, August and September, which is in accordance with the obtained mean *K* values for the Vojvodina Region (Figure 8). On the other hand, Lukić et al. (2019) suggest that both the amount and the intensity of precipitation are increasing and varying in some areas of the Pannonian Basin. The trends generally indicate a progressive increase in the values of the erosion by precipitation at the annual level, which in future may lead to the transition to a higher erosive class and increase the vulnerability to this type of erosion in the Pannonian Basin and Vojvodina Region. Also, the relief properties and the interaction with the general atmospheric circulation in the study area greatly contribute to the spatial pattern of rainfall erodibility potential in terms of intensity, frequency and spatial distribution (Figures 3 and 8). These spatial features correspond with the *RUSLE* soil loss results, presented by Borrelli et al. (2017).

In agricultural areas, evaluation of the vulnerability associated with the high impact of rainfall erosivity is of utmost importance in the context of sustainable agricultural practices and specific local or regional climate conditions (Komac and Zorn 2005; Maracchi, Sirotenko and Bindi 2005). Accordingly, a good understanding of climate variability and main precipitation features is of great importance, especially when dealing with rainfall erosivity in agricultural areas such as Vojvodina Region.

Figure 6: Mean multiannual values of *K* Index during the warm part of the year for Bačka weather stations. ➤ p. 141–143

Figure 7: Mean multiannual values of *K* Index during the warm part of the year for Srem weather station and the Vojvodina Region. ➤ p. 144

