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Research Article

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Rainfall erosivity and extreme precipitation in the Pannonian basin

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Abstract: In order to assess the rainfall erosivity in the Pannonian basin, several parameters which describe distribution, concentration and variability of precipitation were used, as well as 9 extreme precipitation indices. The precipitation data is obtained from the European Climate Assessment and Dataset project for the period 1961-2014, for 8 meteorological stations in northern Serbia, 5 in Hungary and 1 in eastern Croatia. The extreme values of precipitation were calculated following the indices developed by the ETCCDI. *RclimDex* software package was used for indices calculation. Based on statistical analysis and the calculated values, the results have been presented with Geographic Information System (GIS) to point out the most vulnerable parts of the Pannonian basin, with regard to pluvial erosion. This study presents the first result of combined rainfall erosivity and extreme precipitation indices for the investigated area. Results of *PCI* indicate presence of moderate precipitation concentration (mean value 11.6). Trend analysis of *FI* (mean value 22.7) and *MFI* (mean value 70.2) implies a shift from being largely in the low erosivity class, to being completely in the moderate erosivity class in the future, thus indicating an increase in rainfall erosivity for most of the investigated area (except in the northwestern parts). Furthermore, the observed precipitation extremes suggest that both the amount and the intensity of precipitation are increasing. The knowledge about the areas affected by strong soil erosion could lead to introducing effective measures in order to reduce it. Long term analysis of rainfall erosivity is a significant step concerning flood prevention, hazard mitigation, ecosystem services, land use change and agricultural production.

Keywords: erosion, natural hazard, precipitation, rainfall erosivity, extreme precipitation indices, Pannonian basin

1 Introduction

The precipitation is seen as a variable element in time and space and it directly affects natural water cycles, but also provides information on the state of the climate [1]. During the last decades, numerous studies focused on precipitation variability all over the world. The results indicated a significant decrease in the number of rainy days and a significant increase in the precipitation intensity in many places in the world, such as China [2–4] and America [5]. There are numerous studies that investigate the trends in annual and seasonal precipitation, for larger areas [6–8], but also for the entire nations or regions [9–13]. Luković *et*

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al. [14] could not find the significant trends in total annual precipitation for the whole territory of Serbia during the period 1961-2009. However, they found minor tendencies toward drier conditions on a seasonal scale. The winter season, as well as spring are receiving less rain, while autumn experienced wetter conditions. For the territory of Vojvodina, Tošić *et al.* [15] analyzed the precipitation data for more than 90 stations during the period 1949-2006. They found that the time series of leading Principal Component of the Vojvodinian precipitation has a decreasing trend during the winter and spring seasons while the increase was detected for autumn, summer, and annual precipitation. Bartholy and Pongrácz [16] observed the decreased precipitation totals in Hungary and argued that the climate became slightly drier during 20^{th} century. The changes in annual precipitation levels for Croatia were analyzed based on the data for 22 meteorological stations during the period 1950 to 2010. Pannonian part of eastern Croatia experienced a slight increase in precipitation while the other regions recorded stagnation of slight decrease [17]. The general decline of precipitation totals in Croatia are probably due to the spring and autumn reduction in the northern part as well as winter and spring decrease along the coast and in the mountains [18].

Extreme precipitation events, such as droughts [19] and floods [20], are seen as highly variable and could cause economic, as well as ecological damage, but in the worst cases induce increased mortality. Studies around the globe showed that during the last few decades, extreme precipitation events are becoming more frequent (*e.g.* [21–24]). The changes in precipitation are very important due to their significance for economic agriculture, energy production and drinking water supply. Also, the changes in precipitation have a major role in natural hazards such as droughts, floods, landslides and severe soil erosion [25]. The changes in precipitation, along with their extreme values, occur over a wide range of temporal and spatial scales. Many studies conducted globally [26–29]), regionally [30–32] as well as on local scales [11, 33–36], have emphasized growing precipitation variability with rises in northern and central Asia, in the eastern parts of North and South America and in northern Europe [37–40]. On the other hand, some areas such as the Mediterranean display either a decrease in which is not always significant, or the absence of a linear trend (*e.g.* [31, 36, 41–46]).

Magnitude and sign of the trend for extreme precipitation events are different for certain parts of Europe (*e.g.* [47–51]). In the Hungarian part of Pannonian basin during the last 20 years of the 20^{th} century decreases were predominant in both warm and cool seasons [52]. The recent changes in Serbian climate extreme indices were evaluated by Malinović-Milićević *et al.* [53]. They showed that there is a pronounced increase in daily precipitation totals as well as in precipitation intensity, especially in the north and the west of Serbia. Anđelković *et al.* [54] calculated the critical number of meteorological stations above which an event is considered as an extreme precipitation event, or a climate extreme of national significance. The respective authors found that this number is 6.21 stations (theoretically covering more 22.17% of the total territory), meaning that if during one day more than seven stations experience event that is above normal, they could be considered as very harmful and have great consequences for the environment.

Willems [55] found the presence of increasing trends in numerous features of extreme precipitation in Central and Western Europe. Additionally, the study argued that the precipitation extremes in Europe display oscillatory pattern on multidecadal time scales and could be linked to Atlantic Multidecadal Oscillation [56].

The changes in precipitation, the presence of extreme values affect the soil erosion, and unlike some other natural factors, such as relief or soil characteristics, is not responsive to human modification. The soil erosion by water is very complex phenomenon and it is one of the major threats to soil degradation [57–60]. Land loss as a result of erosion can lead to a decrease in organic matter and nutrient content, a change in soil structure, and a decrease in water capacity. Loss in productivity can be significant for the lives of people in the given area; the re-fertile layer of soil, which is the most fertile layer, is also most exposed to pluvial erosive processes [60–62]. In the work of Markantonis *et al.* [63], Rawat *et al.* [64], Berger and Rey [65], Gares *et al.* [66] and Mather [67] it was pointed out that soil erosion is intrinsically entangled with many other natural hazards. Respective authors such as Van Beek [68] and Bosco and Sander [69] pointed out that soil erosion is also part of a system of multiple interacting processes operating in a complex hierarchy. Therefore, mass movements play an important role within soil erosion processes due to their capacity to remove and expose large parts of slopes in a relatively short period. Pradhan *et al.* [70] stated that high soil erosion rates can also lead to an increase of landslide susceptibility due to the reduced capacity of soil to support a good vegetation cover. Landslides may also directly occur on gullies created by surface erosion processes [71].

Soil erosion is generally manifested through three main phases: the tearing of the surface material by the action of a certain agent, the transport of the material and its accumulation. Soil erosion by water is one of the most important causes of degradation of land and a critical environmental hazard in modern times. Soil erosion destroys land resources and increase the risk posed by the blockage of rivers as well as causes degradation of the water quality because of the pesticides, the fertilizers and the nutrients carried by the sediment [72]. Precipitation (pluvial) erosion denotes the potential ability of the atmospheric precipitate to cause soil erosion and represents the climatological component in the overall water erosion process [73].

Numerous indices of rainfall aggressivity (erosivity) have been developed in order to estimate soil erosion. Among those the most appropriate ones are those that relate soil erosion to kinetic energy of rainfall (storm erosivity), such as EI_{30} [74]. However, for the calculation of this index relatively continuous rainfall data series, with a time resolution of at least 15 min (pluviograph data) are needed [75, 76]. High quality datasets on such temporal and regional scale are very rare. In order to avoid this problem, other indices based on monthly data have been proposed, such as Fournier Index *(FI)* and its modification (Modified Fournier Index-*MFI)* by Arnoldus [77]. The *FI* and *MFI* have been used as the input aggressivity factor in the development of regional models [78], since they correspond very good with *USLE* rainfall erosivity factor *(R-factor)* [75, 76, 79–81].

