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# Spatial variability of concentration and aggressiveness of precipitation in North-East of Algeria

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## Abstract

In this study, the spatial variation of daily and monthly concentration precipitation index and its aggressiveness were used in 23 rainfall stations in the extreme north-east of Algeria over the period 1970–2010. The trend was analysed by the Mann–Kendall (MK) test. The results show that daily precipitation concentration index (*CI*) values are noticeably higher in places where the amount of total precipitation is low, the results of MK test show that areas of high precipitation concentration tend to increase. The seasonality and aggressiveness of precipitation are high in the eastern and western parts of the study region (eastern and central coastal of Constantine catchments), whereas a moderately seasonal distribution with low aggressiveness is found in the middle of the study area (plains and central Seybouse catchment). As a result, the modified Fournier index (*MFI*) has a significant correlation with annual precipitation, whereas the *CI* and monthly precipitation concentration index (*PCI*) show an opposite correlation in relation to annual precipitation.

**Key words:** *aggressiveness, concentration index, North-East of Algeria, precipitation trend, seasonality*

## INTRODUCTION

Rainfall is one of the most changeable climate parameters over time and space [APAYDIN *et al.* 2006; IPCC 2007], requiring in-depth research and giving rise to conflicting phenomena [COSCARELLI, CALOIERO 2012] such as droughts [ZHANG *et al.* 2013] and floods [PARAJKA *et al.* 2010]. It has a direct impact on the natural cycles of water resources [RANDALL *et al.* 2007] and affects several parts of the world every year, causing damage at the economic and environmental levels and, in the worst case, substantial losses of human life [EASTERLING *et al.* 2000]. Thus, intense rainfall can be a driver of soil erosion [MICHIELS *et al.* 1992]. This erosion reduces soil fertility, alters the growth conditions for plants, hampers agricultural

practices and causes rapid aggradations of hydraulic structures [ALIJANI *et al.* 2008; SCHOLZ *et al.* 2008]. Understanding the mechanisms of this phenomenon is essential to the management of water resources and the assessment of regional impacts caused by climate fluctuations [BRUNSELL 2010].

Variation in precipitation on the annual, seasonal or monthly scales is one of the key elements affecting water availability, but the concentration of precipitation over time also plays a decisive role. A high concentration of precipitation, represented by high percentages of total annual precipitation in just a few very rainy days, may trigger all or some of the phenomena already mentioned [ALIJANI *et al.* 2008; COSCARELLI *et al.* 2012; HUANG *et al.* 2014; WANLI *et al.* 2013; ZHANG *et al.* 2009].

In this context, a number of studies on the variability of precipitation have been conducted over the last decade in several parts of the world. By way of example, MARTIN-VIDE [2004] explored the spatial distribution of daily precipitation concentration calculated over the period 1951–1990. The results of his study showed that the values of precipitation concentrations clearly divide peninsular Spain into two regions, with the east side representing a high concentration in which 25% of the rainiest days account for at least 75% of total rainfall. In southern Italy (Calabria) over the period 1916–2006, COSCARELLI, CALOIERO [2012] show a very heterogeneous temporal distribution of daily precipitation, characterised in the eastern part of the region, where 25% of rainiest days account for almost 75% of total rainfall. ALIJANI *et al.* [2008] analysed the intensity and concentration of daily precipitation in Iran over the period 1982–2004. Their study indicates that precipitation tends to be irregular and intense across Iran and that at least 20% of the country is exposed to the risk of extreme precipitation. Over the period 1951–2010, PENG *et al.* [2013] studied the spatio-temporal characteristics of precipitation concentration in the upper part of the Huai River in China, using two indices. Their results showed significant seasonality in the distribution of precipitation and a very heterogeneous temporal distribution of daily precipitation in the southern part of the study area. In Turkey, APAYDIN *et al.* [2006] evaluated the erosive potential of precipitation and its impact on erosion by calculating the modified Fournier index (*MFI*) in south-eastern Anatolia. They concluded that the use of the *MFI* was valuable in determining the potential of rainfall to cause soil erosion, by providing them with information on the long-term total variability of the amount of rainfall received. MEDDI [2013] analysed the impact of the variability of spatio-temporal concentration and aggressiveness of precipitation in twelve drainage basins in the West of Algeria from 1930–2007. The results of his study showed a negative trend of the two variables, and decrease of 20% in annual precipitation and the *MFI*. However, DE LUIS *et al.* [2010] analysed trends in total annual precipitation, the precipitation concentration index and modified Fournier index. Their results indicated a decrease in annual precipitation, increases in monthly precipitation concentration index (*PCI*) of also predominated in the Mediterranean Iberian Peninsula during the period 1951–2000. Thus, a decrease in rainfall erosivity is detected.

Algeria, a North African country situated in a transition zone between the temperate and semi-arid to arid regimes, has a high level of climate sensitivity because of the high variability in seasonal and annual rainfall that characterises this zone [BOLLE 2003]. The region is currently subject to increasingly severe droughts [BEKKOUSSA *et al.* 2008; HAIDA *et al.* 1999; LABORDE 1993; MEDDI *et al.* 2009; MEDDI, HUBERT 2003]. Consequently, it is suffering first the gradual degradation of its water resources and, second, ex-

remely high water levels that cause flooding [HAMADACHE *et al.* 2002; DJELLOULI, SACI 2003; MENAD *et al.* 2012]. The expected impacts of the climate crisis in Algeria by 2030 are a temperature increase of between 0.75 and 1.5°C, a 7 to 16% reduction in precipitation, and an increase in the frequency of extreme events (dry/wet spells) of around 10% [PNUD 2015].

In this context, to describe rainfall variability in the study area during the period 1970 to 2010, three types of indices were used: The daily precipitation concentration index developed by MARTIN-VIDE [2004] is used by several authors [ALIJANI *et al.* 2008; BENHAMROUCHE *et al.* 2011; 2012; 2015; BURGUENO *et al.* 2005; CORTESI *et al.* 2012; COSCARELLI, CALOIERO 2012; JAMALUDIN, ABDUL-AZIZ 2012; PATEL, SHETE 2015; PENG *et al.* 2013; WANLI *et al.* 2013; WEIGUANG *et al.* 2013; XUEMEI *et al.* 2011; ZHANG *et al.* 2009]. It makes it possible to determine the relative impact of different classes of daily precipitation and to evaluate the percentage of relative precipitation on very rainy days in total precipitation amounts. The monthly precipitation concentration index developed by OLIVER [1980], which is used to quantify the monthly heterogeneity of precipitation over the hydrological year [ABD ELBASIT *et al.* 2013; CANNAROSSO *et al.* 2006; DE LUIS *et al.* 2000; 2010; 2011; GHENIM, MEGNOUNIF 2013; HUANG *et al.* 2014; MEDDI 2013; MICHIELS *et al.* 1992]. While, the Modified Fournier Index developed by ARNOLDUS [1980] is often used to evaluate the aggressiveness of precipitation and its effects on soil erosion [ABD ELBASIT *et al.* 2013; APAYDIN *et al.* 2006; DE LUIS *et al.* 2010; GHENIM, MEGNOUNIF 2013; MEDDI 2013; MEDDI *et al.* 2014]. The trends of these parameters are analysed in order to detect their temporal behaviour. For this purpose, the non-parametric Mann-Kendall test is used, with a significance level of 95%. Finally, the relationship between these indices and annual precipitation is detected.

