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Annual and Seasonal Characteristics of Rainfall Erosivity in the Eastern Rhodopes (Bulgaria)

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Abstract: Rainfall, with its intensity, duration, and seasonal distribution, is among the main factors causing soil erosion, which is a widespread environmental problem in Bulgaria. Rainfall erosivity shows the potential of precipitation to generate erosion processes and is an essential indicator of the climate vulnerability of a region. This paper aims to evaluate rainfall erosivity in a part of the Eastern Rhodopes Mountains, an area that is characterised by high-intensity erosion processes and high erosion risk. Local peculiarities of rainfall erosivity were revealed by the calculation of some precipitation indices based on the monthly precipitation for the period 2000–2021, such as the precipitation concentration index (*PCI*), Angot precipitation index, Fournier index (*FI*), and modified Fournier index (*MFI*). The analysis of the extremely wet and extremely dry months at the annual and seasonal (October–March and April–September) levels was performed to evaluate the susceptibility to erosion. The results from the study show that rainfall erosivity in the studied area varies from low to moderate in the northern part of the study area and from high to very high in the south. According to the *MFI*, high and very high erosivities have been observed mainly since 2012. The erosivity increases from north to south, to the area with a complex relief, where the combination of orography and atmospheric circulation make favourable conditions for the occurrence of extreme precipitation. The analyses of the calculated indices show that the precipitations in most of the studied area generally have from a low to a moderate erosivity, but this does not exclude the occurrence of cases with high and very high erosivities, which are characteristic of recent years and are related to the increase in annual precipitations and extreme precipitation months. The results of this study can contribute to the development and implementation of measures and preventive activities for the reduction and possible elimination of the negative impacts of extreme precipitation.

Keywords: extreme precipitation; rainfall erosivity; modified Fournier index; precipitation concentration index; Angot precipitation index

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Citation: Nikolova, V.; Nikolova, N.; Stefanova, M.; Matev, S. Annual and Seasonal Characteristics of Rainfall Erosivity in the Eastern Rhodopes (Bulgaria). *Atmosphere* **2024**, *15*, 338. https://doi.org/10.3390/atmos15030338

Academic Editors: Constanta-Emilia Boroneant, Bogdan Antonescu and Feifei Shen

Received: 18 January 2024
Revised: 2 March 2024
Accepted: 6 March 2024
Published: 9 March 2024

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1. Introduction

Despite the general trend towards a decrease in soil erosion in Europe [1], soil erosion by water is still one of the most widespread causes of soil degradation in many countries, including Bulgaria [2–6]. The mean soil loss in the European Union is about 2.46 t/ha annually, but 12.7% of European arable lands have a soil loss of more than 5 t/ha annually. The average soil loss rate in Bulgaria is 2.21% of the total soil loss in the EU [7]. In 2016, agricultural areas and natural pastures affected by moderate to severe soil erosion represented more than 80% of the affected areas in EU-27 countries [1]. The research work of Panagos et al. [8] shows that the mean rainfall erosivity for the European Union and Switzerland in 2050 is expected to increase by 18% in comparison to the one in 2010, and for Bulgaria, the change will be 20.6%. Future projections show that by 2070, at the global level, soil erosion will increase by 30–66% in comparison to 2020, and the main driver for

this is the increase in the rainfall erosivity because of climate change [9]. Agriculture is the sector that is the most negatively affected by soil erosion. On the other hand, land use and tillage practices can significantly contribute to exacerbating soil erosion.

The development of soil erosion is determined by the soil type, topography, climate, land use, and land management. The type of soil and the quantity of unconsolidated deposits influence the duration of the process and its evolution (e.g., the transition from areal to linear) erosion. Among the features of the relief with the greatest influence are the slopes, aspect, exposure, and the location of the flat surfaces. Regarding climatic factors, precipitation (intensity, seasonal distribution, and extreme precipitation) has the greatest importance for soil erosion by water [5,10]. The impact of raindrops breaks the bonds holding soil particles together, allowing the particles to be entrained in flowing water from surface runoff. For the occurrence of soil erosion by water, intense rainfall has the greatest influence, as well as the alternation of dry and rainy periods. On the other hand, research shows that rainfall events of low intensity, long duration, and fewer return periods can significantly contribute to the overall soil erosion [11].

The results from scientific works prove that an increase in the frequency of the occurrence of extreme climate and weather events (heat waves, drought, and heavy rainfalls) was due to the increase in the global air temperature [12,13]. Erosion can be considered as one of the important indicators of the effects of climate change, as it depends on changes in the distribution and regime of precipitation. Analysing rainfall erosivity in a given area provides information on the potential of rainfall to generate erosion processes and contributes to clarifying the vulnerability to climate change in each region [10,14].

The severity of the problems related to the impact of precipitation on soil erosion has caused the strengthening of scientific research in this area in many regions and countries in the world, including Serbia [10,15], the Republic of North Macedonia [16], Romania [17,18], Greece [19,20], Turkey [21], Spain [22], Portugal [23], the Netherlands [24], South America [14,25,26], and China [27,28]. In existing publications, authors analyse the potential of precipitation to generate erosion processes by calculating several indices, among which, the most used are the Fournier index (FI) and the modified Fournier index (MFI). Previous publications on soil erosion in Bulgaria clarify the problem the most often from the point of view of agroecological measures and indicate in which parts of the country erosion is the most active, which types of soil are the most endangered, where the greatest losses of humus horizons are located, and what measures are recommended for strengthening the grounds [3,29–31]. The emphasis of most of the previous publications on erosion in Bulgaria is mainly on the influences of land use/land cover (LULC) changes and anthropogenic activities on the development of erosion processes [6,31]. Despite the role of precipitation in soil erosion processes, the influences of precipitation characteristics on the development of soil erosion at regional and local scales have not yet been sufficiently studied in Bulgaria. This motivated the authors of the present paper to investigate the potential of rainfall to generate erosion processes, for which knowledge is of particular importance in the context of vulnerability and adaptation to climate change. The applied nature of the study is determined by the fact that it analyses local features in the precipitation regime and their erosivities.

The present study aims to enhance the knowledge about the impact of precipitation on soil erosion in the Eastern Rhodopes, Bulgaria—a territory with a high intensity of erosion processes and a high erosion risk according to data from the Ministry of the Environment and Water [32]. Because it is not always possible to have daily precipitation data, especially in the mountainous regions of Bulgaria, a specific goal for the authors of the present study was to demonstrate the use of monthly rainfall data in the analyses of the propagation of erosion processes. To achieve this aim, the following tasks were performed: (1) the precipitation concentrations at annual and seasonal levels were analysed, (2) the rainfall erosivity was evaluated, and (3) the occurrences of extreme precipitation months were determined, and their relationship with the rainfall erosivity was analysed.

2. Materials and Methods

2.1. Study Area

The area of interest is the Eastern Rhodopes Mountains, located in the southern part of Bulgaria (Figure 1). The relief is from low mountainous to hilly with a high horizontal dissection. The territory is included in the Continental–Mediterranean climate zone, where precipitation is mainly concentrated in the cold season and is characterised by high monthly precipitation totals and great intensity. The summer is hot (The mean monthly temperatures for July are between 23 and 25 °C.), with frequent and severe droughts continuing into early autumn [33,34]. In the northern part of the study area, the annual precipitation is about 700 mm, and it reaches 1200 mm in the southern part. Winter (December–February) precipitation totals represent about 28–32% of the annual precipitation, while summer (June–August) precipitation totals are 17–22% of the annual values. The maximum winter precipitation is determined mainly by Mediterranean cyclones passing near the country. Regional differences are exacerbated by the complex topography and the influence of the slope exposure on precipitating cloudiness along frontal systems. In the cold half-year, precipitation often falls from the warm fronts of cyclones. Thunderstorms develop, with heavy precipitation and sometimes hail, even in winter [35]. Some of the highest maximum daily precipitations in Bulgaria have been measured in this area. In Zlatograd, a rainfall of 234 mm/24 h was recorded in October 1970 and 261 mm/24 h in February 1963 [33].