Also, one of the most important aspects of the climate is the concentration of the rainfall amounts throughout the year. Since the precipitation during the year is highly variable, irregular and unpredictable, rainfall distribution varies from year to year. This has to be taken when one considers soil erosion, soil conservation and land evaluation [82, 83]. Precipitation Concentration Index *(PCI)* allows the calculation of the relative distribution of rainfall patterns, and also evaluates the seasonality of the precipitation. Generally, the *MFI* may be expressed as the product of Total Annual Precipitation (*P*) and monthly precipitation concentration (*PCI*) [84]. Based on this, the rainfall erosivity (*MFI*) is more intense where there are high values of precipitation concentration (high *PCI*) and Total Annual Precipitation (*P*).

In this paper climatological parameters from the area of northern Serbia (Vojvodina), Hungary and eastern Croatia will be processed. In order to assess the hazardous vulnerability for this part of the Pannonian basin, three parameters will be used: precipitation amount, rainfall erosivity and extreme precipitation indices.

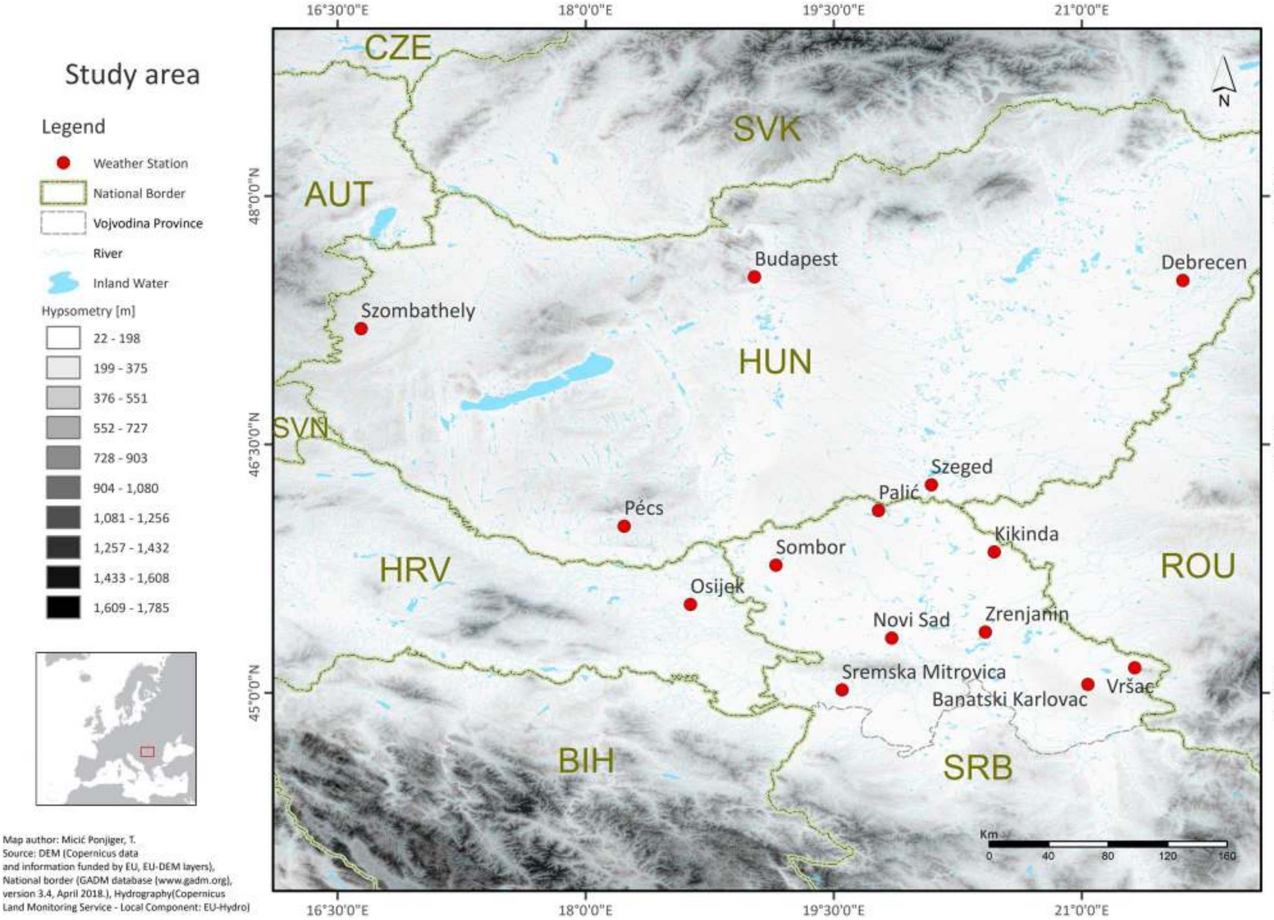
2 Materials and methods

2.1 Study area

The Pannonian basin is located in the central part of Europe. It occupies the territory between 43°50′ and 49°15′ latitude N and 15°06′ and 23°30′ longitude E (Figure 1). The region extends over nine countries: Austria, Slovenia, Hungary, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Romania, Slovakia and Ukraine and largely overlaps with the Pannonian plain. The Great Hungarian Plain, the Danube plain, the Sava plain and the Drava plain constitute the physical characteristics of the Pannonian basin. The Alps range in the west, the Carpathians in the north and east and the Dinaric in the south bound the surroundings of this region [85].

The Pannonian basin represents an area of high diversity of the physical, biophysical and socio-economic conditions. During the past few decades, an increase in number of hydrometeorological extreme events, such as heat waves, droughts and extreme precipitation, have been observed and had powerful effect on various regions in the Pannonian basin [60, 62, 86–95]. Results of the climate change models suggest great impacts on multiple sectors and the ecosystem in the Pannonian basin implying that this part of Europe will be among the hotspot regions with the highest number of severely affected sectors in Europe [95–97].

Since, the Pannonian basin is located in the mid-latitudes of the Northern Hemisphere, the lowest temperatures occur in January and the highest in July and August, the rainfall season ranges from mid-April to September, and the cloud cover is highest from November to January [85, 98–100]. When observing the trends of 10 different meteorological variables Spinioni *et al.* [99] found that temperature was increasing in every season, particularly during the last three decades. This finding was in the good agreement with the trends occurring in Europe. Wind speed was found to decrease in every season throughout the year, while cloud cover and relative humidity decreased in spring, summer, and winter, and increased in autumn. On the other hand relative sunshine duration had trends in the opposite way. For the precipitation and surface air pressure no significant trends were found, even though they increased slightly on an annual basis [99].



Map author: Micić Ponjiger, T.
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)

Figure 1: Meteorological stations in the Pannonian basin used in this study.

2.2 Data and methods

For the purpose of this analysis the daily data on precipitation from the database of the European Climate Assessment and Dataset (ECA&D) for the period 1961-2014 was used. The daily data was then aggregated on monthly and yearly basis. The data were obtained for the calculation of individual indices: *PCI*, *FI*, *MFI* and the extreme rainfall indices.