Figure 8: Distribution of the mean *K* Index classes for the observed period and comparison with the *RUSLE* soil loss values (adapted after Borrelli et al. 2017). ➤ p. 145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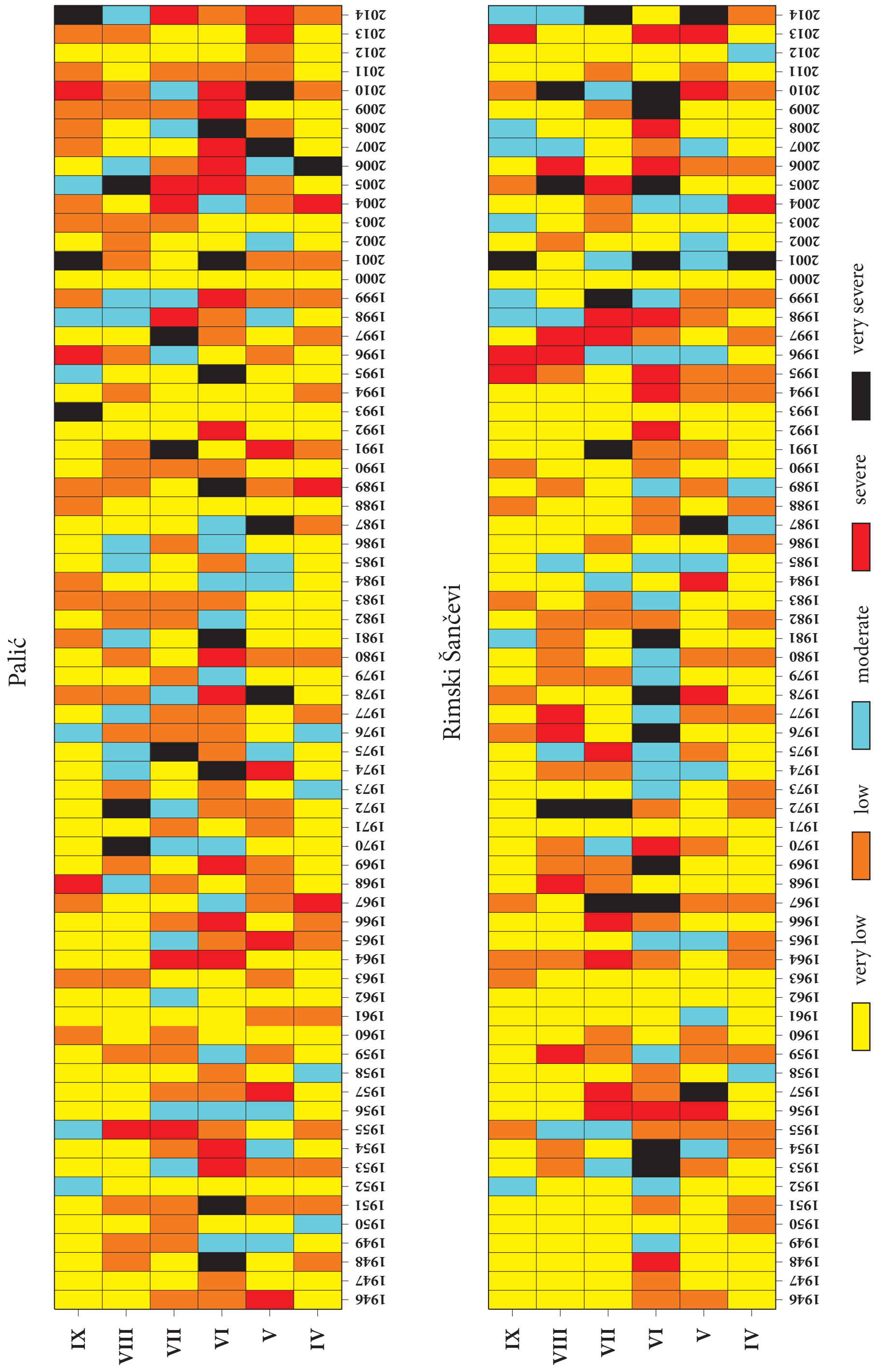