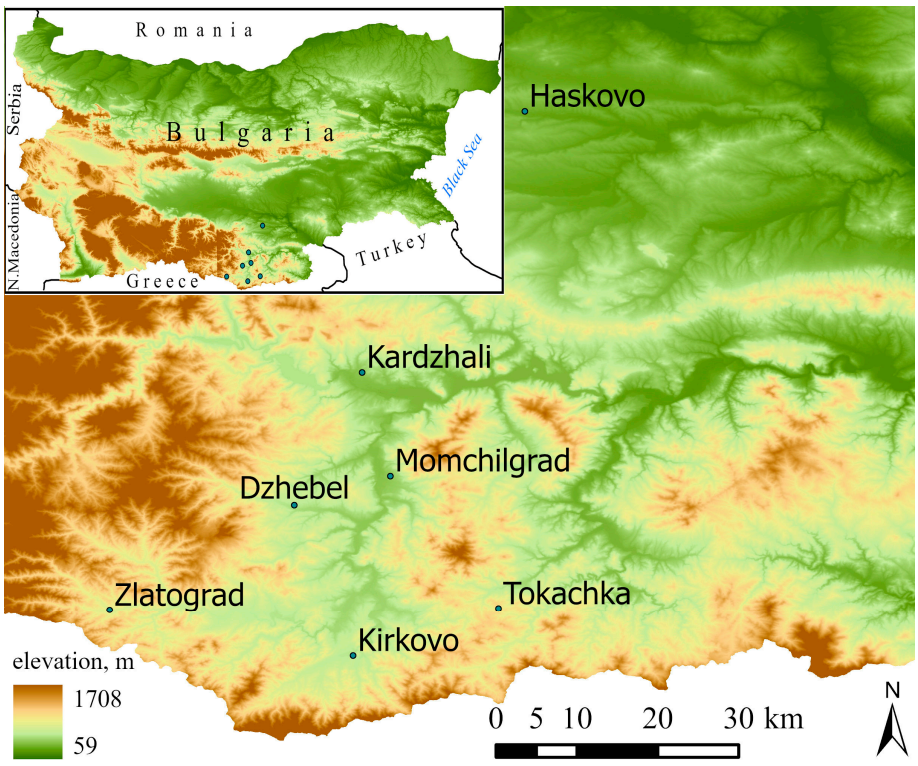


Figure 1. Study area with the locations of the meteorological stations.

During the summer season, precipitation is of low frequency and, in most cases, is associated with the cold fronts of Atlantic cyclones or the fronts of Azores anticyclones carrying cool oceanic air over the Balkans [35]. Under such conditions, owing to the orography, it is possible for more powerful thunderstorms to develop, with intense precipitation. Intense sunlight and high temperatures in summertime dry out Earth's surface, and the soil or rocks easily break down into small particles, which, in a summer storm or in the normal increase in the autumn precipitation, are carried away by the water, and even debris flows can be observed. A high and long-lasting snow cover has not formed in the region of the Eastern Rhodopes. Owing to the relatively high winter temperatures, only 5–8% of the

annual precipitation is in the form of snow [34]. Days with snow cover are no more than 15–25 on average per year. Often, the snow cover melts quickly under the influence of the southern warming winds, accompanied by intense rainfall. Rapid snowmelt and sparse vegetation are prerequisites for intensive areal erosion.

In the present study, data on monthly and annual precipitation from 7 meteorological stations for the period 2000–2021 were used. These stations are included in the national monitoring system of the National Institute of Meteorology and Hydrology (NIMH), Figure 1. The precipitation data were provided to us for scientific purposes by NIMH.

2.2. Data and Methods

Local analyses of erosion account for the rainfall variability in space and time and can be achieved using a dense network of measurements and spatial information, which are, in many cases, difficult to achieve. On the other hand, scientific research proves that analyses of rainfall erosivity through indices based on monthly and annual sums of precipitation (precipitation concentration index—*PCI*, Fournier index—*FI*, and modified Fournier index—*MFI*) give reliable results that reflect climatic features of specific areas and correspond very well to the erosivity R-factor for rainfall erosivity assessment by the USLE model [36–38].

In the present paper, the impact of rainfall on soil erosion by water was determined by the calculation and analyses of precipitation indices, which give information about the precipitation distribution and evaluate the rainfall's potential for triggering soil erosion. These indices are the *FI*, *MFI*, Angot index, and *PCI*. Soil erosion by water depends on not only the intensity and duration of the rainfall but also the occurrence and duration of extremely dry and extremely wet periods. Because of this, we analysed the multiannual changes in the occurrence of extremely dry and wet months in the investigated area.

Precipitation is a highly variable element of the climate that depends on many factors and varies significantly over the years, which greatly complicates its prediction [39]. Therefore, when studying soil erosion by water, the distributions of precipitation by month and season should be analysed. An indicator of the intra-annual and seasonal distributions of precipitation is the precipitation concentration index—*PCI* [40–42]. In the present study, the annual (*PCIann*) and seasonal (*PCIseasonal*) precipitation concentration indices were respectively calculated as follows:

$$PCI_{ann} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \times 100$$

and

$$PCI_{seasonal} = \frac{\sum_{i=1}^{6} p_i^2}{\left(\sum_{i=1}^{6} p_i\right)^2} \times 50,$$

where p_i is the monthly precipitation.

The seasonal PCIs were calculated for the cold half of the year (October–March) and for the warm half (April–September), which correspond to the wet and dry periods, respectively, in the investigated area. Depending on the PCI values, the categories for the distribution of the precipitation are determined [24], as shown in Table 1. Greater unevenness of precipitation is a prerequisite for stronger erosivity.

Table 1. Precipitation distribution based on *PCIs* according to Lukic et al. [24].

Precipitation Distribution	*PCI*
Uniform	$\leq$10
Moderate	>10 $\leq$ 15
Irregular	>15 $\leq$ 20
Strongly irregular	>20

To analyse the precipitation's impact on triggering soil erosion, the Angot precipitation index was calculated, and the susceptibility classes of the precipitation for each month in the years of the investigated period were determined according to [18,43]. The advantages for using the Angot index are that it is based on monthly and annual rainfall values, and the resulting values are easily grouped into established rainfall erosivity classes. For the calculation of the Angot index (K), the following formula was used [17]:

$$K = \frac{p}{P},$$

where $p = \frac{q}{n}$, q is the monthly precipitation, n is the number of days per month, and $P = \frac{Q}{365}$, where Q is the total annual precipitation.

According to the Angot index, precipitation is classified into five classes, depending on the possibility for triggering soil erosion (Table 2).

Table 2. Susceptibility classes for precipitation triggering soil erosion according to Angot precipitation index (K) (after [18]).

Pluviometric attribute	Very dry	Dry	Normal	Rainy	Very rainy
Pluvial erodibility class	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

The average rainfall erosivity was analysed based on the *FI* and *MFI*, which were calculated using the following formulas:

$$FI = \frac{p_{max}^2}{P},$$

where p_{max}^2 is the monthly precipitation of the rainiest month (mm), and P is the annual sum of the precipitation.

The *FI* shows the impact of the extreme precipitation on the soil's erosion. With higher values of the *FI*, precipitation is concentrated in a relatively short period of the year. This means that during the rest of the year, the rainfall is of a limited amount, which indirectly affects the strengthening of erosion processes through unfavourable conditions for the development of vegetation. The Fournier index emphasises the uneven distribution of the precipitation, but by considering only the wettest month, the precipitation, which is important for erosion, that occurs in other months of the year may be missed. Given this, the modified Fournier index [44] was used to assess the erosivity of the rainfall in the present study and is calculated using the following formula:

$$MFI = \sum_{1}^{12} \frac{p_i^2}{P},$$

where p_i is the monthly precipitation, and P is the annual precipitation.

The utilisation of the *MFI* has been recommended by several authors as a reliable index for the assessment of the potential of the precipitation to generate erosion. The authors in [38,45] found a significant correlation between the *MFI* and the rainfall erosivity factor (R) in the universal soil loss equation (USLE).