The list of the meteorological stations used in this study is given in Table 1. For the analysis and calculation of the indices the blended ECA data sets were used. The daily ECA data were tested and homogenized by Wijngaard *et al.* [101]. Only validated participant data indicated by 0 in the column labeled Q (RR) given in each data file in the blended datasets were used.

PCI [102] was used in order to assess regional rainfall erosivity. *PCI* was proposed as an indicator of rainfall concentration and rainfall erosivity [83]. This index was calculated on an annual basis according to Eq. (1):

$$PCI\ annual = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \times 100 \tag{1}$$

where the mean monthly amounts of precipitation are marked with p_i. In order to further examine the impact of erosion and determine the regional distribution of precipitation during the year, *PCI* is calculated at seasonal level for climatological winter (December – January – February), spring (March – April – May), summer (June – July – August) and autumn (September – October – November) according to Eq. (2):

$$PCI\ seasonal = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} p_i\right)^2} \times 25 \tag{2}$$

It was also calculated for wet (from April to September) and dry (from October to March) periods following the Eq. (3) [103]:

$$PCI\ supra\ seasonal = \frac{\sum_{i=1}^{6} p_i^2}{\left(\sum_{i=1}^{6} p_i\right)^2} \times 50 \tag{3}$$

Table 1: Meteorological stations analyzed in this study.

No.	Station name	Country	Latitude	Longitude	Altitude (m)
1.	Sombor	Serbia	45°46’12”	19°09’00”	87
2.	Palić	Serbia	46°06’00”	19°46’12”	102
3.	Rimski Šančevi	Serbia	45°19’48”	19°51’00”	86
4.	Kikinda	Serbia	45°51’00”	20°28’12”	81
5.	Zrenjanin	Serbia	45°22’00”	20°25’00”	80
6.	Banatski Karlovac	Serbia	45°03’00”	21°02’12”	100
7.	Vršac	Serbia	45°09’00”	21°19’12”	83
8.	Sremska Mitrovica	Serbia	45°01’00”	19°33’00”	82
9.	Pécs	Hungary	46°00’21”	18°13’58”	203
10.	Szeged	Hungary	46°15’22”	20°05’25”	82
11.	Debrecen	Hungary	47°29’25”	21°36’39”	108
12.	Budapest	Hungary	47°30’40”	19°01’14”	153
13.	Szombathely	Hungary	47°11’54”	16°38’52”	201
14.	Osijek	Croatia	45°32’00”	18°38’00”	88

Table 2: *PCI* value classes based on [102, 103].

Spatial distribution	*PCI* values
Uniform distribution	≤ 10
Moderate distribution	>10 ≤ 15
Irregular distribution	>15 ≤ 20
Strongly irregular distribution	>20

Table 3: Erosive classes of *FI* and *MFI* indices based on [102, 110, 111]

Erosive class	*FI*	Erosive class	*MFI*
Very low	0 – 20	Very low	0 - 60
Low	20 – 40	Low	60 - 90
Moderate	40 – 60	Moderate	90 - 120
Severe	60 – 80	High	120 - 160
Very severe	80 – 100	Very high	> 160
Extremely severe	> 100		

According to the presented equations, the lowest theoretical value on the annual, seasonal and supra-seasonal scale of *PCI* is 8.3, indicating the perfect uniformity in precipitation distribution (*i.e.*, that same amount of precipitation occurs in each month). Also, on all scales, a *PCI* value of 16.7 will indicate that the total precipitation was concentrated in half of the period and a *PCI* value of 25 will indicate that the total precipitation occurred in one third of the period (*i.e.* total annual precipitation occurred in 4 months; total supra-seasonal precipitation occurred in 2 months and total seasonal precipitation occurred in 1 month). According to this classification, Oliver [102] suggested that *PCI* values of less than 10 represent a uniform precipitation distribution (*i.e.* low precipitation concentration); values from 11 to 15 denote a moderate precipitation concentration; values from 16 to 20 denote irregular distribution and values above 20 represent a strong irregularity (*i.e.* high precipitation concentration) of precipitation distribution (Table 2) [103–105].

FI and *MFI* are perceived as useful in studies that are focused on assessment of rainfall aggressiveness and are subjected to the correlation to other climatic variables that are contributing factors in the triggering/or reactivation of erosion phenomena (*e.g.* [58, 103, 105, 106]). *FI* is calculated as follows:

$$FI = \frac{p^2 max}{P} \tag{4}$$

where p_{max} is the maximum precipitation amount of the wettest month of the year and P is the mean annual rainfall amount.

This index has some disadvantages as an indicator of soil erosion within the *USLE* model, as low values of monthly rainfall amounts can have substantial erosive power, an increase in total rainfall amount should result in an increase of erosivity. It is also illogic that if the maximum monthly rainfall p_{max} remains the same while the mean annual rainfall increases the *FI* decreases. For these reasons, Arnoldus [77] modified *FI* into *MFI*, taking into account the atmospheric precipitation of all months during the year. The relationship between these two indices is described in numerous studies and is often used to achieve more complete display of the evolution of precipitation ero-

Table 4: Definitions of 9 precipitation indices used in this study.

Index ID	Indicator name	Definition	Units	Index ID	Indicator name	Definition	Units
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm	*CWD*	Consecutive wet days	Maximum number of consecutive days with RR>=1 mm	days
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm	*R95p*	Very wet days	Annual total PRCP when RR>95th percentile	days
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0 mm) in the year	mm/ day	*R99p*	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
R10mm	Number of heavy precipitation days	Annual count of days when PRCP>=10 mm	days	*PRCPTOT*	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1 mm)	mm
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1 mm	days				

sion in a given area (*e.g.* [60, 80, 107–109]). *MFI* is presented as a product of squared monthly precipitation amount (p) and total annual rainfall (P) [84] and can be calculated according to Eq. (5):

$$MFI = \sum_{i=1}^{12} \frac{p^2}{P} \tag{5}$$

The erosive classes of the two indices (*FI*, *MFI*) are presented in Table 3.

The extreme values of precipitation were calculated following the indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) (http://cccma.seos.uvic.ca/ETCCDI) (Table 4). The *RclimDex* software package was used for this occasion. Nine precipitation indices were used for further analysis, and they are presented in Table 4.

For the spatial presentation of selected hazard indices in this paper, the Geographic Information Systems (GIS), ArcMap 10.6 software was applied. The most suitable interpolation method for the precipitation data visualization was the Ordinary Cokriging (COK) [112], which was employed through the ArcMap (extension Geostatistical Analyst).

The obtained time series of precipitation and pluvial indices were tested for trends using the nonparametric Mann-Kendall test (MK). According to Gilbert [113] the MK test relates the relative magnitudes of data rather than the data values themselves. In the MK test two hypotheses are examined: the null hypothesis (H_0) that states there is no trend in the time series and the alternative hypothesis (H_a) which states there is a significant trend in the series, for a certain significance level. Statistical significance (as seen as the probability p) takes values between 0 and 100 in percentage. In fact, p is used to test the level of confidence in H_0. If the computed p value is lower than the chosen significance level, α (*e.g.* $\alpha = 1\%$, $\alpha = 5\%$, $\alpha = 10\%$), the H_0 should be rejected, and H_a should be accepted. On the other hand, if computed p value is greater than the significance level α, the H_0 cannot be rejected [113]. In order to prevent the effects of the serial correlation in time series, the Yue-Pilon method was used [114]. For this purpose, *R* package *ZYP* (http://www.r-project.org) was utilized.