## STUDY SITE AND DATA USED

The region concerned by this study is north-eastern Algeria (Fig. 1), which is situated between longitudes 6°56' and 8°40'E and latitudes 36°12' and 37°06'N, with a surface area of 8 146 km<sup>2</sup>. It is part of the East and Center coastal of Constantine and the Seybouse catchment areas. Forming a key part of the Tell Atlas, whose geomorphology is comprised of a mountain range, plains and catchment areas, it is characterised by two main landforms, the Edough massif in Annaba province and the Cheffia massif in El Taref province. It has a temperate Mediterranean climate characterised by two seasons: a mild wet season from October to May, and a relatively short hot, dry season [SADOUNE 2012].

The north-eastern region is one of the rainiest parts of the country [DJABRI *et al.* 2012; MEDDI, TOUMI 2013; NOUACEUR, LAIGNEL 2015] and is subject to highly irregular spatio-temporal variations in

**Table 1.** Geographic coordinates of the rain gauge stations used, average annual precipitation  $P$ , and coefficient of variation  $CV$  for 23 rain gauge stations in north-eastern Algeria (1970–2010).

| Stations (map code)   | Latitude (N) | Longitude (E) | Altitude, m | Annual $P$ , mm | $CV$ , % |
|-----------------------|--------------|---------------|-------------|-----------------|----------|
| Azzaba (AZ)           | 36°44'39"    | 7°5'12"       | 91          | 622             | 30       |
| Ain Cherchar (AC)     | 36°45'21"    | 7°16'57"      | 34          | 758             | 40       |
| Bekouche Lakhdar (BL) | 36°41'27"    | 7°18'6"       | 80          | 537             | 33       |
| Bouati Mahmoud (BM)   | 36°35'41"    | 7°19'21"      | 150         | 688             | 27       |
| Berrahal (BE)         | 36°50'15"    | 7°26'41"      | 33          | 657             | 19       |
| Annaba Port (AP)      | 36°54'53"    | 7°45'15"      | 50          | 635             | 30       |
| Medjaz Amar (MA)      | 36°27'29"    | 7°18'43"      | 333         | 610             | 29       |
| Guelma (GU)           | 36°27'35"    | 7°26'14"      | 304         | 538             | 27       |
| Heliopolis (HE)       | 36°30'44"    | 7°26'53"      | 259         | 594             | 25       |
| Bouchegouf (BC)       | 36°27'23"    | 7°42'24"      | 87          | 558             | 27       |
| Nechmaya (NE)         | 36°36'51"    | 7°30'25"      | 284         | 626             | 36       |
| Boukhamouza (BK)      | 36°35'8"     | 7°44'19"      | 140         | 646             | 27       |
| Kef Mourad (KM)       | 36°41'59"    | 7°46'14"      | 20          | 568             | 30       |
| El Kerma (EK)         | 36°45'44"    | 7°40'9"       | 15          | 592             | 31       |
| Pont Bouchet (PB)     | 36°49'31"    | 7°44'16"      | 3           | 604             | 26       |
| Ain Berda (AB)        | 36°41'41"    | 7°35'15"      | 100         | 631             | 24       |
| Bouhadjar (BH)        | 36°30'29"    | 8°6'0"        | 300         | 557             | 37       |
| Ain Kerma (AK)        | 36°35'22"    | 8°11'5"       | 280         | 678             | 28       |
| Cheffia Barrage (CHB) | 36°37'1"     | 8°1'36"       | 170         | 771             | 31       |
| Bouteldja (BT)        | 36°46'55"    | 8°11'11"      | 25          | 795             | 35       |
| Lac Des Oiseaux (LDO) | 36°47'17"    | 8°7'5"        | 6           | 752             | 22       |
| Ain Assel (AA)        | 36°46'27"    | 8°21'60"      | 35          | 847             | 19       |
| Roum Souk (RS)        | 36°47'30"    | 8°32'38"      | 150         | 750             | 34       |

Source: own elaboration.

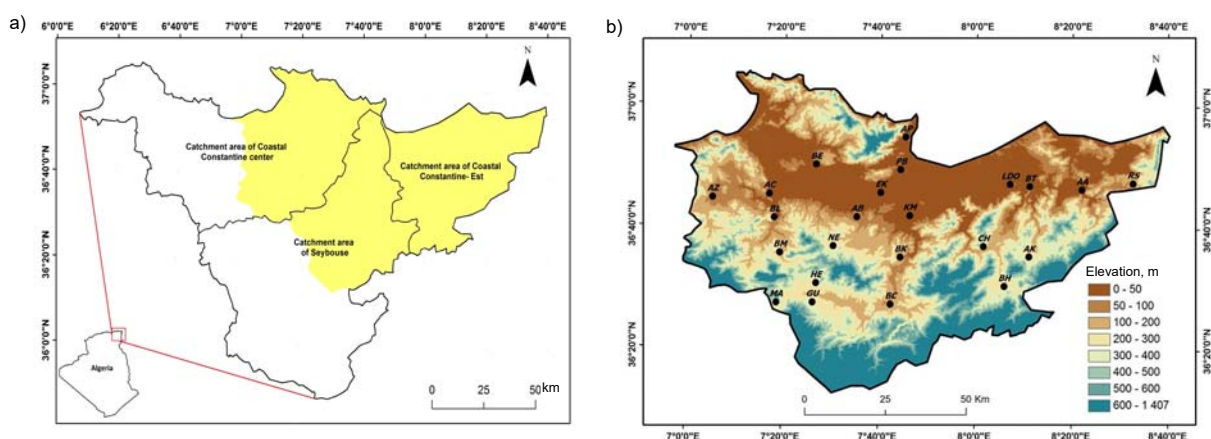


Fig. 1. Study site: a) geographical situation of the region of study, b) location of the rain gauge stations; stations code as in Tab. 1; source: own elaboration

precipitation [KHEZAZNA *et al.* 2017; MEDDI, TOUMI 2013]. Its spatial distribution is characterised by a marked north-south gradient and a weaker west-east gradient [LABORDE 1993; TOUZI 2001; TOUZI, LABORDE 2000].