The *FI* and *MFI* were calculated for each year, and their averages were calculated for the period 2001–2021. Six classes of rainfall erosivity can be determined based on the values of the *FI*, and five classes can be determined according to the *MFI* (Table 3).

Table 3. The rainfall erosivity classes (based on Fournier index—*FI* and modified Fournier index—*MFI*) according to Lukic et al. [10].

Erosivity Class	*FI; MFI*
Very low	$0 < FI \leq 20$; $0 < MFI \leq 60$
Low	$20 < FI \leq 40$; $60 < MFI \leq 90$
Moderate	$40 < FI \leq 60$; $90 < MFI \leq 120$
Severe	$60 < FI \leq 80$; $120 < MFI \leq 160$
Very severe	$80 < FI \leq 100$; $160 < MFI$
Extremely severe	$100 < FI$

The trend in the rainfall erosivity during the period 2001–2021 was analysed based on the linear regressions of the *FI* and *MFI*, and the significance of the regression coefficients was determined by *t*-tests and a level of 0.05.

The occurrences of extremely dry and extremely wet months are determined according to the 10th and 90th percentiles of the distribution of the precipitation data for each month. The months with a total precipitation of equal to or less than that in the 10th percentile are considered as extremely dry months, while the extremely wet months are the months with monthly values of equal to or above that in the 90th percentile. Extreme precipitation months were analysed at annual and seasonal levels for the cold (October–March) and warm (April–September) half-years.

The impacts of extremely dry and extremely wet months on the rainfall erosivity were studied based on the correlations between the *MFI* and the numbers of extremely dry and wet months, respectively—the Pearson correlation coefficients were calculated, and the *T*-statistics were used to determine the statistical significance of the correlations at a level of 0.05.

3. Results and Discussion

3.1. Annual Cycle of Precipitation and Precipitation Concentration Index (PCI)

For the period 2000–2021, the average annual precipitation at the investigated stations was between 706 mm (at the station in Kardzhali) and 1213 mm (at the station in Kirkovo), as shown in Table 4. The annual precipitation totals increase from north to south. The increase in the altitude of the studied territory from north to south is not the main reason for the increase in precipitation amounts. The increase in the precipitation is mainly related to the exposure of the slope and the location relative to the mountain ridges on the one hand and the trajectories of Mediterranean cyclones on the other [35].

Table 4. Multiannual precipitation (mm) for the period 2000–2021 (The stations are arranged from north (left) to south (right).).

	Haskovo	Kardzhali	Dzhebel	Momchilgrad	Zlatograd	Kirkovo	Tokachka
P (mm)	710	706	881	876	1113	1213	1165

The average monthly maximum is observed in the cold part of the year (December or January) and has values of 76 and 86 mm in the north part of the study area (at stations in Haskovo and Kardzhali, respectively), 159 mm in January at the station in Tokachka, and 198 mm in December at the station in Kirkovo (in the south part of the region). The average monthly minimum varies between 23 and 36 mm and was observed in August (Figure 2). The uneven monthly distribution of the rainfall has a negative impact and is a prerequisite for erosion.

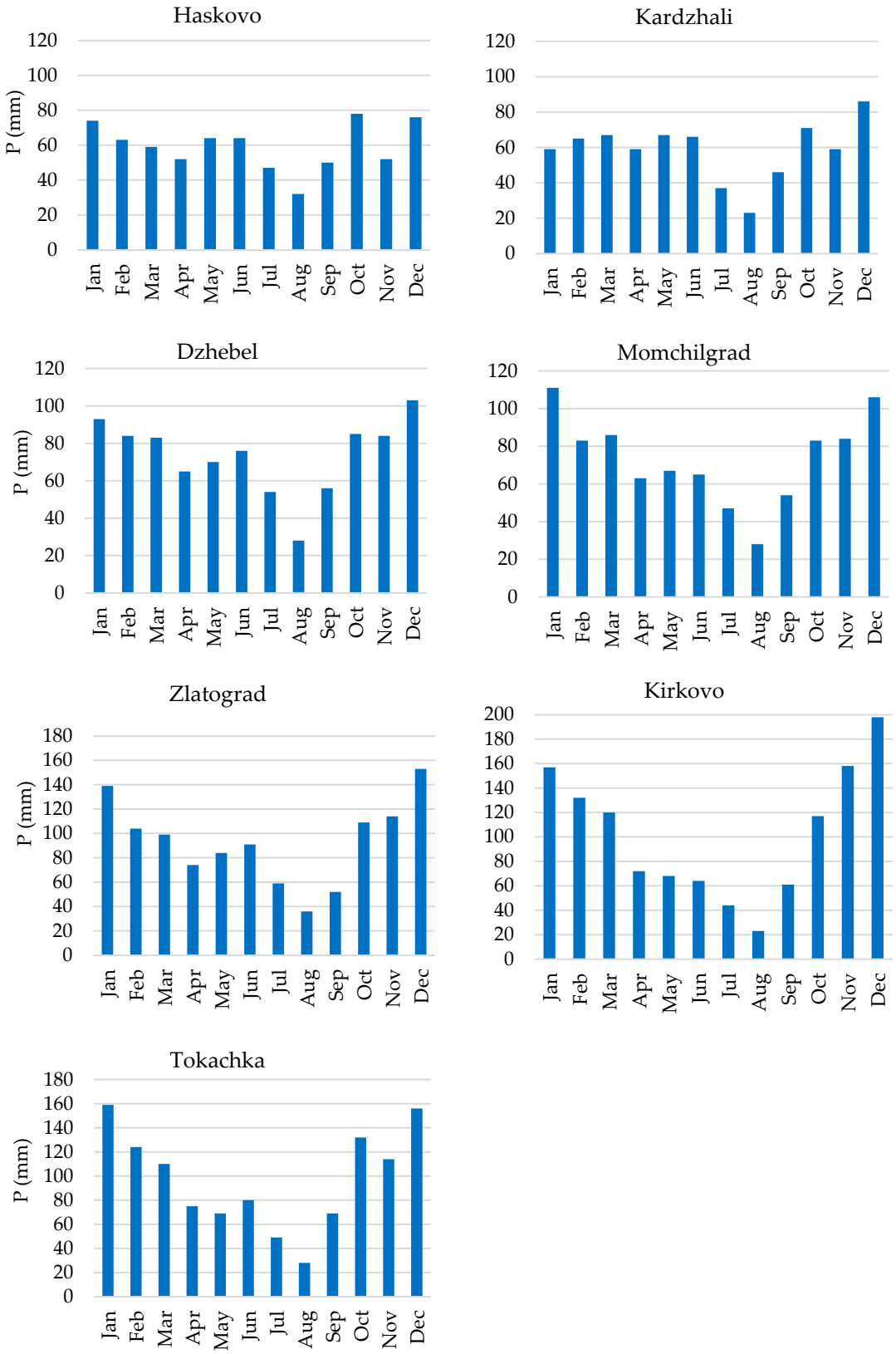


Figure 2. Annual cycle of precipitation for the period 2000–2021.

The disintegration of soil particles is facilitated during a dry period, and the manifestation of intense precipitation after a relatively long dry period is a prerequisite for more intense erosion.

The *PCI* was calculated at the annual and seasonal levels (for the cold and warm halves of the year). At most of the studied stations, monthly precipitation amounts were moderately distributed during the year—for between 80 and 95% of the years, at separate stations, *PCIann* showed moderate precipitation concentrations. Different results were obtained for stations in Kirkovo and Tokachka (in the southernmost part of the investigated territory), where *PCIann* shows irregular distributions, respectively, in 59 and 36% of the years in the period 2000–2021. The years 2016, 2012, and 2020 make an impression, with the highest values of *PCIann*, which indicate strongly irregular precipitation concentrations at two stations and irregular concentrations at the other stations. The high PCI values in these years are due to a wet spring followed by a very dry summer. In May 2012, the monthly precipitation was over 200 mm at all the studied stations, with the highest monthly precipitation observed at the Kirkovo station—269 mm. The years 2006 and 2009 stand out, with the lowest values of *PCIann* (between 9 and 12).