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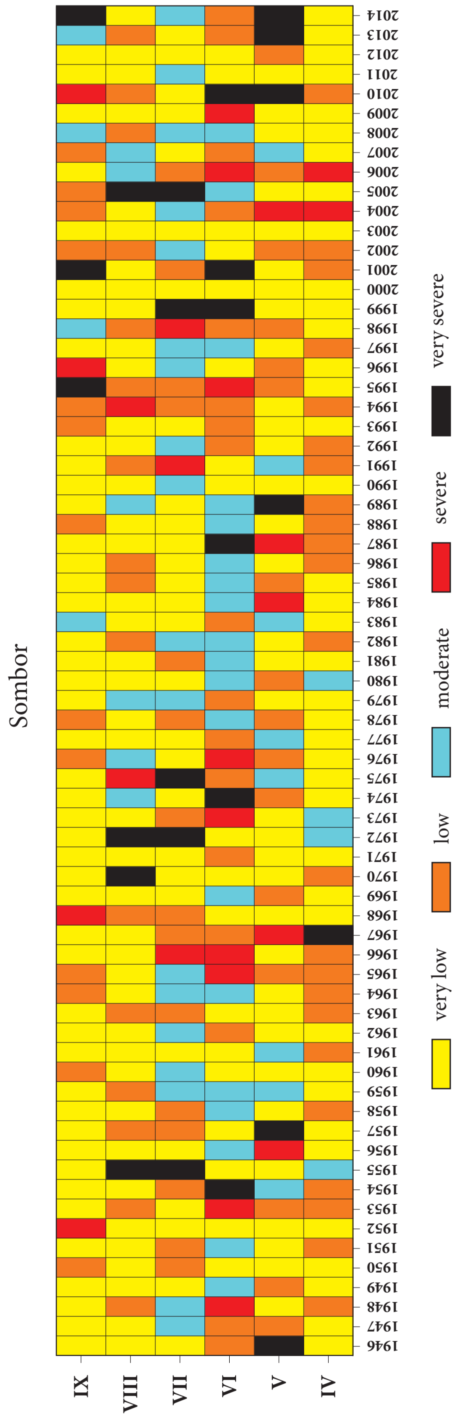
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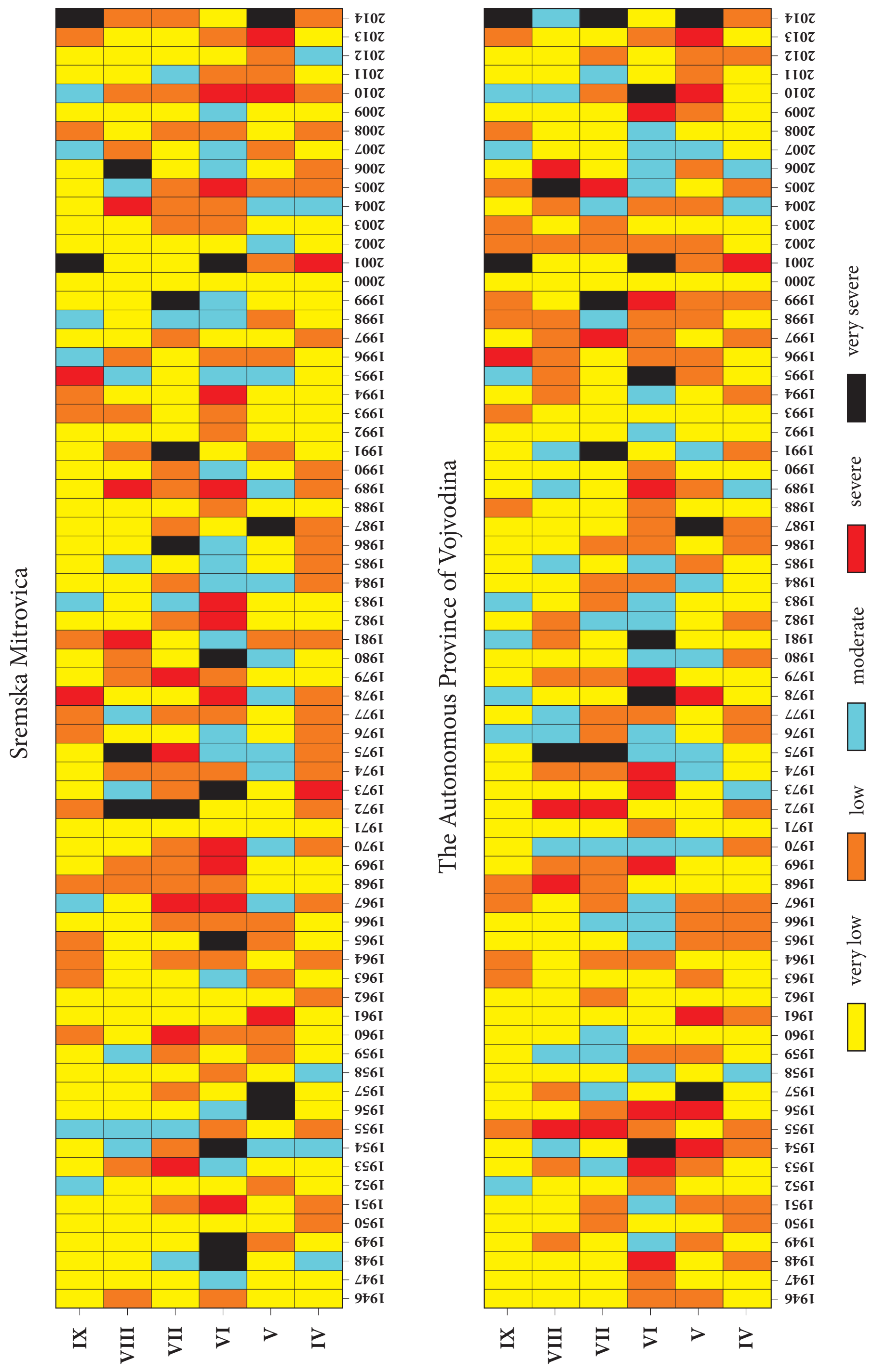
Sremska Mitrovica
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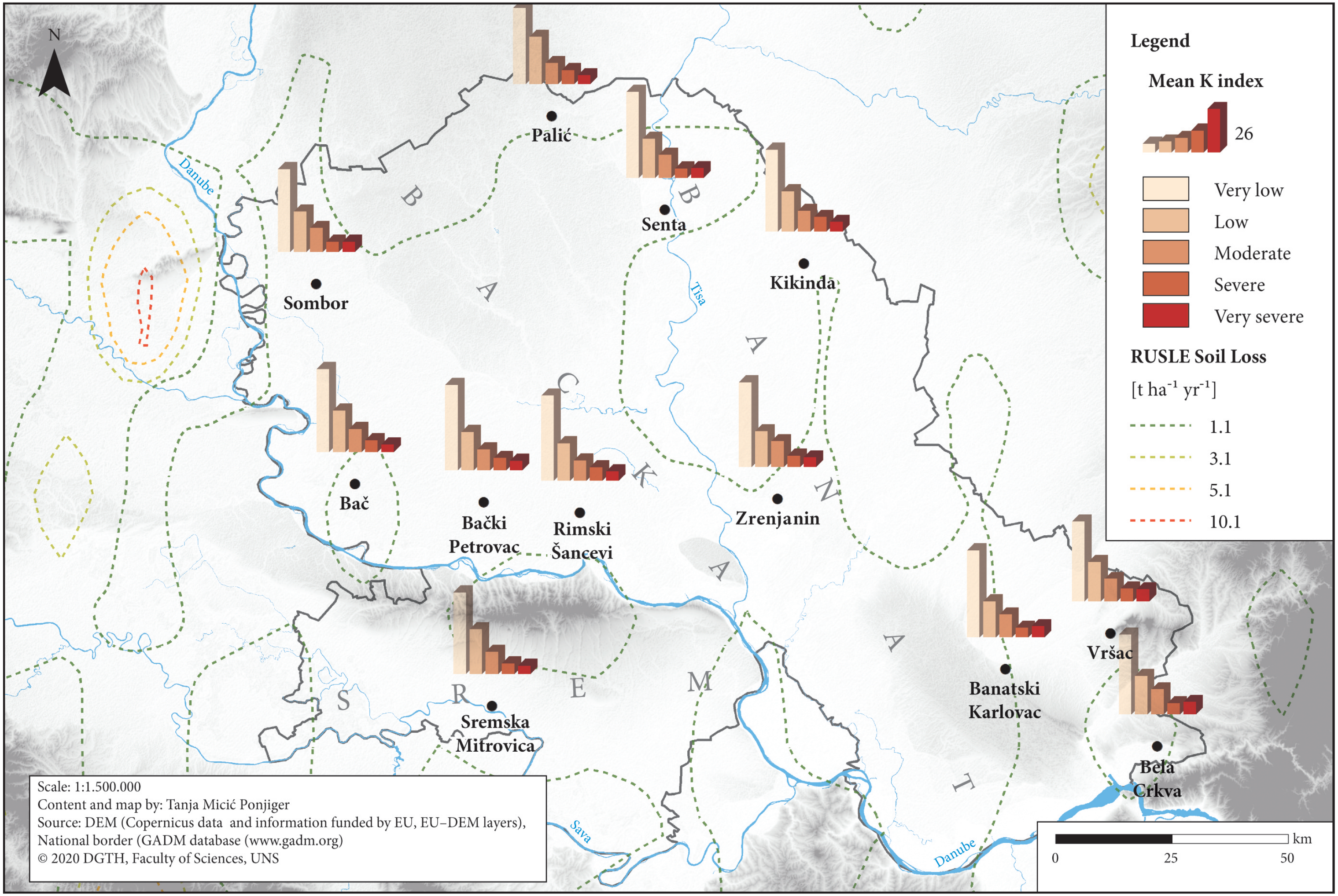