Its hydrographic network is dominated by the Seybouse, one of the most important wadis in North Africa in terms of its length and the number of its tributaries. It stretches southwards over a distance of 160 km to the Ain Berda region, and its mouth is near the city of Annaba [KHANCHOUL 2006]. The average temperature is between 8°C and 15°C in winter and 25°C in July and August.

Daily precipitation data of 23 rain gauge stations during 1970–2010 recorded in North-East of Algeria

and collected by the National Agency of Hydraulic Resources (Fr. Agence Nationale des Ressources Hydrauliques – ANRH). The distribution of rain gauge stations is shown in Figure 1, and Table 1 shows the geographical coordinates of these stations.

## METHODS

In this study, the spatial evolution models of the daily precipitation concentration index, the monthly concentration index and rainfall erosivity of precipitation in the North-East of Algeria in 1970–2010 are analysed by the Mann–Kendall test. The detailed principles of calculating indices and methods are described in the following text.

### THE DAILY PRECIPITATION CONCENTRATION INDEX (CI)

The daily precipitation concentration index (*CI*) proposed by MARTIN-VIDE [2004] is essential to determine the relative impact of the different classes of daily precipitation and to evaluate the weight of the highest daily amount in the total value of precipitation. The methodology used in this work is based on the fact that the contribution of days with a given rainfall level to the total precipitation amount is generally influenced by a negative exponential distribution [BROOKS, CARRUTHERS 1953; MARTIN-VIDE 2004]. This is because in the classification and tabulation of daily precipitation amounts by length, their absolute frequencies decrease exponentially, starting with the lowest class. Therefore, in a given time and place, the probability of small daily amounts of precipitation is higher than that of large daily amounts.

MARTIN-VIDE [2004] introduce the calculation procedure as follows.

1. A limit of  $0.1 \text{ mm} \cdot \text{d}^{-1}$  was used to separate wet and dry days, and the daily rainfall amounts in each station were divided into several classes with intervals of 1 mm (in ascending order) to classify precipitation values.
2. The number of days with a precipitation range falling within the intervals in each class is counted, and the amount of associated precipitation is calculated.
3. The cumulative sum of output elements from stage (2) is calculated.
4. Based on the results of stage (3), the cumulative percentage of rainy days and the percentage of the amount of associated precipitation are obtained.

These percentages are related to positive exponential curves known as normalised rainfall curves [JOLLIFFE, HOPE 1996]. Based on the work by RIEHL [1949] and OLASCOAGA [1950], MARTIN-VIDE [2004] shows that such functions are of the type:

$$Y = aX \cdot \exp(bX) \quad (1)$$

Where:  $a, b = \text{constants}$ .

The parameters  $a$  and  $b$  in Equation (1) were determined by the least squares method, proposed in equations (2) and (3)

$$\ln a = \frac{\sum X_i^2 \sum \ln Y_i + \sum X_i \sum X_i \ln X_i - \sum X_i^2 \sum \ln X_i - \sum X_i \sum X_i \ln Y_i}{N \sum X_i^2 - (\sum X_i)^2} \quad (2)$$

$$b = \frac{N \sum X_i \sum \ln Y_i + \sum X_i \sum \ln X_i - N \sum X_i \ln X_i - \sum X_i \sum \ln Y_i}{N \sum X_i^2 - (\sum X_i)^2} \quad (3)$$

Where:  $N = \text{the number of non-zero classes}$ .

Once both constants  $a$  and  $b$  has been determined, the definite integral of the exponential curves between 0 and 100 shows the area under the curve, which is given by the formula below:

$$S = \left[ \frac{a}{b} e^{bx} \left( x - \frac{1}{b} \right) \right]_0^{100} \quad (4)$$

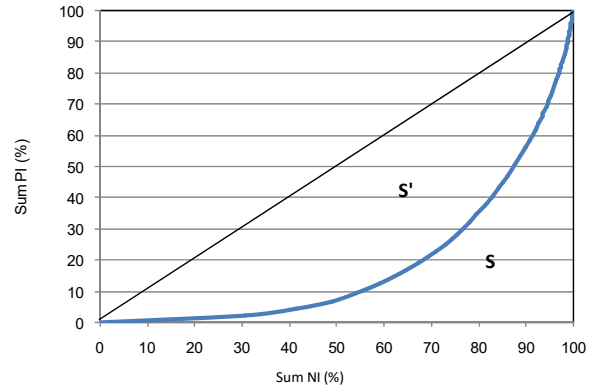


Fig. 2. Concentration curve of Nechmaya (1970–2010);  $S$  as in Eq. (4),  $S'$  as on Eq. (5),  $\sum NI (\%) = \text{the cumulative percentage of rainy days}$ ,  $\sum PI (\%) = \text{the cumulative percentage of rainfall amounts}$ ; source: own elaboration

The concentration curve for the station in Nechmaya is presented in Figure 2. This station has the highest daily precipitation amounts among those analysed.

The area  $S'$  compressed by the curve and the equidistribution line (Fig. 2) is the difference between 5 000 (lower triangle) and the value of Equation 4:

$$S' = 5000 - S \quad (5)$$

The daily precipitation concentration index (*CI*) is calculated using the following formula:

$$CI = S'/5000 \quad (6)$$

It should be noted that the value of *CI* is the fraction of  $S'$  and the surface area of the lower triangle delimited by the equidistribution line.

For Nechmaya (NE), the application of formulas (2), (3) and (6) gives the following results:  $a = 0.0200$ ;  $b = 0.0384$  and  $CI = 0.64$ .

Through the exponential concentration curves, the precipitation rate provided by 25% of rainy days, in other words, those with the highest amounts has been calculated.

### THE MONTHLY PRECIPITATION CONCENTRATION INDEX (PCI)

The heterogeneity of monthly rainfall was studied using the precipitation concentration index developed by OLIVER [1980], who applied it and tested its effectiveness in representative stations in the United States, Africa and Australia, while proposing it as an indicator of rainfall erosivity [MICHELS *et al.* 1992]. According to the study by OLIVER [1980], a uniform distribution of rainfall is indicated by a low value of the index, whereas a high value points to strong seasonality. The index is given by equation 7:

$$PCI = 100 \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \quad (7)$$

Where:  $P_i = \text{the amount of precipitation in month } i$ , calculated for each weather station and for each year of the study period.