3 Results and discussion

One of the main triggering factors of erosion in the Pannonian basin is precipitation amount (*e.g.* [115]). In order to gain more complete insight into erosivity in this part of Europe the trends in annual amount of precipitation are discussed.

The Table 5 shows the calculated trends in annual precipitation amounts at the investigated stations. It could be seen that the larger parts of the area display an increase in total annual rainfall with the exception of three stations, Debrecen, Budapest and Szombathely, where the decrease was observed. Only Budapest meteorological station exhibits a statistically significant declining trend at the given confidence level ($p<0.05$).

Figure 2a shows the spatial distribution pattern of the precipitation values for the investigated period. In the Pan-

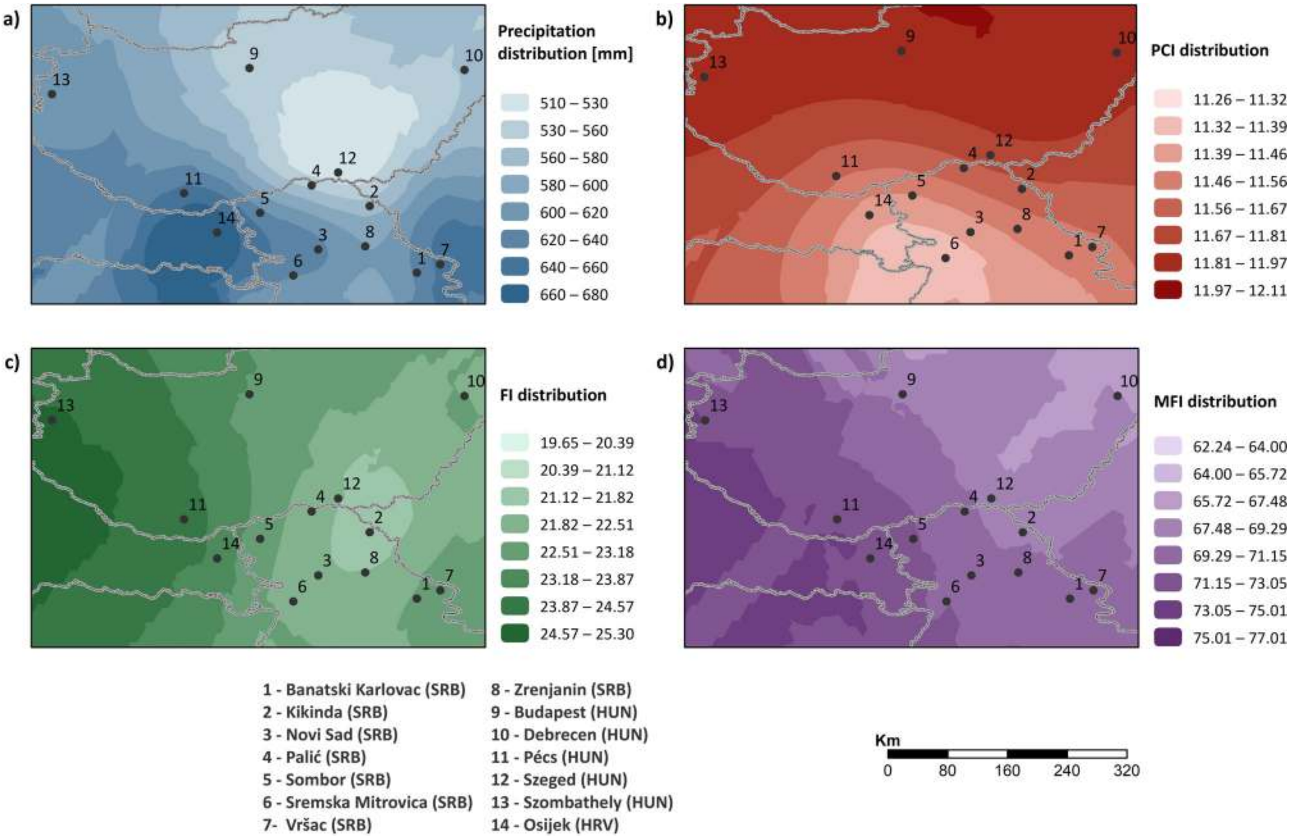


Figure 2: Spatial patterns of pluvial parameters used in this study for the observed period.

Table 5: Trends in annual precipitation amount at the investigated stations.

No.	Station name	Country	Trend (mm/y)	*p*-value
1.	Sombor	Serbia	0.75	0.5
2.	Palić	Serbia	1.38	0.35
3.	Rimski Šančevi	Serbia	1.87	0.16
4.	Kikinda	Serbia	0.57	0.62
5.	Zrenjanin	Serbia	0.9	0.82
6.	Banatski Karlovac	Serbia	0.66	0.8
7.	Vršac	Serbia	0.58	0.18
8.	Sremska Mitrovica	Serbia	0.41	0.9
9.	Pécs	Hungary	1.159	0.6
10.	Szeged	Hungary	0.98	0.5
11.	Debrecen	Hungary	−0.065	0.6
12.	Budapest	Hungary	−2.056	0.03
13.	Szombathely	Hungary	−0.5	0.74
14.	Osijek	Croatia	0.637	0.77

nonian basin the rainy season lasts from May to July and there are more rainfall over the mountains (up to 1,650 mm in the Ukrainian Carpathians and in the Tatra Mountains) than in the plain terrain. According to Spinioni *et al.* [99] the lowest annual precipitation totals are observed for eastern Hungary (550 mm), the lowest summer totals in Northern Serbia (80 mm), while the lowest winter totals in northern Romania (70 mm). Statistically significant trends in Pannonian basin for precipitation totals during the period 1961 – 2010 were not found, but the small increase was detected during the last few decades compared to the 1980's, which was characterized as the driest decade [99]. Furthermore, regional intensity and frequency of extreme precipitation in the Pannonian basin has increased between 1976 and 2001, while the total precipitation has decreased in the region. Bartholy and Pongrácz [52] emphasized that the increase of extreme rainfall events, coupled with a lower frequency, lead to constant precipitation totals during the investigated period.

For the future, the results of the climate models indicate that drier summers are very likely to occur, mainly in the southern parts of the Pannonian basin [116]. More frequent and more intense extreme precipitation events are projected for winter and autumn seasons, especially in the northern regions. Spatial distribution of precipitation is not going to change significantly in the future, but the annual distribution of precipitation will most likely be restructured [100].

3.1 Precipitation Concentration Index (*PCI*)

The results of *PCI* tendencies for all meteorological stations are shown in Figure 4, while the spatial distribution pattern of the index values can be seen on Figure 2b. In northern Serbia *PCI* values belong to the group of moderate precipitation distribution (values from 11 to 15). The highest index values were obtained for Banatski Karlovac (18.22 units) in 2014, when the highest rainfall amount was recorded in this area (976.98 mm). The north of the Vojvodina province shows more uniform distribution. At the investigated stations the presence of a statistically significant trend in the variability of *PCI* was not observed. Only Sombor, Zrenjanin and Vršac meteorological stations display a declining trend in *PCI* values, while other record a slight increase, but the trends were not statistically significant at given significance levels.