The analysis of the distribution of the precipitation in the cold (October–March) and warm (April–September) half-years shows greater variations in *PCIseasonal* after 2010, as well as in years with irregular precipitation concentrations ($15 > PCI \leq 20$) and even strongly irregular concentrations ($PCI > 20$) during the warm half-year, which leads to a greater probability of erosion in summertime (Figure 3).

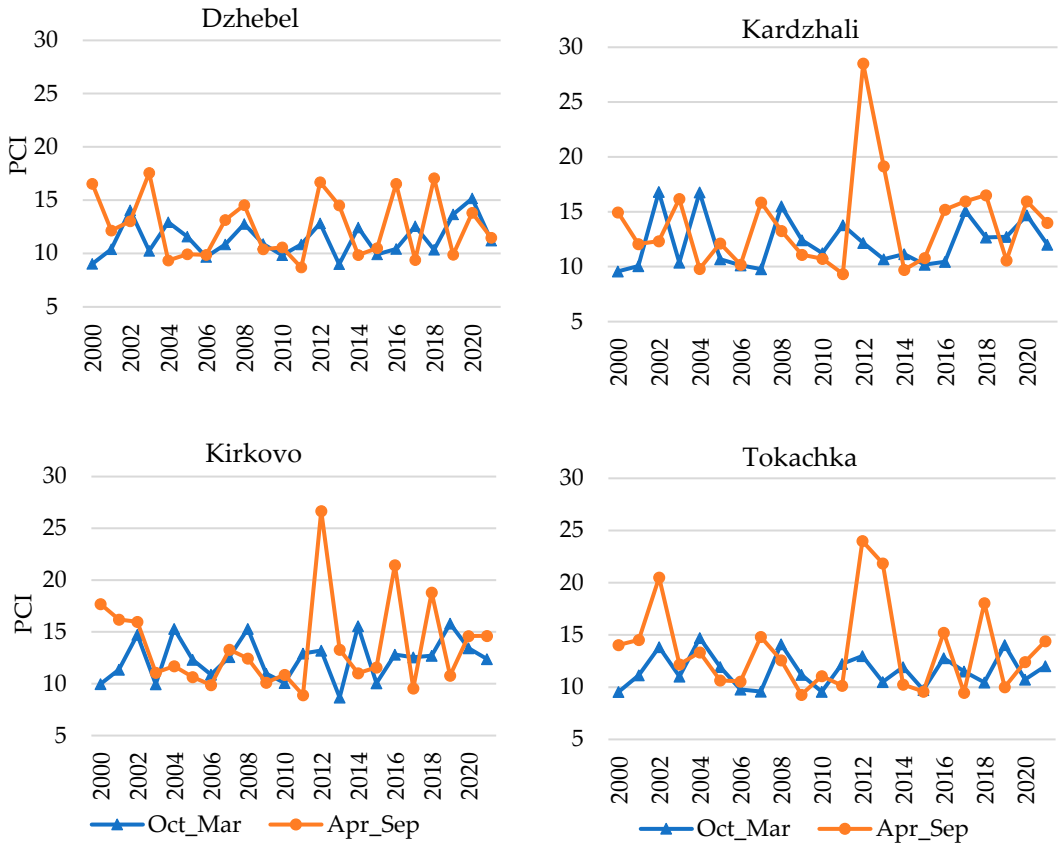


Figure 3. Time sequences of *PCI* for the cold (October–March) and warm (April–September) half-years.

Summer is usually a dry period in the studied territory, which does not favour the occurrence of erosion processes by water, but, on the other hand, such processes can be activated in the event of single, intense rainfall, which is not an exception in this area. By infiltrating soil, water compresses the air in and destabilises dry soil aggregates, and the particles are easily carried away by the surface runoff [46].

The strongly irregular precipitation concentration for April–September 2012 ($PCI > 20$), Figure 3, is due to the high monthly precipitation for May, with values between 177 mm (at the station in Dzhebel) and 269 mm (at the station in Kirkovo). In May 2012, the monthly

precipitation was over 50% and, at some stations, 70% of the precipitation amount for the period April–September 2012. The high monthly precipitation totals in May 2012 were related to intense precipitation on 18 May 2012, when a 24-h rainfall of 101.8 mm from rain and hail was recorded at the station in Kirkovo [47]. The cause of the high rainfall on 18 May 2012 was a Mediterranean cyclone centred over the Aegean Sea, which moved north and northeast over Bulgaria. A second-degree hazard (code "orange") due to intense rainfall was declared in this area.

3.2. Angot Precipitation Index

Most of the studied territory is characterised by winter maxima of precipitation, caused by the influence of Mediterranean cyclones. According to the Angot precipitation index, most of the months in the analysed period have from very low to low erosivities of precipitation, and in summer, this is characteristic of almost all the months. In connection with the precipitation regime and the winter maximum, months with high and very high rainfall erosivities are observed in the period November–February. For the southern part of the studied region, in November–February, about 20–30% of the months in the period 2001–2021 have high or very high erosivities, and in the regions of the Tokachka and Kirkovo stations in December, this indicator is 40 and 50%, respectively (Figure 4).

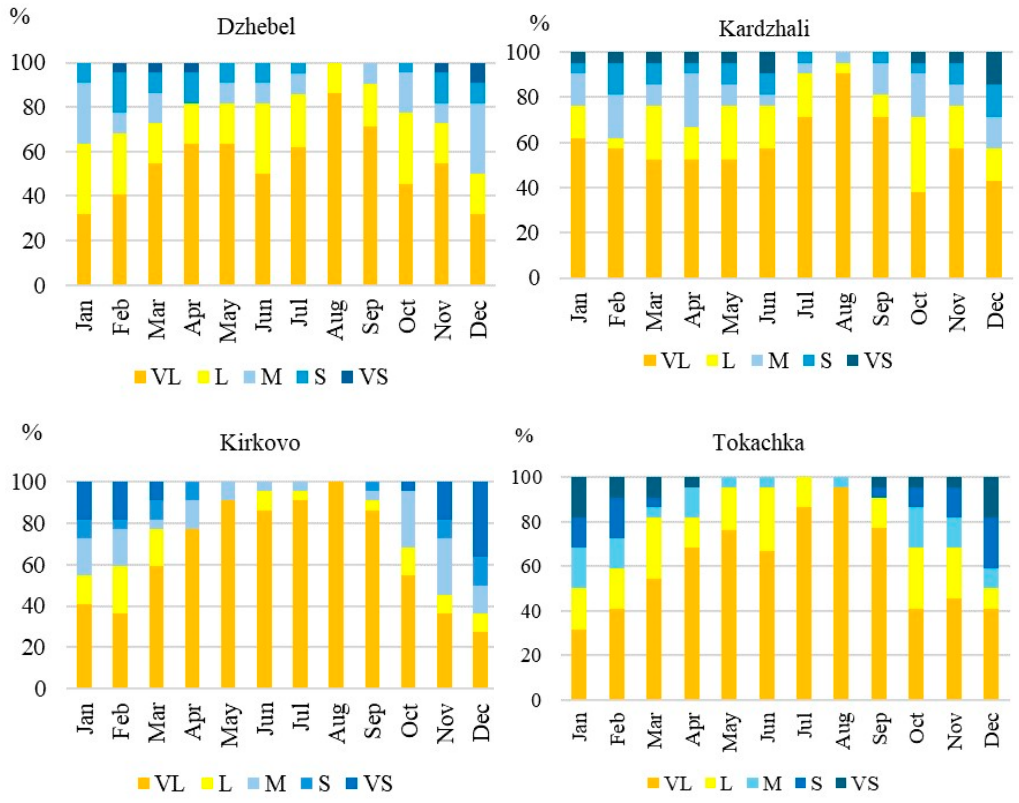


Figure 4. Percentage of months with different classes of precipitation erosivity according to Angot precipitation index (VL—very low; L—low; M—moderate; S—severe; VS—very severe).