OLIVER [1980] reached the conclusion that *PCI* values of less than 10 indicate a uniform precipitation distribution throughout the year; values from 11 to 15 denote a moderate concentration; values from 16 to 20 indicate a seasonal distribution; and values above 20 represent strong seasonal effects.

### THE MODIFIED FOURNIER INDEX (*MFI*)

The modified Fournier index by ARNOLDUS [1980] is calculated from the monthly precipitation amounts for each individual year and on average over a certain number of years [APAYDIN *et al.* 2006]. It can be calculated according to the following equation:

$$MFI = \sum_{i=1}^{12} \frac{P_i^2}{P_t} 100 \quad (8)$$

Where:  $P_i$  = monthly precipitation in month  $i$ ;  $P_t$  = annual precipitation.

It indicates the concentrated impact of rainwater on soil erosion. The higher the value, the higher the seasonal abundance of rainfall [ABD ELBASIT *et al.* 2013]. The *MFI* is divided into five classes: from 0 to 60, it indicates very low aggressiveness; from 60 to 90, it indicates low erosivity; from 90 to 120, it denotes moderate erosivity; from 120 to 160, high precipitation aggressiveness; and above 160, very high precipitation aggressiveness [ABD ELBASIT *et al.* 2013; APAYDIN *et al.* 2006].

### THE MANN-KENDALL TEST

The trend analysis has proven to be a useful tool for the effective planning of water resources. The Mann-Kendall (MK) test is a non-parametric statistical test [KENDALL 1975; MANN 1945]. It is one of the tests most commonly used to detect trends in hydrological time series [SHENG, CHUNYUAN 2004] and in several indices linked to precipitation, as well as to test their significance. Its use is highly recommended by the World Meteorological Organization.

It can be used to examine the existence of a linear trend (whether upward or downward) in a time series. The  $H_0$  hypothesis tested is that "there is no trend". If  $p < \alpha$ , the significance threshold chosen, the  $H_0$  hypothesis is rejected and we conclude that there is a significant trend at the chosen threshold. The robustness of the test has been validated by several comparison tests conducted by YUE and WANG [2004].

The statistical parameter,  $S$  of MK, is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(X_j - X_i) \quad (9)$$

Where:  $X_j$  = the sequential values of data;  $n$  = equal to the length of all data,

$$\text{sgn}(X_j - X_i) = \begin{cases} +1 & \text{if } X_j > X_i \\ 0 & \text{if } X_j = X_i \\ -1 & \text{if } X_j < X_i \end{cases} \quad (10)$$

It has been proven that where  $n \geq 8$ , ( $S$ ) approximately follows a normal distribution with the mean equal to 0 and the variance as follows:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^n t_i i(i-1)(2i+5)}{18} \quad (11)$$

Where:  $t_i$  = the number of measurement periods  $i$ .

The normalised statistic ( $Z$ ) of the MK test and the corresponding  $p$ -value ( $p$ ) for the unilateral test are respectively given by

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} & \text{if } S < 0 \end{cases} \quad (12)$$

$$p = 0.5 - \phi(|Z|) \quad (13)$$

$$(\phi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{-\frac{t^2}{2}} dt) \quad (14)$$

A positive value of  $Z$  indicates an upward trend, and a negative value indicates a downward trend, whereas a zero value of  $Z$  indicates the absence of a trend.

Table 2 presents the results of the Mann-Kendall test applied to annual precipitation and different indices used in north-eastern Algeria over the period 1970–2010.

**Table 2.** Number of stations with significant positive (SP), insignificant positive (ISP), significant negative (SN), insignificant negative (ISN), and no change (NC) trends at 95% level of significance for annual precipitation ( $P_t$ ), daily precipitation concentration index ( $CI$ ), monthly precipitation concentration index ( $PCI$ ) and modified Fournier index ( $MFI$ ) used in this study

| Parameter | Number of stations with |     |    |     |    |
|-----------|-------------------------|-----|----|-----|----|
|           | SP                      | ISP | SN | ISN | NC |
| $P_t$     | 2                       | 15  | 1  | 5   | 0  |
| $CI$      | 5                       | 7   | 4  | 6   | 1  |
| $PCI$     | 1                       | 10  | 0  | 12  | 0  |
| $MFI$     | 5                       | 12  | 0  | 6   | 0  |

Source: own elaboration.

## RESULTS AND DISCUSSION

### SPATIAL VARIABILITY AND TRENDS OF ANNUAL PRECIPITATION

The annual precipitations over the period 1970–2010 where statistics are summarised in Table 1, show a spatial variability ranging on average from 537 to 847 mm (Fig. 3). The eastern region (Coastal of Constantine East) recorded higher annual precipitation at Ain Assel (847 mm) station. This region is characterized as a wetland and the rainiest in Algeria. While the low annual precipitation values were recorded in the center (Seybouse) and the West (Coastal of Constantine Center) of the region studied, especially at Guelma (538 mm) and Bekouche Lakhdar (537 mm) stations. In terms of inter-annual variability, the

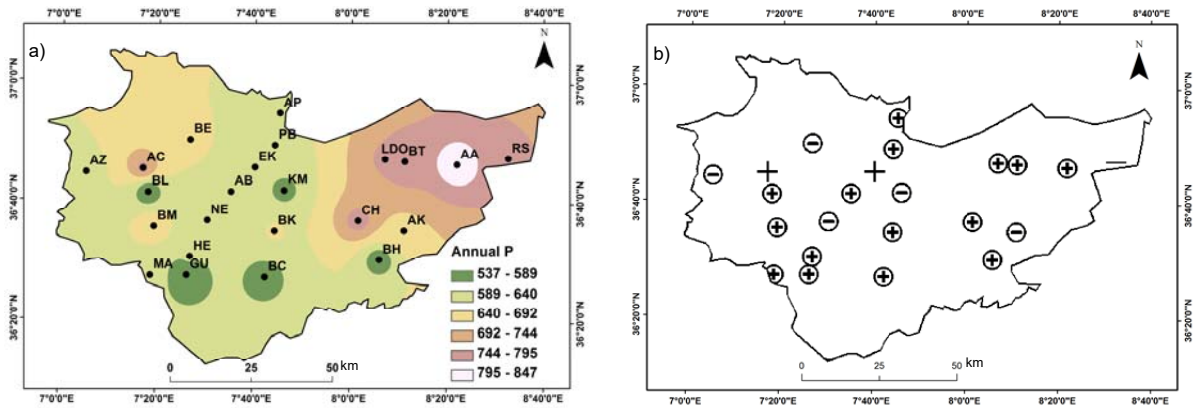


Fig. 3. Spatial distribution in the study region during 1970–2010 of: a) annual precipitations, b) trends for annual precipitation (if the trend is non-significant, the plus or minus signs are circled); station codes as in Tab. 1; source: own study

coefficient of variation ( $CV$ ) varied from 19% to 40% with the lowest value occurring at Berrahal and Ain Assel stations and the highest at Ain Cherchar station.