PCI during the half-year periods (wet and dry) indicate that values for the wet part of the year (from April to September) correspond to moderate precipitation distribution (Figure 4). Highest values are recorded for certain years, so the level of *PCI* of 43.88 units was recorded for the Kikinda station in 2014, which indicates a high precipitation concentration. For the station Rimski Šančevi irregular precipitation concentration (16.01) was observed in 2003, but also in 1992. Irregular distribution of precipitation (16.39) was recorded at Palić at the same year. The meteorological station Zrenjanin records the largest number of unusually high values of *PCI*: 16.56 (1961), 19.08 (1972) and 17.65 (1992) indicating irregular precipitation concentration without the presence of statistical significance. The values for the dry semi-annual period (from October to March) belong to the group of uniform precipitation distribution, with increasing trend in 75% of the observed stations. The statistically significant increasing trend at the confidence level of 90% and higher was observed for Banatski Karlovac, Kikinda, Rimski Šančevi and Vršac stations (Figure 4).

The seasonal values of *PCI* for the Vojvodina area show generally uniform values. The winter season exhibits higher values than other seasons for all analyzed stations during the investigated period. Statistically significant increasing trend was not detected. The spring season (March-May) exhibits values that range from 3.4 for Sremska Mitrovica station to 3.55 for Palić station. Trend analysis indicates that the stations have an increasing trend, but statistically significant trends were not found (Figure 3).

The *PCI* values during the summer season (June-August) are ranging from 3.3 for the Vršac station to 3.6 for Palić station. Based on the trend analysis it can be noted that all stations show an increase in *PCI* values. Only Vršac station recorded a statistically significant increasing trend ($p<0.1$) for summer season (Figure 3).

During the autumn season (September-November) the values range from 3.5 for Sombor station to 3.8 for Zrenjanin station. All the observed stations show decreasing trend, but only Kikinda has a statistical significance at 90% confidence interval (Figure 3).

Since all the observed seasonal *PCI* values weight below 10, it can be pointed out that there is a uniform precipitation distribution within the investigated area. The winter season indicates much higher *PCI* values than the other seasons, but variation within the seasons is low.

PCI for the stations in Hungary ranges from 11 to 15, similarly to Vojvodina region (northern Serbia). According to the index classification this area can be seen as having a moderate precipitation concentration. The highest index value was recorded at Debrecen station in 2011 (19.19), indicating the irregular concentration precipitation. Generally, meteorological stations in Hungary do not show the presence of a statistically significant trend, although the trend has a positive tendency that indicates an increase in the index value at annual level.

This suggests that in the future, moderate precipitation concentration could shift into the second class: an irregular precipitation concentration in this part of the Pannonian basin.

PCI during the half-year periods (wet and dry) indicate that values for the wet part of the year (from April to September) correspond to moderate precipitation distribution (Figure 4). The highest value for the entire investigated period was detected at Debrecen station (18.8) in 1974, which indicates an irregular precipitation concentration. For the Budapest station irregular precipitation concentration (16.9) was observed in 1965. Irregular distribution of precipitation (18.7) was recorded at Szeged and Szombathely (17.8) respectively. Statistically significant increasing or decreasing trends were not recorded for the stations in Hungary (Figure 4).

The values for the dry semi-annual period (from October to March) belong to the group of moderate precipitation distribution, with increasing trend in 60% of the observed stations. The statistically significant increasing trend at the confidence level of 99% was observed for Budapest meteorological station (Figure 4).

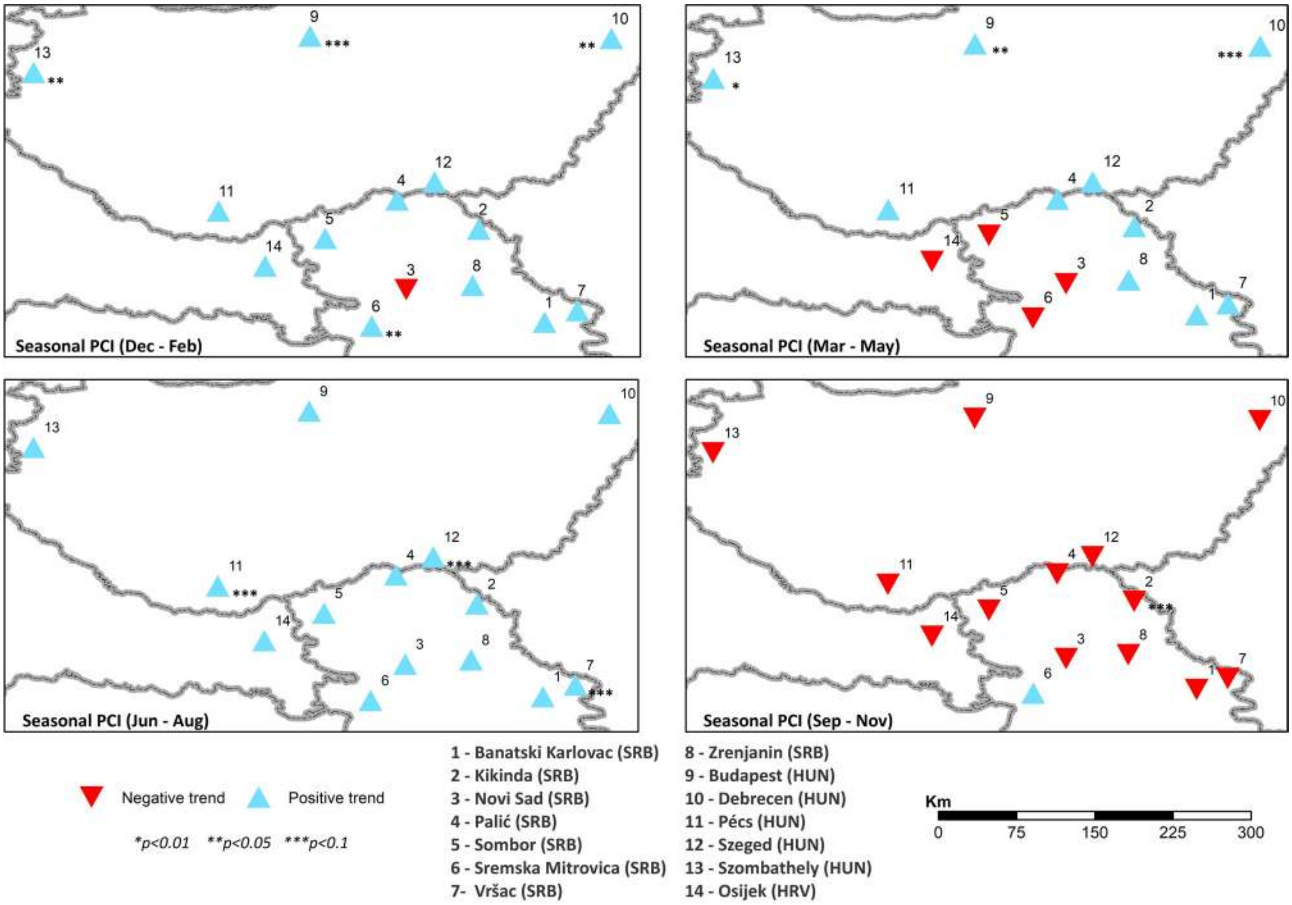


Figure 3: Seasonal *PCI* trends for the observed period in the investigated area.

Seasonal variations of *PCI* for Hungary have similar tendency as the ones in northern Serbia, but with pronounced presence of statistically significant trends. For the winter season the increasing trend is present at all investigated stations but Budapest, Debrecen and Szombathely have statistically significant trend (Figure 3). Similar situation is observed for spring season with the same tendencies for the observed stations (Figure 3). Summer season is also characterized by an increase of *PCI* values, but here only station Pécs and Szeged display statistically positive trend at 90% significance level. Due to the decline in precipitation during autumn, declining trends were detected at all investigated stations, but without statistical significance (Figure 3).