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Content and map by: Tanja Mićić Ponjiger
Source: DEM (Copernicus data and information funded by EU, EU–DEM layers),
National border (GADM database (www.gadm.org)
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In order to protect areas that are potentially endangered by rainfall erosion, it is necessary to assess the intensity of these processes, and then evaluate the negative impact of social structures. As pointed out by Panagos et al. (2015a), rainfall erosivity in Europe is a key parameter for estimating soil erosion loss and risk in various regions. Authors outline that the European continental climatic zone is characterized by warm summers and cold winters, and thus highly susceptible to the variability of rainfall erosivity. The mean rainfall erosivity factor for the Pannonian zone (central Danubian basin) is 660.1 $\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}}$ and corresponds well with the findings of Mezősi and Bata (2016) and Lukić et al. (2019).

The results of *NAO* and *MEI* indices were correlated with the mean annual precipitation data for the study area and *K* index values. Correlation between the teleconnection patterns and precipitation parameters was estimated in order to investigate the possible relationships between rainfall erosivity and atmospheric variability by applying Pearson's correlation analysis at the 5% ($p < 0.05$) significance level. A correlation between the *NAO* index and precipitation (–0.19), as well as the *K* index (–0.20), is presented in Figure 9. The negative correlation coefficient indicates the wetting effect on the *K* index. Based on contemporary findings it can be pointed out that *NAO* considerably affects rainfall in this part of Europe (e.g., Tošić et al. 2014; Luković et al. 2015; Radaković et al. 2018), and since the *K* index is based on precipitation amounts, *NAO* has a certain influence on it as well. As pointed out by Bice et al. (2012), *NAO* generally has a strong influence on winter precipitation in the Pannonian Basin, with negative *NAO* phases corresponding to periods of high precipitation. Results of Malinović-Milićević et al. (2018) indicate that the amount and intensity of precipitation in Serbia had a statistically significant increase during autumn, and were most pronounced in the northern (Vojvodina) and western parts of the country. The authors showed that »dry« regimes dominate over »wet«, with an increasing trend of »warm« regimes and decreasing trend of »cold« regimes. The correlation between the examined extreme indices and the large-scale circulation patterns showed that East Atlantic (*EA*) and *NAO* patterns had a significant influence on the duration of winter warm periods, while their influence on the duration of cold periods cannot be confirmed with certainty. The East Atlantic/West Russia (*EAWR*) pattern affects statistically significant positive autumn trends of all intensity and frequency indices. In winter, it has an impact on the frequency of »dry« and »wet« conditions and the intensity of the precipitation. On the other hand, the correlation between *MEI* and precipitation (0.006) cannot be confirmed for the given significance level ($p < 0.05$). Hence, no significant correlations were detected between observed precipitation parameters, *NAO* and *MEI*, thus generally indicating the absence of strong linearity between the *K,* and these two large-scale processes of climate variability. As shown by Dehghani et al. (2020), large-scale circulation drivers have a considerable impact on precipitation in different regions, where various climate indices in different phases may decrease the seasonal precipitation (even up to 100%). On the other hand, seasonal precipitation may increase more than 100% in different seasons due to the impact of these indices.