The overall results indicate that the stations in the East have experienced higher variability in annual precipitation than the stations situated in other regions.

From a regional viewpoint, this variability is due to the existence of gradients [DJELLOULI 1990]:

- A longitudinal gradient: rainfall increases from West to East. This gradient is due to two phenomena: in the West, the Spanish Sierra Nevada and the Moroccan Atlas act as a screen and thus remove the Atlantic influence; and in the East, the heavy rainfall is attributed to rainy weather from northern Tunisia.
- A latitudinal gradient: average annual precipitation decreases from North to South. This decrease from the coastal to the Saharan regions is due to the great distance travelled by depressions, which must cross the two Atlas ranges on their way, and to the growing predominance of the tropical anticyclone higher in the troposphere.
- A universal altitudinal gradient that varies according to the distance from the sea.

At the station level, in addition to the aforementioned gradients, we have had to take into account the influence of the configuration of the mountain ranges. Their influence on rainfall in the mountain weather stations as well as in the neighbouring regions is largely due to their general morphology, to their relative altitude in relation to that of their foothills and, finally, to their general orientation in relation to rain squalls, which justify the variations in rainfall from one part of the study region to another.

The results of the Mann–Kendall test on a database of annual precipitation values are presented in Table 2 with a confidence level of 95%, and Figure 3b shows their spatial distribution over the period 1970–2010. We see a non-significant increase in 15 stations, while five stations showed a non-significant negative trend. Two stations in Ain Charchar and El Kerma are dominated by a significant increase in annual precipitation with a confidence level of 95%. Moreover, only

one station in Roum Souk shows a significant downward trend.

#### SPATIAL VARIABILITY AND TRENDS OF DAILY PRECIPITATION CONCENTRATION

The daily precipitation concentration, studied by the  $CI$ , or simply the percentage of 25% of rain contributed by very rainy days, were estimated according to the exponential curves given by equation (1) for the 23 weather stations in north-eastern Algeria. The  $CI$  results are illustrated in Table 3. The values  $a$  and  $b$  are constants calculated according to Equations (3) and (4). Figure 4a, b shows the spatial distribution of  $CI$  and trends in the study region.

The maximum value of the precipitation concentration index  $CI$  is 0.64 in the station of Nechmaya, situated in the central Seybouse catchment, where almost 73% of precipitation is contributed by 25% of rainiest days. This irregularity can be explained by the relief and the position of the station, which is limited in the south by Houara Mountain in Guelma province, with an altitude of 1 292 m, and is exposed in the north to the influence of the Mediterranean climate. In this region, the mountains act as a barrier to the Mediterranean fronts (wet and hot) coming from the sea, while the hilly relief produces a mosaic of local climates in all depressions (Guelma, Bouchegouf), introducing marked differences in average rainfall irrespective of altitude or distance from the sea. COLACINO *et al.* [1997] showed that orography influences the amount of precipitation and its distribution in the region, which explains the difference in the  $CI$  values.

Similar results were obtained from other rain gauges, such as the stations in Pont Bouchet, Cheffia and Lac des Oiseaux, which also have high  $CI > 0.60$  values comprised between 0.61 and 0.62. In these regions, the irregularity of daily amounts of precipitation is mainly due to a high proportion of low rainfall amounts, in which the zones with the most intense precipitation have given a high precipitation concentration index value, with precipitation characteristics marked by the Mediterranean Sea.

**Table 3.** Values of constants  $a$  and  $b$ , the daily precipitation concentration index ( $CI$ ), monthly precipitation concentration index ( $PCI$ ) and modified Fournier index ( $MFI$ ), and percentage of precipitation contributed by 25% ( $P25\%$ ) of the rainiest days for 23 rain gauge stations across north-eastern Algeria (period 1970–2010)

| Stations (code map)   | $a$    | $b$    | $CI$ | $P25\%$ | $PCI$ | $MFI$ |
|-----------------------|--------|--------|------|---------|-------|-------|
| Azzaba (AZ)           | 0.0423 | 0.0313 | 0.58 | 68.9    | 17.8  | 110   |
| Ain Cherchar (AC)     | 0.0431 | 0.0310 | 0.58 | 68.6    | 16.0  | 121   |
| Bekouche Lakhdar (BL) | 0.0450 | 0.0302 | 0.59 | 68.1    | 16.5  | 88    |
| Bouati Mahmoud (BM)   | 0.0689 | 0.0261 | 0.56 | 64.0    | 15.5  | 108   |
| Berrahal (BE)         | 0.0479 | 0.0298 | 0.58 | 67.4    | 16.3  | 110   |
| Annaba Port (AP)      | 0.0378 | 0.0323 | 0.59 | 68.9    | 16.4  | 105   |
| Medjaz Amar (MA)      | 0.0806 | 0.0244 | 0.55 | 62.8    | 15.4  | 94    |
| Guelma (GU)           | 0.0439 | 0.0305 | 0.59 | 69.0    | 15.3  | 81    |
| Heliopolis (HE)       | 0.0441 | 0.0304 | 0.59 | 68.9    | 15.7  | 94    |
| Bouchegouf (BC)       | 0.0408 | 0.0311 | 0.60 | 69.7    | 15.2  | 84    |
| Nechmaya (NE)         | 0.0200 | 0.0384 | 0.64 | 73.5    | 16.6  | 101   |
| Boukhamouza (BK)      | 0.0696 | 0.0260 | 0.56 | 64.3    | 15.2  | 98    |
| Kef Mourad (KM)       | 0.0689 | 0.0261 | 0.56 | 64.0    | 15.9  | 91    |
| El Kerma (EK)         | 0.0841 | 0.0242 | 0.54 | 62.3    | 16.3  | 96    |
| Pont Bouchet (PB)     | 0.0341 | 0.0329 | 0.61 | 71.3    | 15.3  | 93    |
| Ain Berda (AB)        | 0.0411 | 0.0312 | 0.60 | 69.7    | 14.9  | 94    |
| Bouhadjar (BH)        | 0.0571 | 0.0280 | 0.57 | 65.8    | 16.7  | 94    |
| Ain Kerma (AK)        | 0.0874 | 0.0238 | 0.54 | 59.8    | 17.9  | 121   |
| Cheffia Barrage (CHB) | 0.0312 | 0.0338 | 0.62 | 71.5    | 15.5  | 119   |
| Bouteldja (BT)        | 0.0601 | 0.0276 | 0.56 | 64.9    | 16.5  | 127   |
| Lac Des Oiseaux (LDO) | 0.0377 | 0.0318 | 0.61 | 70.2    | 16.1  | 120   |
| Ain Assel (AA)        | 0.0401 | 0.0316 | 0.59 | 68.9    | 15.5  | 131   |
| Roum Souk (RS)        | 0.0553 | 0.0285 | 0.56 | 65.1    | 17.8  | 129   |

Source: own study.