The Pannonian part of eastern Croatia also does not show the presence of a statistically significant trend and lies within the moderate precipitation concentrations recorded for the Osijek station (values from 11 to 15). The highest recorded value in Osijek is 16.08 for 1972 and falls within the irregular precipitation concentration class (Figure 4).

PCI during the wet half-year period indicate that values for this part of the year (from April to September) correspond to moderate precipitation distribution (Figure 4). The highest value at Osijek station was detected in 1992 and it was 16.6, which belongs to irregular precipitation concentration. The presence of statistically significant declining trend was not detected. The values for the dry semi-annual period (from October to March) belong to the group of moderate precipitation distribution, with increasing trend for Osijek station. The statistically significant increasing trend was not observed (Figure 4).

Seasonal variations of *PCI* at Osijek correspond to the situation observed for Vojvodina region with increasing tendencies for winter and summer and declining values for spring and autumn (Figure 3).

The *PCI* index was used to assess the changes in precipitation concentrations in different parts of the world. Spatial and temporal variations of this parameter were investigated in China [117–123], Italy [124, 125], Portugal [126], Spain [127, 128], Iran [129] and Turkey [130]. The opposite relationship between seasonal *PCI* and annual precipitation was found for Spain [103]. The respective authors

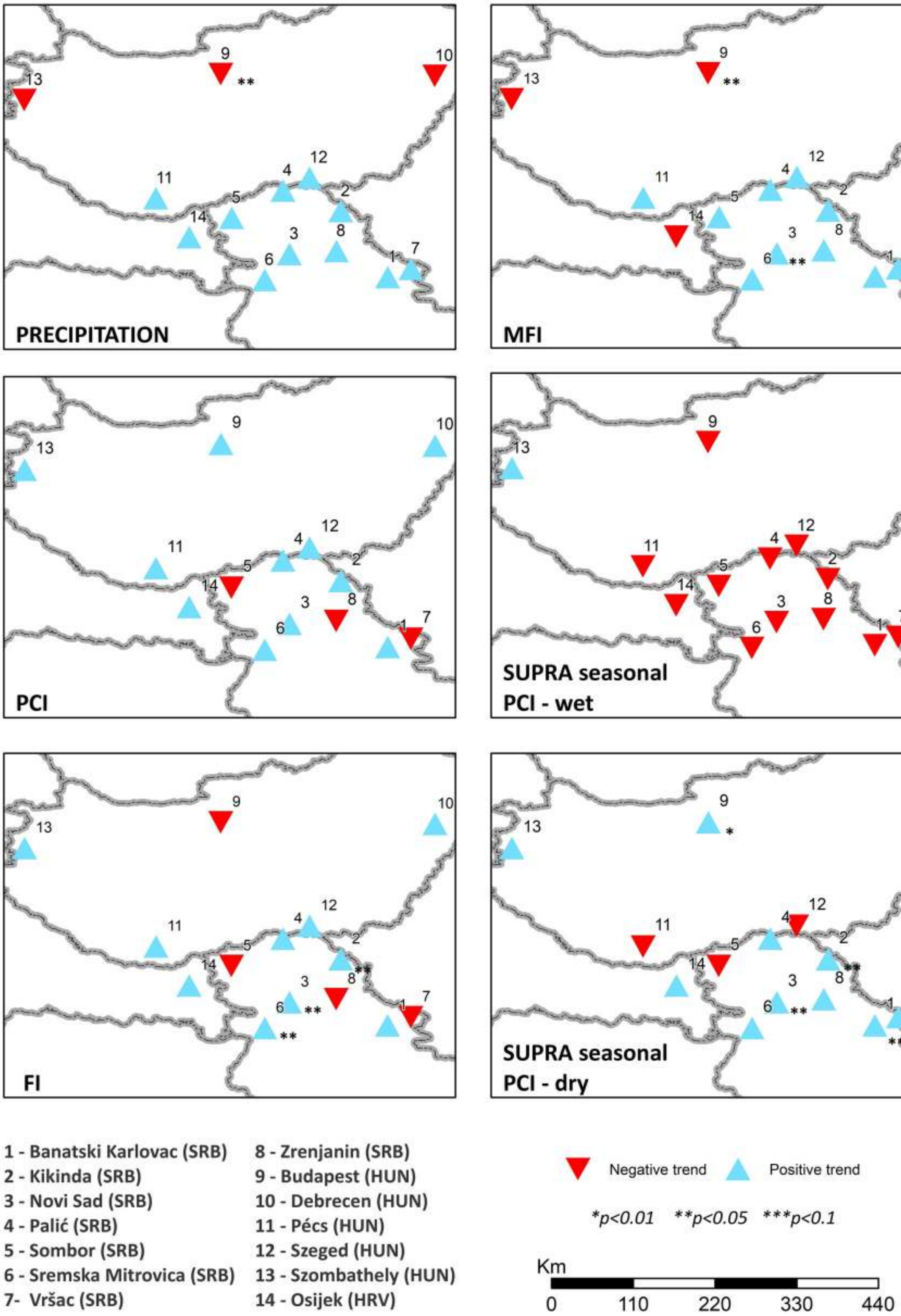


Figure 4: Tendencies of the pluvial erosion parameters and indices for the observed period in the investigated area.

showed that the *PCI* is superior for quantifying the heterogeneity of the monthly and daily precipitation in Spain. The similar pattern is observed for the Pannonian region. *PCI* distribution is not uniform over the whole territory, the seasonality is more pronounced especially during winter season.

When exploring the correlation between the precipitation and the North Atlantic Oscillation index (NAO) in Vojvodina, Tošić *et al.* [15] found that it is negative and significant. This implies that the positive phase of the NAO results in decreased intraseasonal fluctuations and deficient precipitation over Vojvodina. The significant correlation (at the 1% level of significance) is observed between the East Atlantic/West Russian index (EA/WR) and precipitation totals for winter and autumn precipitation.

Tošić [131] investigated spatial and temporal variability of winter and summer precipitation over Serbia and Montenegro. Respective author pointed out that the large-scale atmospheric circulation could be responsible for the winter and summer precipitation variability. The time series associated with the first precipitation pattern (PC1) emphasized a decreasing trend in winter precipitation (that was also reported for southern Europe by other researchers). Strong correlation between the winter PC1 and the NAO index indicated that the NAO could be responsible for the winter precipitation variability over the investigated area. The second winter and summer EOF patterns displayed an opposite sign of climate variability between areas with Mediterranean and continental climates, highlighting the influence of orography and the Adriatic Sea on the precipitation regime. Also, all of the performed analyses were coherent in demonstrating that winter precipitation in Vojvodina region is influenced by the NAO. An intensification of the positive phase of the NAO could be one of the causes of the observed decrease in winter precipitation in northern Serbia [15]. The differences in magnitude and sign of the trends detected in this study and the previously published studies could be due to the different time spans of the precipitation series as well as used methods.

Similary, the studies (*e.g.* [132]) showed that decreased precipitation totals in Hungary could be linked to the intensification of the NAO and the northeastward shift of the mean positions of the main pressure centers over the Atlantic. Similar results were obtained for Pannonian part of Croatia indicating that NAO in general, have a strong influence on winter precipitation in this region, with negative NAO phases corresponding to periods of high precipitation [133].