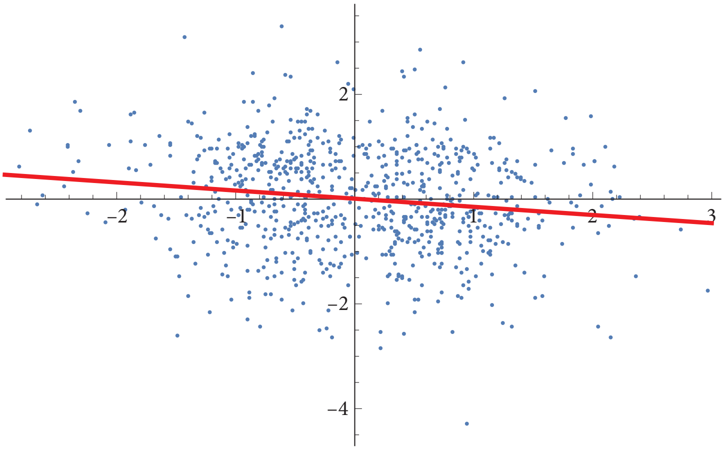
5 Conclusion

Soil erosion by water has often been overlooked (Zorn 2015) as an important land degradation (Zorn and Komac 2013b) and environmental problem. In the Soil Thematic Strategy of the European Commission (Communication … 2006) it is listened among the eight main threats to soil in the EU (Panagos 2015b).