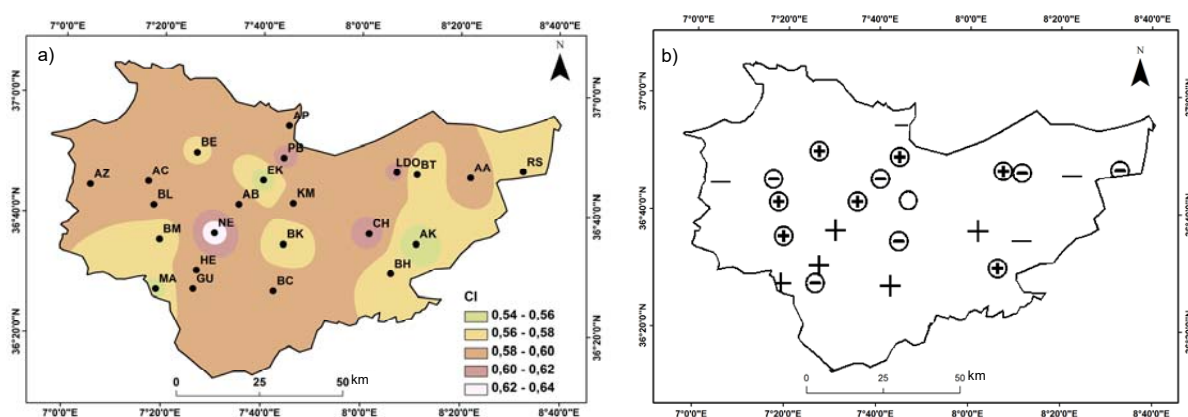


Fig. 4. Spatial distribution in the study region over the period 1970–2010 of: a) the daily precipitation concentration index ( $CI$ ), b)  $CI$  trends (if the trend is non-significant, the plus or minus signs are circled); station codes as in Tab. 1; source: own study

By contrast, the lowest  $CI$  value was detected around the stations of El Kerma and Ain Kerma, situated in the Seybouse basin and in the coastal eastern of Constantine catchment areas, with a value of  $CI = 0.54$ . This value indicates that the daily amounts recorded in these stations are more regular throughout the year. The results in % of precipitation indicate that there is a variation of 13.5%, which shows very different behaviour between the side where precipitation is most concentrated and the side where the daily amount is more regular. The other stations with intermediate values show between 0.539 and 0.616 (average = 0.58).

If we adopt the same classification as BENHAMROUCHE *et al.* [2015], where:  $CI > 0.61$  is high,

$0.55 < CI < 0.61$  is moderate and  $CI < 0.55$  is low, we note that in the study area, the concentration average is moderate on more than 82% of stations. This result does not coincide with those of other studies. Indeed, BENHAMROUCHE *et al.* [2015], analysed the  $CI$  in 42 rain gauge spread over the Algerian territory, their results showed a high average daily concentration nearly 74% of the values are greater than 0.61. On the other hand, GHENIM and MEGNOUNIF [2016] evaluated the concentration of precipitation in the Kebir-Rhumel catchment, they concluded that the  $CI$  is low, indeed 80% of the 20 stations studied show a concentration of less than 0.55.

In China for example, PENG *et al.* [2013] estimated the concentration of daily rainfall in the Huai River

is high since the values range from 0.64 to 0.72, whereas it is less significant in the Lancang River basin where the concentration is high on 20 stations out of the 31 studied and moderate on the rest [WANLI *et al.* 2013]. In Europe, the *CI* index ranges between 0.51 and 0.72, the highest values were detected in the Western Mediterranean basin (along the Spanish and French Mediterranean coasts) and Sicily. The values are moderate around the Black Sea, especially in Romania, Moldavia and Western Ukraine. The concentrations were judged as low in the North-West coast of Norway, Great Britain, Ireland, Netherlands and Denmark [CORTESE *et al.* 2012]. These regions do not receive the same amounts of precipitations as the area studied and do not enjoy the same climatic conditions, it does not explain the variability of *CI* that remains mainly related to the intensity of the rainfall and their non-homogeneity of occurrence.

The results of the Mann–Kendall test to the *CI* values for each station are presented in Table 2. The spatial distribution of *CI* precipitation concentration trends was dominated by positive trends. Figure 4b indicates that in the zones with high precipitation concentration, the *CI* values tend to increase at a significance level of 95% for five stations, including the one in Nechmaya. However, a significant downward

trend is seen mainly in four stations that are dominated by low *CI* values: one example is the station in Ain Kerma, although 14 stations have no statistically significant trend. This last observation is quoted by GHENIM and MEGNOUNIF [2016]. It is due to the significant irregularity of rainfall in northern Algeria.

#### SPATIAL VARIABILITY AND TRENDS OF MONTHLY PRECIPITATION CONCENTRATION

The distribution of the average monthly precipitation concentration index (*PCI*) values for all of the years in the study period (1970–2010), for each of the 23 stations separately, are listed in Table 3. Their spatial distribution is represented in Figure 5a.