3.2 Fournier (*F*) and Modified Fournier Index (*MFI*)

Figure 2c shows the spatial distribution pattern of the *FI* values for the investigated period in the Pannonian basin. Based on the detailed results of the *FI*, it can be noticed that the area of northern Serbia generally belongs to the erosive class of low values (20-40). The weather station Vršac (102.88) and its surroundings recorded the highest value for 2014 (indicating the presence of extremely high erosivity), while the station Palić recorded the lowest value on the territory of Vojvodina during 1983 (8.60 – very low erosivity). Only Banatski Karlovac station (63.50 in 1999 and 62.78 in 2014) and Vršac (63.24 in 1987) recorded a moderate high erosion class for the mentioned years. The trend values for 5 out of 8 stations indicate a slight rise in the index value on an annual basis, while the presence of a negative trend was observed for the stations Sombor, Vršac and Zrenjanin. The stations Banatski Karlovac, Palić, Zrenjanin, Sombor and Vršac do not show the presence of a statistically significant trend of variability of *FI*, while the stations Kikinda, Sremska Mitrovica and Rimski Šančevi show statistical significance at the confidence levels of 95% and 90%. The examined area of Hungary also belongs to the erosive class of low values (20-40). The Szeged's meteorological station (63.19 in 1992) shows the highest value, while the station Pécs (6.93) has the lowest value recorded for 1983. Rising trend is noticed for all stations except Budapest meteorological station where a negative trend is observed but without statistical significance. The Osijek weather station in Croatia also belongs to the same erosive class with the highest index value of 81.79 in 1972, while the lowest was recorded in 1971 (10.75). The station generally has a positive trend but without statistical significance (Figure 4). The investigated trends generally point to a progressive increase in the values of the erosion index at the annual level, which in the future can lead to the transition to higher erosive classes and increase the sensitivity in the Pannonian basin. These results are generally accompanied by observations that Lukić *et al.* [60, 62] pointed out in their selected case studies and meteorological stations in the north and south of Vojvodina.

The results of *MFI* correspond to the results of the *FI*, and according to this index, the investigated area belongs to the erosive class of low values (Figure 2d). The weather station Vršac (149.16 in 2014) and its surroundings show the highest index value, while the Rimski Šančevi record the lowest value for 2000 (86.93). However, as this index is a modification of *FI*, it is more sensitive to the average monthly *PCI* values, and the results are significantly more reliable and indicate a higher diversity of erosive classes during the examined period. The results of the MK trend test indicate that the statistically significant positive trend is observed only for the Rimski Šančevi station (an increase of 0.3 units per year). On the annual basis the *MFI* values are increasing at all stations in Vojvodina (Figure 4).

For the investigated stations in Hungary it was noted that the maximum value occurs in the area of Debrecen (126.22 in 1970), and the minimum is recorded at Szeged station (34.51) during 1971. The declining trend (−0.183) at the level of significance of 0.03 (p<0.05), was detected at Budapest station. The decreasing trend was also observed at Szombathely station (−0.024) but without the presence of statistical significance. Osijek station records the highest value of 142.26 (1972) and the lowest of 35.81 (2000). The *MFI* values are decreasing, but the trend test showed no statistical significance (Figure 4). As with *FI*, the investigated *MFI* trends generally indicate a progressive increase in the values at the annual level (except for the northwestern parts of the Pannonian basin), which in the future could lead to a transition to higher erosion classes and an increase in hazardous sensitivity in the investigated area.

Mezo˝si and Bata [115] found a significant correlation between the Rainfall erosivity factor (*R*) and the *MFI* by using the precipitation data of the past nearly 30 years for Hungary. They managed to compute a 50-80% increase in rainfall intensity for this century, by using calculated trends and the data provided by the model results. Good correlation between rainfall intensity (*R*) and the calculated *MFI* values for Hungary indicated that the increase in *R* also corresponds with the increase in *MFI* values. On the other hand, the estimated increase in intensity significantly lags behind the maximum values of certain regions in Italy, Croatia, or Slovenia (as well as western Scotland and southern Spain) [134]. The extent of soil erosion was calculated using the climate data provided by the models. The results predict greater *R* values and greater erosivity values on multy-decadal scales even though summer precipitation is decreasing. Apart from the *R*, the extent of soil erosion is also regulated by terrain, soil, and land cover related data [115].

Panagos *et al.* [134] observed similar condition for the Pannonian zone. Results of this study are in good accordance with the results of respective authors.

3.3 Extreme Precipitation Indices

The spatial distribution of the extreme precipitation indices (Figure 5) is analyzed on annual basis for the study period (1961-2014). The results of MK test indicate that values of *RXIday* index are increasing at all investigated stations except for Debrecen and Szombathely. The statistically significant trend was observed at only four stations in Vojvodina region (Figure 5). Monthly maximum consecutive 5-day precipitation index tends to decrease in some areas in the east, south and west of Hungary. Similarly the statistical significance of the rising trend was observed for only four stations in Vojvodina. Daily precipitation intensity index (*SDII*) for the investigated part of Pannonian basin is increasing except for Szombathely and Budapest stations. Statistical significant increase was observed in the southern part of the area (Vojvodina and south of Hungary) (Figure 5).

The number of heavy precipitation days (*R10mm*) is increasing, with varying degree of statistical significance at only three stations in Vojvodina (Banatski Karlovac, Kikinda and Palić) (Figure 5). The number of consecutive dry days (*CDD*) is declining in the southern part of the investigated area with only one station recording statistical significance (Rimski Šančevi in northern Serbia). The number of consecutive wet days (*CWD*) is declining in Hungary, and in Osijek this value is rising. The only station with the significant positive trend is Pécs.

Annual total precipitation when it exceeds 95th percentile (*R95p*) is increasing in the investigated area, with the exception of Budapest meteorological station (Figure 5). The increasing trend is significant at different confidence intervals (Figure 5). There are few stations that have negative trends such as Szombathely and Debrecen.

For *R95p* and *R99p* positive station trend for Europe dominates the period between 1946 and 1999 [47]. The mentioned authors also found that positive trend is mostly correlated with stations where the annual amount of precipitation increases. On the other hand, a negative trend does occur mostly at stations in areas with decreased precipitation. Similarly, for the Carpathian basin Bartholy and Pongrácz [52] found that the regional intensity and frequency of extreme precipitation has increased during the period between 1976 and 2001, while the total precipitation has decreased in the region.

Also, several IPCC emission scenarios have been compared and GCM outputs have been used to calculate precipitation extremes in Carpathian basin. The results suggested that climate of this region may become drier in summer and wetter in winter [16, 99, 100]. During the twentieth century, on the wettest day across Serbia the average annual precipitation increased by nearly 9%. Statistically insignificant increasing trends were found on each of the ten wettest days across Serbia. At the end of the 20th century in Serbia heavy precipitation indices also increased.