In winter, especially in recent years, in the studied territory, precipitation is often rain and less often snow, which favours soil erosion by water. Investigating monthly and annual variations in hail events in Bulgaria for the period 1991–2020, Bocheva and Pophristov [35] established a significant increase in hail days in South Bulgaria in the cold half of the year (October–March). The higher precipitation amounts during the cold part of the year and the associated higher erosivity of the precipitation can be explained by the more northerly positions of the frontal zones of passing Mediterranean cyclones. This leads to more intense precipitation in the Eastern Rhodopes, a more frequent occurrence of thunderstorms in the

region, and an increase in the number of days with intense precipitation, including hail, especially in the cold part of the year [35].

The increase in convective storms and hail events is among the main factors triggering soil erosion by water. During snowfalls, owing to the higher air temperatures in the southern part of Bulgaria and when warm air blows in from the south, the snow cover is ephemeral and often melts very quickly, which causes floods and can lead to soil erosion.

3.3. Fournier Index and Modified Fournier Index

According to the *FI*, in most cases, the rainfall erosivity in the investigated area was from low to moderate. In the southeast, the average rainfall erosivity for the period 2000–2021 increases and reaches high and very high classes. The trend in the *FI* for the period 2000–2021 is positive, but it is not statistically significant. Bearing in mind the fact that the *FI* is based on the highest monthly rainfall and does not take into account the annual rainfall cycle, the values of the *MFI* have been calculated and analysed, giving more detailed information on the erosivity of the rainfall.

The *MFI* shows that the rainfall erosivity in the studied area varied during the individual years in the period 2000–2021 from low to very high. Above 70% of the years in the period 2000–2021, the stations in Dzhebel, Kardzhali, and Haskovo have moderate rainfall erosivities, and in the southern part of the investigated territory (at stations in Kirkovo and Tokachka), most of the years have very high erosivities (Table 5).

Table 5. Percentages of the years during the period 2000–2021 with different classes of rainfall erosivity according to the MFI (as percentages of the total number of years in the period 2000–2001).

Station	Moderate	High	Very High
Haskovo	89	11	
Kardzhali	83	17	
Dzhebel	73	27	
Zlatograd	23	45	32
Momchilgrad	50	36	14
Kirkovo	4	23	73
Tokachka	18	37	45

The lowest values of the *MFI* were obtained for the first decade of the investigated period, while the highest values were in the second decade (Table 6). For the period 2000–2011, at 43% of the investigated stations, the average rainfall erosivity is moderate, and only one station indicates a very high erosivity. In the second half of the studied period, 43% of the stations have a very high rainfall erosivity. Despite the trend in the *MFI* not being statistically significant for all the investigated stations, the results show a positive trend and an increase in the rainfall erosivity (Table 6).

Table 6. Trend, minimum and maximum *MFI* values, and years of occurrence for the period 2000–2021 (bold values of trend are statistically significant at a level of 0.05).

Station	Min *MFI*/Year	Max *MFI*/Year	*MFI* Trend/10 Years
Haskovo	43.0 (2000)	141.0 (2012)	13.975
Dzhebel	61.0 (2011)	144.0 (2021)	**17.561**
Zlatograd	71.0 (2000)	263.0 (2013)	**47.544**
Momchilgrad	71.0 (2000)	263.0 (2013)	19.029
Kirkovo	83.0 (2011)	250.0 (2017, 2021)	**27.583**
Tokachka	72.0 (2008)	271.0 (2012)	13.653

The spatiotemporal distribution of the *MFI* shows an increase in the rainfall erosivity from the north (at stations in Haskovo and Kardzhali) to the south (at stations in Momchilgrad, Kirkovo, and Tokachka) towards recent years (Figure 5). These characteristics of

the rainfall erosivity follow the physical and geographical features of the territory and the manifestation of extremely wet and dry months during the studied period.

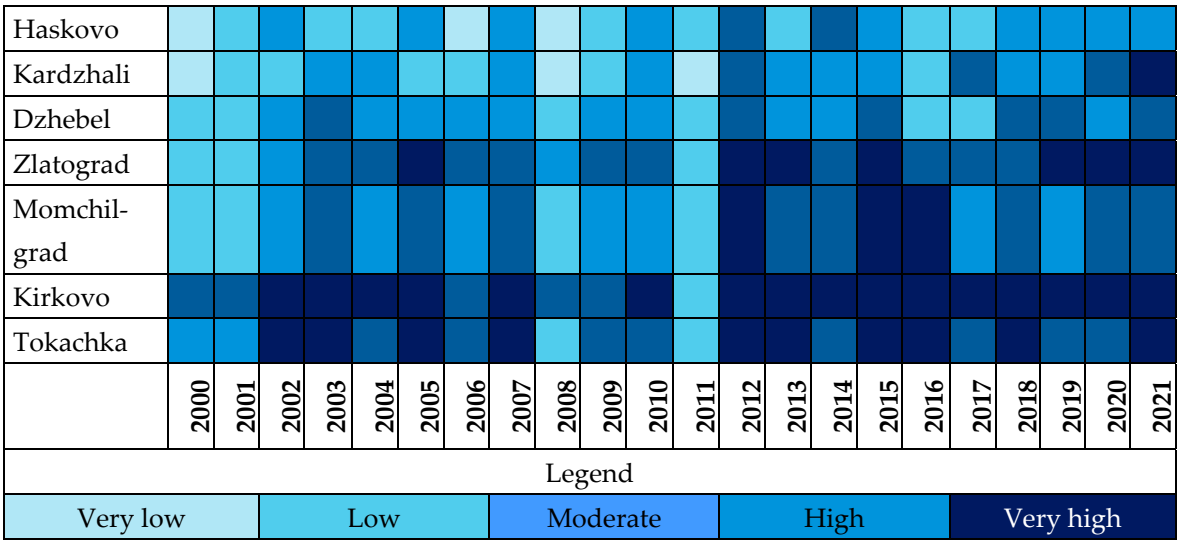


Figure 5. Rainfall erosivity according to the *MFI* for the period 2000–2021.

The results of the present study show that the *MFI* gives more detailed information about and is more reliable for rainfall erosivity analyses than the *FI*. Similar results regarding the applicability of the *MFI* were found by other authors [10,48].

Rainfall erosivity is more severe in areas with a high annual rainfall or a strong rainfall concentration (high *PCI*) [49]. The average multiannual precipitation totals for the period 2000–2021 are 1165 mm at the station in Tokachka and 1213 mm at the station in Kirkovo, while at the station in Haskovo, the annual precipitation is 710 mm. The high and very high rainfall erosivities in 2012 are due to high monthly precipitations in the cold months (November–February) and heavy precipitation caused by the combination of Mediterranean cyclones, which are typical for this part of the year, and the orography [50].

3.4. Extremely Wet and Extremely Dry Months

An increase in extreme precipitation months (dry and wet) was observed for all the investigated stations. Similar results were obtained by Nikolova et al. [51] and Svetozarevic and Nikolova [52] for the north and northwest parts of Bulgaria. This is also in line with the conclusions of the IPCC [53] about an increase in extreme events of a different nature at the same places. Comparing the two periods (2000–2010 and 2011–2021), a greater increase in the second period is observed in terms of extremely wet months (Figure 6). During the period 2011–2021, the extremely wet months were 59% of all the extremely wet months for the period 2000–2021.

A statistically significant positive trend in the annual number of extreme precipitations in southeastern Bulgaria was also found by Bocheva et al. [54] for the period 1951–2010. An increase in the number of extremely wet months and their alternation with extremely dry periods are prerequisites for higher erosivities of precipitation—during dry periods, the cohesiveness of soil particles is reduced, and the particles are easily carried away in the event of heavy precipitation.