The *PCI* distribution is not uniform across the whole of the study region, and the *PCI* values range from 14.86 to 17.86. These results indicate the presence of a moderately seasonal to seasonal precipitation regime, according to the classification by OLIVER [1980]. This seasonality is stronger in the East of the study region (coastal eastern of Constantine catchment areas), especially in the Ain Kerma and Roum Souk, where the *PCI* reaches 17.8 and 17.9 respectively, and in the West of the study region (coastal center of Constantine catchment areas), in particular

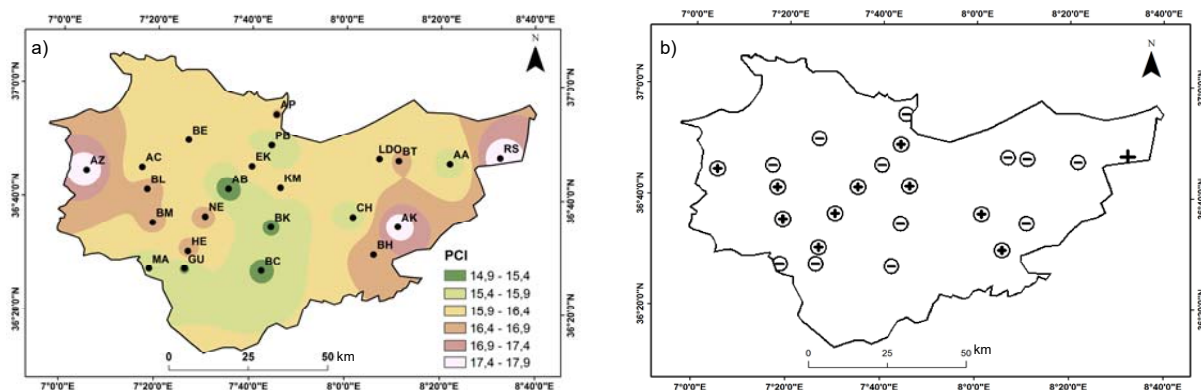


Fig. 5. Spatial distribution in the study region over the period 1970–2010 of the: a) monthly precipitation index (*PCI*), b) *PCI* trends (if the trend is non-significant, the plus or minus signs are circled); station codes as in Tab. 1; source: own study

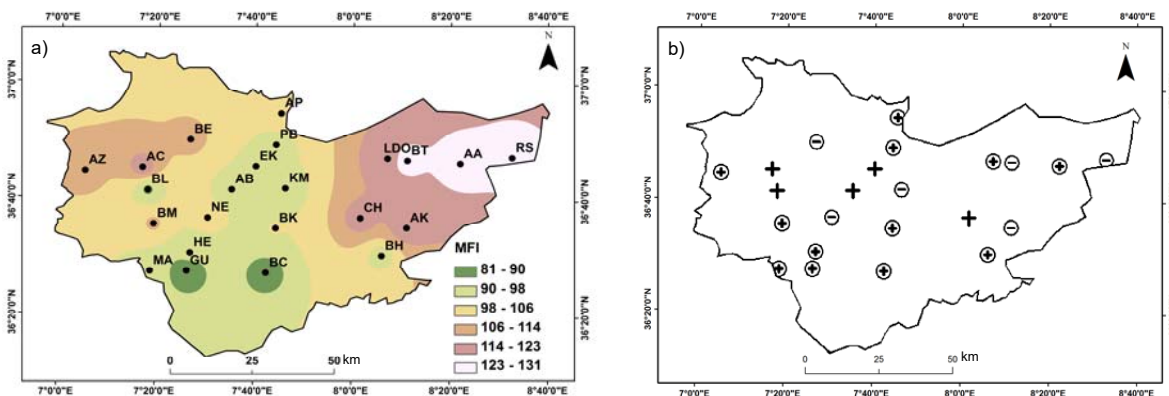


Fig. 6. Spatial distribution in the study region over the period 1970–2010 of the: a) modified Fournier index (*MFI*), b) *MFI* trends (if the trend is non-significant, the plus or minus signs are circled); station codes as in Tab. 1; source: own study



in Azzaba, which has a value of 17.8. In these stations, during the summer period (June, July, August), the *PCI* concentration values are highly irregular. However, the middle of the study region (plains and central Seybouse) corresponds to a moderately seasonal distribution, which indicates that precipitation is uniformly distributed over several months of the year.

The results of the Mann–Kendall test to the *PCI* values calculated for each station are presented in table 2. From a spatial viewpoint, the *PCI* monthly precipitation concentration trends are distributed heterogeneously in the study region (Fig. 5b). This value is statistically significant at the 95% level only in the station in Roum Souk, which had an increase in MK trend. Of the 22 remaining stations with non-significant trends, 12 stations were negative and 10 positive.

### SPATIAL VARIABILITY AND TRENDS OF AGGRESSIVENESS OF PRECIPITATION

The aggressiveness of precipitation was studied using the modified Fournier index (*MFI*). The results are illustrated in Table 3, with values comprised between 81 and 131. Figure 6 shows the spatial distribution of the *MFI*. High precipitation aggressiveness was detected in the eastern part of the study region. It reached the maximum value in the stations in Ain Assel, Roum Souk and Bouteldja, and in the southern part of the study region (Azzaba, Ain Charchar, Berahal), whereas precipitation aggressiveness was moderate and low in the middle of the study region. This geographical distribution of precipitation erosivity is closely linked to annual precipitation in the study region, which explains the increase of *MFI* in the regions that receive more than 750 mm of precipitation.

Table 2 summarises the results of the Mann–Kendall test on precipitation aggressiveness (*MFI*) and Figure 6b presents the spatial distribution of this test. The trends in precipitation erosivity are upward in five stations marked by heavy precipitation (Ain Charchar, Bekouche Lakhdar, El Kerma, Ain Berda, Cheffia), at a level of 95%, with 12 statistically non-significant positive stations and six non-significant negative stations.

From a regional viewpoint, these results are in agreement with those of MEDDI *et al.* [2014], which analysed 117 stations in northern Algeria during the period 1950–2006. Their study showed that a decrease about 30% of *MFI* in the central and western regions. While, the eastern regions of the North of Algeria have not experienced this decline and characterised by the highest rainfall erosivity.

### RELATIONSHIP BETWEEN INDICES AND ANNUAL PRECIPITATION

In order to study in greater detail the changing characteristics of the precipitation indices, a more detailed analysis was conducted of the linear correlations between the indices (*CI*, *PCI*, *MFI*) and annual

precipitation in the extreme north-east of Algeria over the period 1970–2010.