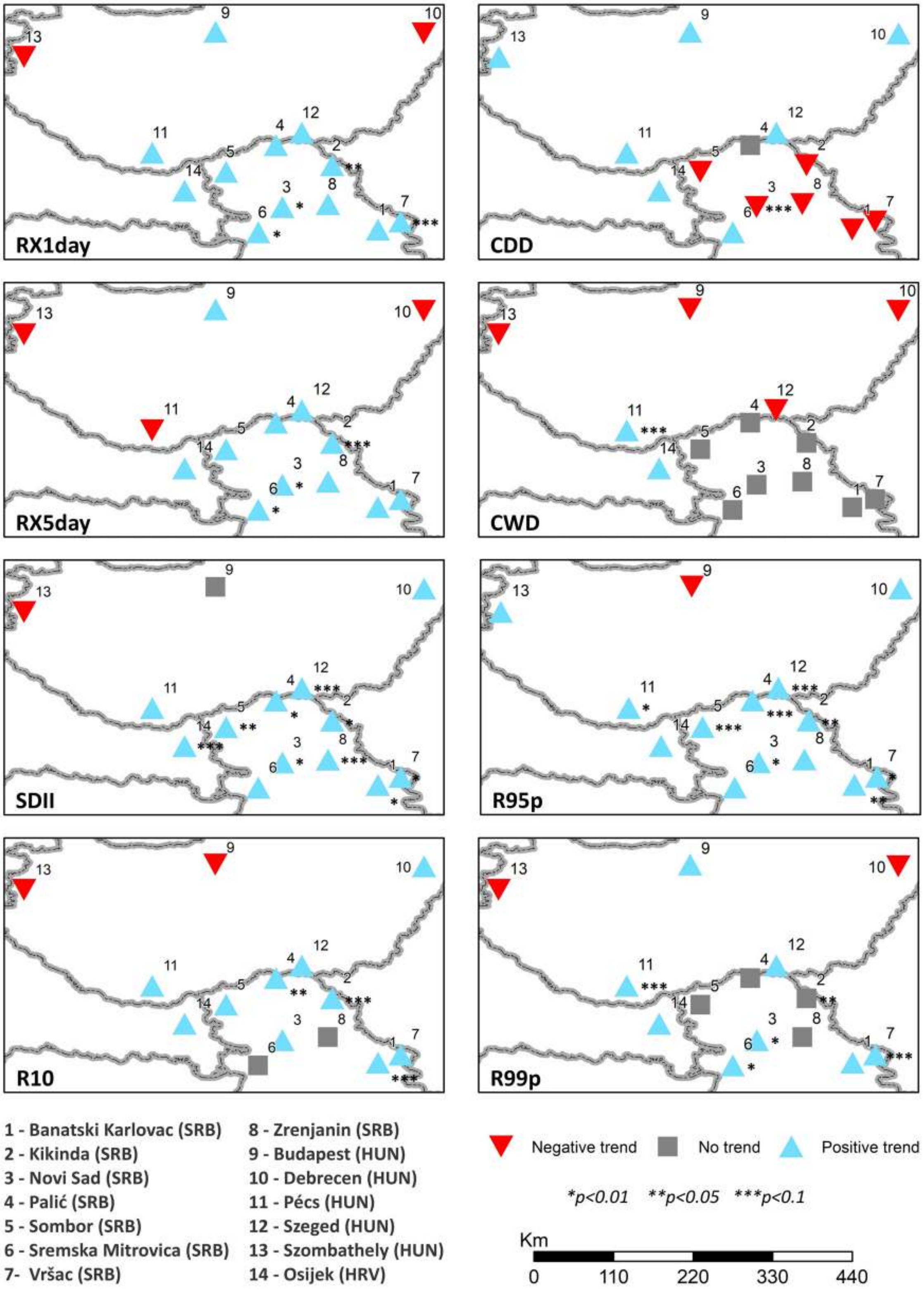


Figure 5: Tendencies for the extreme precipitation indices for the observed period in the investigated area.

Similar results were obtained by Malinović-Milićević *et al.* [135]. Amount and intensity of precipitation in Serbia had statistically significant increase but only during autumn and were most pronounced in the northern (Vojvodina) and western parts of the country. Generally, no significant decrease in the maximum number of consecutive dry days or increase in the wet days (except in autumn) was found. The authors showed that that "dry" regimes dominate over "wet", with 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 EA and NAO had significant influence on duration of winter warm periods, while their influence on duration of cold periods cannot be confirmed with certainty.

4 Conclusion

The potential of rain to generate soil erosion is known as rainfall erosivity, and its estimation is of great importance for the understanding of climatic vulnerability of a given region. Also, the occurrence of extreme events such as very heavy precipitation episodes, have a great impact on society due to the greater climate variability effects.

Observation of rainfall erosivity in the Pannonian basin was carried out on the basis of the analysis of rainfall aggressiveness trends, extreme precipitation indices, and their spatial variability for the period 1961-2014. This study presents the first results of combined rainfall erosivity and extreme precipitation indices for the investigated area. Furthermore, the analysis, applied to the present climate conditions, reveal necessary information which can be used by decision makers on various levels, for the development of prevention activities and for the promotion of mitigation measures at all levels: local, national and regional.

Trends in annual precipitation amounts indicate that the larger parts of the investigated area display an increase in total annual rainfall with the exception of Debrecen, Budapest and Szombathely, where the decrease was observed.

In northern Serbia *PCI* values belong to the group of moderate precipitation distribution, and the presence of a statistically significant trend in the variability of *PCI* was not observed. For the stations in Hungary, *PCI* suggests that this area can be seen as having a moderate precipitation concentration. Meteorological stations in Hungary do not show the presence of a statistically significant trend, although the trend has a positive tendency that indicates an increase in the index value at annual level. The Pannonian part of eastern Croatia also does not show the presence of a statistically significant trend and lies within the moderate precipitation concentrations class.

The seasonal values of *PCI* for the Vojvodina area (northern Serbia) generally show uniform values, where the winter season exhibits higher values than other seasons for all investigated stations during the investigated period. Statistically significant increasing trend was not detected. *PCI* on seasonal scale for Hungary have similar tendency as the ones in northern Serbia, but with pronounced presence of statistically significant trends. On the other hand, seasonal variations of *PCI* for Pannonian part of Croatia correspond to the situation observed for Vojvodina region with increasing tendencies for winter and summer seasons and declining values for spring and autumn seasons, but without statistical significance.

The area of northern Serbia, Hungary and eastern Croatia generally belongs to the erosive class of low values (20-40). The investigated trends generally point to a progressive increase in the values of the erosion index at the annual level, which in the future can lead to the transition to higher erosive classes and increase the sensitivity to pluvial erosion in the Pannonian basin. The results of *MFI* correspond to the results of the *FI*, and according to this index, the investigated area belongs to the erosive class of low values. The observed *MFI* trends generally follows the *FI* indicating a progressive increase in the values at the annual level (except for the northwestern parts of the Pannonian basin), which in the future could lead to a transition to higher erosion classes and an increase in hazardous sensitivity in the Pannonian basin.

The precipitation extremes suggest that both the amount and the intensity of precipitation are increasing and varying in some areas of the Pannonian basin, which is in a good agreement with the studies conducted for Serbia, Hungary and Croatia, as well as the ones done for the European continent.

The results of this study can contribute to the erosivity studies since the focus is given to the dynamics of the main climatological agent of erosion – precipitation. Hence, utilization of the more complex and sensitive indices such as EI_{30} along with physically based models for estimating soil erosion rates (*e.g. USLE*, *RUSLE, RUSLE2*), can provide a more suitable approach for detailed rainfall erosivity estimation in some future studies when it comes to filling the gap on the rainfall erosivity map of Europe provided by Panagos *et al.* [134]. Since erosion is highly dependent on topography and land use, the next stage of the investigation of these parameters should be oriented towards incorporation into the GIS environment in order to determine erosion potential and its spatial causality.

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