The analysis of the distribution of the number of extreme precipitation months during the cold and warm parts of the year for two 10-year periods (Figure 7) shows an increase in extreme months during the second decade, and the highest value of the increase was observed for extremely wet months during the cold period (October–March) in 2022–2020. According to the data for heavy precipitation events in Bulgaria for the period 1991–2017, Bocheva and Pophristov [50] point out that the increase in the precipitation amounts is related to the increase in the number of days with heavy precipitation. The authors

indicate that especially in winter, this is due to southern cyclones (Mediterranean cyclones). The activity of Mediterranean cyclones over the Balkans was also indicated by Bocheva et al. [54] as the reason for the increase in the frequency of the extreme precipitation in Bulgaria, especially in Eastern Bulgaria. Other authors [55] have associated the increase in heavy precipitation events with increasing air temperatures and longer warm periods, resulting in conditions for convective precipitation. According to [56], for every 1 °C of warming, the water-holding capacity of the air increases by about 7%; because of this, the water vapor in the atmosphere increases, and the occurrence of intense precipitation becomes more frequent. Despite some uncertainties related to regional climate models, e.g., CP_RegCM_3km overestimates extreme precipitation (99p), especially in mountainous areas during summer [57,58], and RegCM_15km underestimates extreme precipitation (99p) [58], the existing publications prove, for the territory of Bulgaria, increases in extreme precipitation in winter and spring and a decrease in summer.

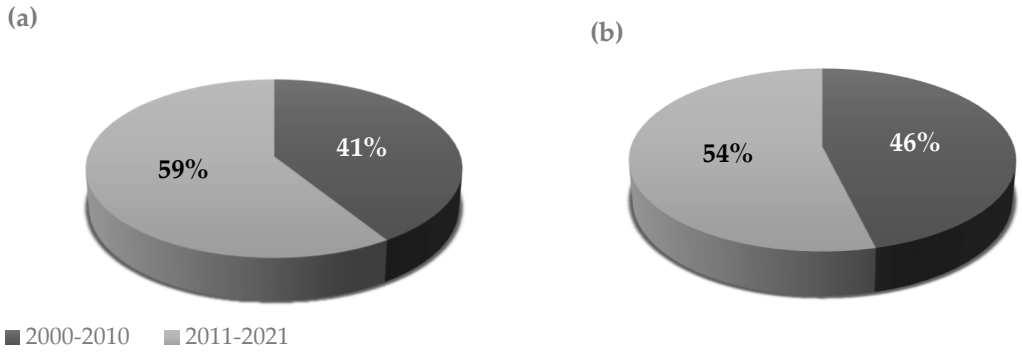


Figure 6. Distributions of extreme precipitation months: (**a**) extremely wet months during two periods (as percentage of extremely wet months for the period 2000–2021; (**b**) extremely dry months during two periods (as percentage of extremely dry months for the period 2000–2021.

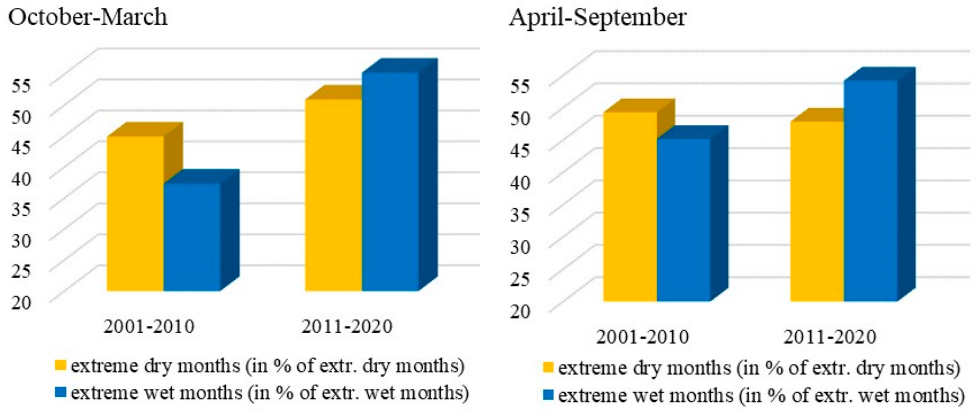


Figure 7. Distributions of extremely dry and wet months during the cold (October–March) and warm (April–September) half-years for two 10-year periods.

The correlation between the *MFI* and the number of extremely dry months is weak, negative, and statistically insignificant. The lowest values of the correlation coefficients were obtained for the stations in Kirkovo (−0.23) and Dzhebel (−0.30). On the other hand, the *MFI* correlates very well with the number of extremely wet months—in most cases, the correlation coefficients are above 0.63, and for the stations in Dzhebel and Haskovo, above 0.80 (Table 7).

Table 7. Correlation coefficients between the MFI and the precipitation characteristics for the period 2000–2021. Values in bold are statistically significant at $p = 0.05$.

Station	Dry Months	Wet Months	Annual Precipitation	October–March		April–September	
				Dry Months	Wet Months	Dry Months	Wet Months
Haskovo	−0.16	**0.83**	**0.86**	0.23	**0.61**	−0.16	**0.50**
Kardzhali	0.10	0.37	**0.48**	−0.18	0.20	0.35	0.04
Dzhebel	−0.30	**0.80**	**0.85**	−0.21	**0.44**	−0.17	**0.49**
Zlatograd	−0.04	**0.55**	**0.82**	−0.09	**0.64**	0.09	0.05
Momchilgrad	0.14	**0.47**	**0.75**	−0.15	**0.44**	0.26	0.14
Kirkovo	−0.23	**0.50**	**0.84**	−0.03	0.32	0.12	−0.08
Tokachka	0.13	**0.63**	**0.79**	0.09	0.19	0.38	0.07

The correlation analysis shows strong statistically significant correlations between the *MFI* and both the number of extremely wet months as well as the annual precipitation. At the seasonal level, these correlations are weak and not statistically significant, except for the number of extremely wet months at some separate stations. It is noteworthy that the stations with the highest frequency of very high rainfall erosivity years according to the *MFI* (Kirkovo and Tokachka) show the lowest values of the correlation coefficient between the *MFI* and the number of extreme precipitation months, while the correlation with the annual precipitation is high and statistically significant.

4. Conclusions

The rainfall erosivity in the Eastern Rhodopes, one of the most erosion-prone areas of Bulgaria, was evaluated for the period 2000–2001. The aim of the study was achieved by calculating and analysing some indices, such as the *PCI*, Angot precipitation index, *FI*, and *MFI*. The 10th and 90th percentiles were used as thresholds for the determination of extremely dry and extremely wet months, respectively. This paper emphasises the applicability of monthly precipitation data in studying the average rainfall erosivity, thereby providing important information for areas for which pluviographic records are not available.

According to the *PCI*, this region has a mainly uniform precipitation distribution over the year, but some years (e.g., 2012, 2016, and 2020) make an impression, with irregular and even strongly irregular precipitation concentrations, which are a consequence of high precipitation amounts observed mainly in April and May in these years. On the other hand, on average, for the period 2000–2021, the Angot index shows a greater share of winter months with severe or very severe erosivity because of the higher monthly precipitation amounts for the winter period.

The analyses based on the *FI* and *MFI* show that the *MFI* gives more detailed information about the changes in the rainfall erosivity over the investigated period. In general, the investigated territory is characterised by a moderate rainfall erosivity, but in the second half of the study period (2000–2021), cases with high and very high erosivities increased, which coincided with the occurrence of extremely dry and extremely wet months. Increases in the numbers of dry and wet months have been found, and the highest increase has been observed in the wet months in the cold half-year. Strong and statistically significant correlations were established between the values of the *MFI* and the number of wet months during the years of the study period and with the annual precipitation.

The increasing winter precipitation, the number of extreme precipitation months (dry and wet), and the higher rainfall erosivity in recent years show that the development and implementation of measures for sustainable land use and management in agriculture are needed for the investigated territory of the Eastern Rhodopes.