Figure 7 shows the existence of a negative correlation between the *CI* values and annual precipitation over the study period with a relatively low coefficient of determination. It indicates that the highest *CI* values are those that present low annual precipitation values, and vice versa. This result shows that the con-

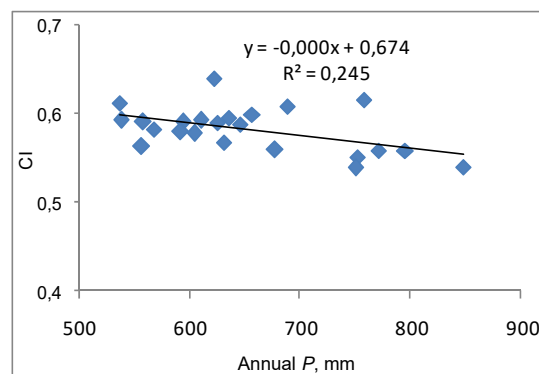


Fig. 7. Relationship between daily precipitation concentration index (*CI*) and average annual precipitation (*P*) in 23 rainfall gauge stations; source: own study

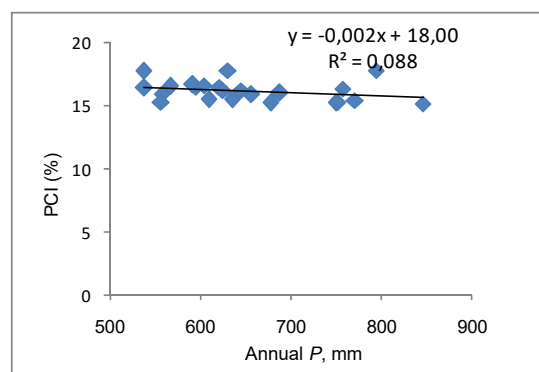


Fig. 8. Relationship between monthly precipitation concentration index (*PCI*) and average annual precipitation (*P*) in 23 rainfall gauge stations; source: own study

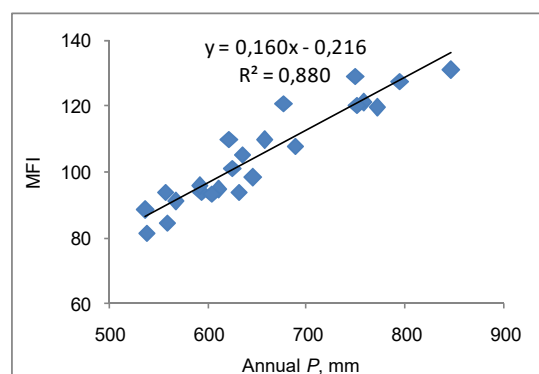


Fig. 9. Relationship between modified Fournier index (*MFI*) and average annual precipitation (*P*) in 23 rainfall gauge stations; source: own study

centration of precipitation on rainiest days is apparently higher in places where annual precipitation is low. This confirms the results of the studies by MARTIN-VIDE [2004] in peninsular Spain, XUEMEI *et al.* [2011] in China, and BENHAMROUCHE *et al.* [2015] in Algeria. Figure 8 presents a non-significant negative correlation ( $R^2 = 0.088$ ) between the *PCI* and average annual precipitation, which shows opposite behaviour between annual precipitation and seasonal precipitation concentration. Consequently, monthly precipitation variability during the year is apparently higher in some places where annual precipitation is low (for example Bouhadjar, Bekouche Lakhdar), whereas significant monthly variability during the year can be found in other places where annual precipitation is high, for example in the eastern part of the study region (Roum Souk). This variability is mainly caused by the irregular distribution of precipitation. While Figure 9 shows a positive significant correlation ( $R^2 = 0.88$ ) between precipitation aggressiveness and annual precipitation, this also implies that precipitation erosivity will increase proportionally with the increase in annual precipitation, and vice versa.

## CONCLUSIONS

The analysis of variability of precipitation concentration of the indices daily precipitation concentration index (*CI*), monthly precipitation concentration index (*PCI*) and modified Fournier index (*MFI*) precipitation aggressiveness and their trends in 23 rain gage stations situated in north-eastern Algeria during the period 1970–2010 is based on the following conclusions:

- The north-eastern Algerian region has presented variability in *CI* values and the results obtained have shown that there are regions where the *CI* values are greater than 0.6, with a percentage of precipitation contributed by the highest quartile of rainy days of around 70% of the amount of total annual precipitation. These zones are those that present low values for annual precipitation and rainy days. The results of the Mann–Kendall (MK) test indicate that the zones with high *CI* precipitation concentration tend to see an increase at the 95% significance level.
- Statistical analysis of the monthly precipitation concentration index (*PC*) indicate that precipitation concentration has seasonal effects in the East and West of the study region, especially during the summer period, and we note a moderately seasonal distribution in the middle of the study region. The results of the MK test are statistically non-significant, except in the single station of Roum Souk, which presents a significant increase in the *PCI*.
- The *MFI* results clearly divide north-eastern Algeria into two parts: the eastern and the western side (eastern and central coastal of Constantine catchment areas) present high precipitation aggressive-

ness, whereas the middle of the study region (plains and central Seybouse catchment) have moderate to low precipitation erosivity. The results of the MK trend indicate that the north-east is dominated by a significant increase in precipitation aggressiveness.

- The results of the correlation between *CI* and annual precipitation are negative, which indicates that low precipitation levels make the highest contribution to the overall irregularity of precipitation. Similarly, variations in *PCI* indicate that the amount of seasonal precipitation does not necessarily follow all annual variations. On the other hand, the *MFI* precipitation aggressiveness is consistent with the amount of annual precipitation, this distribution shows that the *MFI* follows the distribution of annual precipitation, it is high if the amount of precipitation is more than 750 mm in the study region.

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**Przestrzenne zróżnicowanie koncentracji opadów i ich potencjału erozyjnego  
w północno-wschodniej Algierii**

**STRESZCZENIE**

W przedstawionych badaniach analizowano przestrzenną zmienność dobowej i miesięcznej koncentracji opadów i ich potencjału erozyjnego w północno-wschodniej Algierii na podstawie danych z 23 posterunków opadowych z okresu 1970–2010. Trendy analizowano testem Manna–Kendalla. Wyniki wykazały, że wskaźnik dobowej koncentracji opadów ( $CI$ ) był znacząco wyższy w miejscach o niewielkiej całkowitej ilości opadów. Testy Manna–Kendalla dowiodły rosnącej powierzchni obszarów o dużej koncentracji opadów. Sezonowość i potencjał erozyjny opadów były duże we wschodniej i zachodniej części badanego obszaru (wschodnia i centralna, przybrzeżna część zlewni Constantine), podczas gdy umiarkowany rozkład opadów w sezonie i niski potencjał erozyjny były typowe dla środkowej części badanego obszaru (równiny i środkowa część zlewni Seybouse). Modyfikowany wskaźnik Fouriera (potencjał erozyjny) był istotnie skorelowany z wielkością rocznych opadów, natomiast wskaźniki koncentracji dobowych ( $CI$ ) i miesięcznych ( $PCI$ ) opadów wykazywały odwrotną korelację z rocznymi opadami.

**Słowa kluczowe:** potencjał erozyjny, północno-wschodnia Algieria, sezonowość, trendy opadów, wskaźnik koncentracji opadów