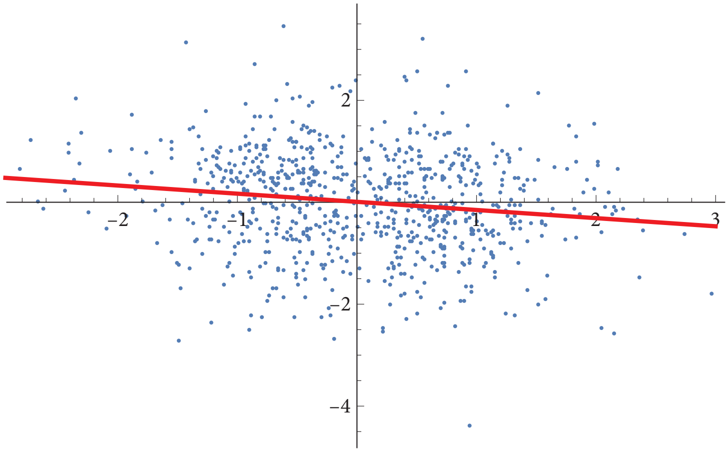
In this study the *K* index was used to determinate the characteristic types of monthly and annual variation of precipitation based on regional and local comparisons. Results of this study indicate that the Vojvodina Region has experienced the presence of various susceptibility classes of precipitation liable for triggering soil erosion from April until September. June and July are the months with higher frequency of very severe erodibility classes, with the distribution of 8.70% and 5.80%, respectively. Most of the distributed erodibility classes observed for the study area belong to moderate, varying from 7.25% (in April) up to 27.54% (in June). On the other hand, a progressive increase in the values of the rainfall erosivity at the annual level (induced by climate variability), in the future can lead to the transition to a higher erosive class and increase the vulnerability to rainfall erosion in the Pannonian continental climatic zone.

Figure 9: Correlation between *NAO* and precipitation (a), *NAO* and *K* Index (b), and *MEI* and precipitation (c). ➤ p. 147

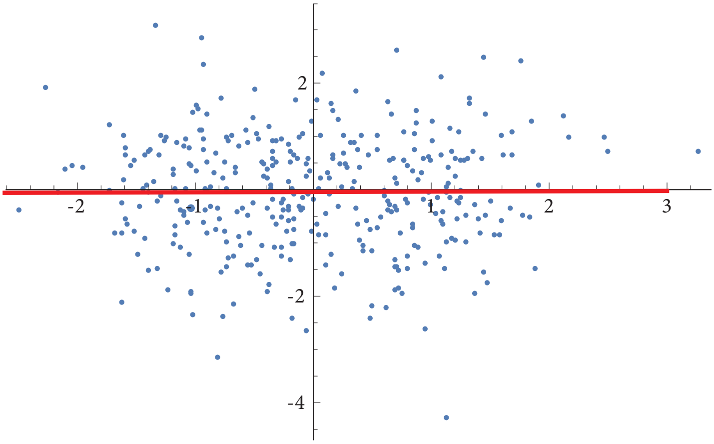
a) NAO (x)–Precipitation (y) correlation



b) NAO (x)–Angdot index (y) correlation



c) MEI (x)–Precipitation (y) correlation



As precipitation is seen as one of the main triggering factors for flash floods, landslides, and soil erosion, future extreme weather events are likely to have seriously damaging effects on crops and pastures, thus changing the land use and land cover.

In the further research it is necessary to look more into the relationship between *NAO* and its impact on changes in seasonal precipitation. For Serbia, these changes should be investigated in detail using a wet season concept between October and March, as previously discussed by Luković et al. (2015). This approach may be suitable since it could investigate the probability of an increase or decrease in precipitation amounts associated with the above-mentioned indices and seasonal rainfall erosivity rates as well.

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