Author Contributions: Conceptualisation, V.N. and N.N.; methodology, N.N.; data processing, V.N., M.S. and S.M.; analysis, V.N., N.N. and S.M.; paper writing, V.N. and N.N.; visualisation, V.N., N.N. and M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research and APC were funded by the National Science Fund, Ministry of Education and Science (Bulgaria); Competition for financial support for basic research projects—2019 (Contract No. КП-06-Н34/3, signed on 5.12.2019), projects: "Application of geoinformation technologies in erosion research in mountain areas—Case studies of Eastern Rhodopes (Bulgaria)"; and National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers No. 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement No. Д01-271/09.12.2022).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Acknowledgments: We would like to thank the anonymous reviewers for their time and comments.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Eurostat. Agri-Environmental Indicator—Soil Erosion. 2020. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_soil_erosion (accessed on 15 January 2024).
2. Borrelli, P.; Alewell, C.; Alvarez, P.; Anache, J.A.A.; Baartman, J.; Ballabio, C.; Bezak, N.; Biddoccu, M.; Cerdà, A.; Chalise, D.; et al. Soil erosion modelling: A global review and statistical analysis. *Sci. Total Environ.* **2021**, *780*, 14649. [CrossRef]
3. Rousseva, S. Factors and rates of soil erosion in the Balkan Peninsula. In Proceedings of the International Conference "Ecology Interdisciplinary Science and Practice (Part One), Sofia, Bulgaria, 25–26 October 2012; pp. 43–47.
4. Panagos, P.; Ballabio, C.; Borrelli, P.; Meusburger, K.; Klik, A.; Rousseva, S.; Tadić, M.P.; Michaelides, S.; Hrabalíková, M.; Olsen, P.; et al. Rainfall erosivity in Europe. *Sci. Total Environ.* **2015**, *511*, 801–814. [CrossRef]
5. Ballabio, C.; Borrelli, P.; Spinoni, J.; Meusburger, K.; Michaelides, S.; Beguería, S.; Klik, A.; Petan, S.; Janeček, M.; Olsen, P.; et al. Mapping monthly rainfall erosivity in Europe. *Sci. Total Environ.* **2017**, *579*, 1298–1315. [CrossRef] [PubMed]
6. Özşahin, E.; Duru, Ü.; Eroğlu, İ. Land Use and Land Cover Changes (LULCC), a Key to Understand Soil Erosion Intensities in the Maritsa Basin. *Water* **2018**, *10*, 335. [CrossRef]
7. Panagos, P.; Borrelli, P.; Poesen, J.; Ballabio, C.; Lugato, E.; Meusburger, K.; Montanarella, L.; Alewell, C. The new assessment of soil loss by water erosion in Europe. *Environ. Sci. Policy* **2015**, *54*, 438–447. [CrossRef]
8. Panagos, P.; Ballabio, C.; Meusburger, K.; Spinoni, J.; Alewell, C.; Borrelli, P. Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets. *J. Hydrol.* **2017**, *548*, 251–262. [CrossRef] [PubMed]
9. Panagos, P.; Borrelli, P.; Matthews, F.; Liakos, L.; Bezak, N.; Diodato, N.; Ballabio, C. Global rainfall erosivity projections for 2050 and 2070. *J. Hydrol.* **2022**, *610*, 127865. [CrossRef]
10. Lukić, T.; Lukić, A.; Basarin, B.; Ponjiger, T.M.; Blagojević, D.; Mesaroš, M.; Milanović, M.; Gavrilov, M.; Pavić, D.; Zorn, M.; et al. Rainfall erosivity and extreme precipitation in the Pannonian basin. *Open Geosci.* **2019**, *11*, 664–681. [CrossRef]
11. Baartman, J.E.M.; Temme, A.J.A.M.; Veldkamp, T.; Jetten, V.G.; Schoorl, J.M. Exploring the role of rainfall variability and extreme events in long-term landscape development. *Catena* **2013**, *109*, 25–38. [CrossRef]
12. Zscheischler, J.; Seneviratne, S. Dependence of drivers affects risks associated with compound events. *Sci. Adv.* **2017**, *3*, e1700263. [CrossRef]
13. Vogel, M.; Hauser, M.; Seneviratne, S. Projected changes in hot, dry and wet extreme events' clusters in CMIP6 multi-model ensemble. *Environ. Res. Lett.* **2020**, *15*, 1748–9326. [CrossRef]
14. Mello, C.R.; Viola, M.R.; Beskow, S.; Norton, L.D. Multivariate models for annual rainfall erosivity in Brazil. *Geoderma* **2013**, *202–203*, 88–102. [CrossRef]
15. Lukić, T.; Leščešen, I.; Sakulski, D.; Basarin, B.; Jordaan, A. Rainfall erosivity as an indicator of sliding occurrence along the southern slopes of the Bačka loess plateau: A case study of the Kula settlement, Vojvodina (North Serbia). *Carpathian J. Earth Environ. Sci.* **2016**, *11*, 303–318.
16. Alili, I. Rainfall erosivity in the Republic of North Macedonia: Fournier index approach. *Eng. Geol. Hydrogeol.* **2023**, *37*, 89–100. [CrossRef]
17. Dragotă, C.S.; Grigorescu, I.; Dumitraşcu, M.; Kucsicsa, G. Pluvial hazards assessment in the Danube floodplain. The Calafat–Turnu MĂagurele sector. *Probl. Geogr.* **2014**, *1–2*, 100–114. Available online: https://geoproblems.eu/wp-content/uploads/2016/01/2014_12/9_dragota_2014_12.pdf (accessed on 8 March 2024).
18. Dumitraşcu, M.; Dragotă, C.S.; Grigorescu, I.; Dumitraşcu, C.; Vlădut, A. Key pluvial parameters in assessing rainfall erosivity in the south-west development region, Romania. *J. Earth Syst. Sci.* **2017**, *126*, 60. [CrossRef]
19. Panagos, P.; Ballabio, C.; Borrelli, P.; Meusburger, K. Spatio-temporal analysis of rainfall erosivity and erosivity density in Greece. *Catena* **2016**, *137*, 161–172. [CrossRef]

20. Efthimiou, N. Evaluating the performance of different empirical rainfall erosivity (R) factor formulas using sediment yield measurements. *Catena* **2018**, *169*, 195–208. [CrossRef]
21. Oğuz, I. Rainfall erosivity in North-Central Anatolia in Turkey. *Appl. Ecol. Environ. Res.* **2019**, *17*, 2719–2731. [CrossRef]
22. Hernando, D.; Romana, M.G. Estimating the rainfall erosivity factor from monthly precipitation data in the Madrid Region (Spain). *J. Hydrol. Hydromech.* **2015**, *63*, 55–62. [CrossRef]
23. Nunes, A.N.; Lourenço, L.; Vieira, A.; Bento-Gonçalves, A. Precipitation and Erosivity in Southern Portugal: Seasonal Variability and Trends (1950–2008). *Land Degrad. Dev.* **2016**, *27*, 211–222. [CrossRef]
24. Lukić, T.; Basarin, B.; Micić, T.; Bjelajac, D.; Maris, T.; Marković, S.B.; Pavić, D.; Gavrilov, M.B.; Mesaroš, M. Rainfall erosivity and extreme precipitation in the Netherlands. *Q. J. Hung. Meteorol. Serv.* **2018**, *122*, 409–432.
25. Riquetti, N.V.; Mello, C.R.; Beskow, S.; Viola, M.R. Rainfall erosivity in South America: Current patterns and future perspectives. *Sci. Total Environ.* **2020**, *724*, 138315. [CrossRef]
26. Colman, C.B.; Oliveira, P.T.S.; Almagro, A.; Soares-Filho, B.S.; Rodrigues, D.B.B. Effects of Climate and Land-Cover Changes on Soil Erosion in Brazilian Pantanal. *Sustainability* **2019**, *11*, 7053. [CrossRef]
27. Yue, B.J.; Shi, Z.H.; Fang, N.F. Evaluation of rainfall erosivity and its temporal variation in the Yanhe River catchment of the Chinese Loess Plateau. *Nat. Hazards* **2014**, *74*, 585–602. [CrossRef]
28. Yue, T.; Yin, S.; Xie, Y.; Yu, B.; Liu, B. Rainfall erosivity mapping over mainland China based on high-density hourly rainfall records. *Earth Syst. Sci. Data* **2022**, *14*, 665–682. [CrossRef]
29. Rousseva, S.; Malinov, I.; Stefanova, V. Soil Erosion Risk Assessments Using GIS Technologies—Bulgarian Experience. *Bulg. J. Agric. Sci.* **2016**, *22*, 205–208.
30. Pavlova-Traykova, E.; Nedkov, S.; Zhiyanski, M. Integral approach to the flood protection effect of forests with special consideration of erosion control in Bulgaria: Review. In Proceedings of the 11th Scientific Seminar, Sofia, Bulgaria, 1 December 2021; pp. 77–87.
31. Özşahin, E.; Eroğlu, I. Soil Erosion Risk Assessment due to Land Use/Land Cover Changes (LULCC) in Bulgaria from 1990 to 2015. *Alinteri J. Agric. Sci.* **2019**, *34*, 1–8. [CrossRef]
32. Ministry of Environment and Water. *National Report on the Environment and the Protection of the Environment*; Ministry of Environment and Water: Sofia, Bulgaria, 2020. (In Bulgarian)
33. Topliiski, D. *Climate of Bulgaria*; Amstels Foundation: Sofia, Bulgaria, 2006; p. 360. (In Bulgarian)
34. Velev, S. *Climate of Bulgaria*; Heron Press: Sofia, Bulgaria, 2010; p. 189. (In Bulgarian)
35. Bocheva, L.; Pophristov, V. Recent Trends in Hail Precipitation for Administrative Districts of Bulgaria. In *Environmental Protection and Disaster Risks. EnviroRISKs 2022. Lecture Notes in Networks and Systems*; Dobrinkova, N., Nikolov, O., Eds.; Springer: Cham, Switzerland, 2023; Volume 638. [CrossRef]
36. Diodato, N.; Bellocchi, G. Estimating monthly (R) USLE climate input in a Mediterranean region using limited data. *J. Hydrol.* **2007**, *345*, 224–236. [CrossRef]
37. Patriche, C.V.; Roșca, B.; Pîrnău, R.G.; Vasiliniuc, I.; Irimia, L.M. Simulation of Rainfall Erosivity Dynamics in Romania under Climate Change Scenarios. *Sustainability* **2023**, *15*, 1469. [CrossRef]
38. Mezősi, G.; Bata, T. Estimation of the changes in the rainfall erosivity in Hungary. *J. Environ. Geogr.* **2016**, *9*, 43–48. [CrossRef]
39. Apaydin, H.; Erpul, G.; Bayramin, I.; Gabriels, D. Evaluation of indices for characterizing the distribution and concentration of precipitation: A case for the region of Southeastern Anatolia Project, Turkey. *J. Hydrol.* **2006**, *328*, 726–732. [CrossRef]
40. de Luis, M.; Gonzales-Hidalgo, J.C.; Bruneti, M.; Longares, L.A. Precipitation concentration changes in Spain 1946–2005. *Nat. Haz. Earth Syst. Sci.* **2011**, *11*, 1259–1265. [CrossRef]
41. Lu, Y.; Jiang, S.; Ren, L.; Zhang, L.; Wang, M.; Liu, R.; Wei, L. Spatial and Temporal Variability in Precipitation Concentration over Mainland China, 1961–2017. *Water* **2019**, *11*, 881. [CrossRef]
42. Amiri, M.A.; Gocić, M. Analyzing the applicability of some precipitation concentration indices over Serbia. *Theor. Appl. Climatol.* **2021**, *146*, 645–656. [CrossRef]
43. Lukić, T.; Ponjiger, T.M.; Basarin, B.; Sakulski, D.; Gavrilov, M.; Marković, S.; Zorn, M.; Komac, B.; Milanović, M.; Pavić, D.; et al. Application of Angot precipitation index in the assessment of rainfall erosivity: Vojvodina Region case study (North Serbia). *Acta Geogr. Slov.* **2021**, *61–62*, 123–153. [CrossRef]
44. Arnoldus, H.M. An approximation of the rainfall factor in the Universal Soil Loss Equation. In *Assessments of Erosion*; De Boodts, M., Gabriels, D., Eds.; John Wiley and Sons Ltd.: Chichester, UK, 1980; pp. 127–132.
45. Ma, X.; Zheng, M. Statistical evaluation of proxies for estimating the rainfall erosivity factor. *Sci. Rep.* **2022**, *12*, 12092. [CrossRef] [PubMed]
46. Mohtar, Z.A.; Yahaya, A.S.; Ahmad, F. Rainfall Erosivity Estimation for Northern and Southern Peninsular Malaysia using Fourneir Indexes. *Procedia Eng.* **2015**, *125*, 179–184. [CrossRef]
47. National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences. May 2012. In Bulgarian. Available online: https://bulletins.cfd.meteo.bg/bull/Buletin_NIMH_201205.pdf (accessed on 8 March 2024).
48. Nikolova, N.; Matev, S.; Alili, I. Assessment of rainfall erosivity in Southwest Bulgaria using the Fournier index. *Rev. Bulg. Geol. Soc.* **2022**, *83*, 221–224. [CrossRef]
49. de Luis, M.; González-Hidalgo, J.C.; Longares, L.A. Is rainfall erosivity increasing in the Mediterranean Iberian Peninsula? *Land Degrad. Dev.* **2010**, *21*, 139–144. [CrossRef]

50. Bocheva, L.; Pophristov, V. Seasonal Analysis of Large-Scale Heavy Precipitation Events in Bulgaria. *AIP Conf. Proc.* **2019**, *2075*, 200017. [CrossRef]
51. Nikolova, N.; Matev, S.; Pophristov, V. Rainfall Erosivity and Extreme Precipitation Months—A Comparison between the Regions of Lovech and Kardzhali (Bulgaria). In Proceedings of the 21st International Multidisciplinary Scientific GeoConference SGEM, Albena, Bulgaria, 16–22 August 2021; Volume 21, pp. 389–396. [CrossRef]
52. Svetozarevic, J.; Nikolova, N. Seasonal distribution of extreme precipitation months in Northwest Bulgaria. In Proceedings of the Third Conference Climate, Atmosphere and Water Resources in the Face of Climate Change, Sofia, Bulgaria, 14–15 October 2021; pp. 15–22.
53. Core Writing Team; Lee, H.; Romero, J. (Eds.) *IPCC: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2023; 184p. [CrossRef]
54. Bocheva, L.; Marinova, T.; Nikolova, T. Comparative analysis of severe storms, connected with extreme precipitation in Bulgaria (1951–2010). *J. Int. Sci. Publ. Ecol. Saf.* **2014**, *8*, 461–468. Available online: https://www.scientific-publications.net/en/article/1000118/ (accessed on 15 December 2023).
55. Spiridonov, V.; Balabanova, S. The impact of climate change on intensive precipitation and flood types in Bulgaria. In *Climate and Land Use Impacts on Natural and Artificial Systems*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 153–169, ISBN 978-0-12-822184-6. [CrossRef]
56. Kevin, E.T. Changes in precipitation with climate change. *Clim. Res.* **2011**, *47*, 123–138. [CrossRef]
57. Gadzhev, G.; Ivanov, V.; Valcheva, R.; Ganev, K.; Chervenkov, H. HPC Simulations of the Present and Projected Future Climate of the Balkan Region. In *Advances in High Performance Computing. HPC 2019. Studies in Computational Intelligence*; Dimov, I., Fidanova, S., Eds.; Springer: Cham, Switzerland, 2021; Volume 902. [CrossRef]
58. Valcheva, R.; Popov, I.; Gerganov, N. Convection-Permitting Regional Climate Simulation over Bulgaria: Assessment of Precipitation Statistics. *Atmosphere* **2023**, *14*, 1249. [CrossRef]

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