Larhyss Journal, ISSN 1112-3680, n°26, Juin 2016, pp. 85-97

SPATIAL DISTRIBUTION AND TEMPORAL TRENDS IN DAILY AND MONTHLY RAINFALL CONCENTRATION INDICES IN KEBIR-RHUMEL WATERSHED

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ABSTRACT

In this study, the spatial and temporal patterns of rainfall concentration on daily and monthly scale were investigated in the Kebir-Rhumel watershed located in the northeast of Algeria. Based daily rainfall dataset between 1968 and 2013 of 20 weather stations, two indices were used in the study: the Precipitation Concentration Index (PCI) and the Concentration Index (CI), for measuring seasonality and daily heterogeneity of rainfall. In addition, the trends of annual rainfall, PCI and CI were tested by the Mann–Kendall method.

The results show a disparity in rainfall amounts between norths sufficiently watered with a significant decrease in southbound. The values of the concentration (for daily and monthly scales) seem generally inversely proportional to the rainfall amounts. The concentration in the watershed is seasonal with a tendency towards the irregularity. The positive trends in annual precipitation, PCI and CI were found in most stations, although the trends were only very little statistically significant.

Key-words: Rainfall, PCI, CI, trend, Kebir-Rhumel, Algeria.

RESUME

Dans cette étude, les configurations spatiales et temporelles de la concentration des précipitations aux échelles quotidienne et mensuelle ont été étudiées dans le bassin versant du Kebir-Rhumel situé dans le nord-est de l'Algérie. Basée sur un ensemble de données des précipitations journalières de 20 stations météorologiques entre 1968 et 2013, deux indices ont été utilisés pour mesurer la saisonnalité et l'hétérogénéité quotidienne de précipitations: l'indice de concentration des précipitations (PCI) et de l'indice de concentration (CI). En outre, les tendances de précipitations annuelles, PCI et CI ont été testées par la méthode de Mann-Kendall.

Les résultats montrent une disparité dans des quantités de précipitations entre le nord suffisamment arrosé avec une diminution significative dans la direction du sud. Les valeurs de la concentration (quotidienne et mensuelle) semblent en général inversement proportionnelles à la quantité de pluie. La concentration dans le bassin versant est saisonnière avec une tendance à l'irrégularité. Les tendances positives des précipitations annuelles, PCI et CI ont été trouvées dans la plupart des stations, même si les tendances étaient très peu statistiquement significatives.

Mots-clés: Précipitations, PCI, CI, tendance, Kebir-Rhumel, Algérie.

INTRODUCTION

For some time, there has been much talk of climate change. The two climatic parameters that change is the most experienced are temperature and rainfall. The latter is of greater variability in time and space, directly affects the natural cycles of water resources and provides information on the state of the climate (IPCC, 2007). The disturbances that have affected rainfall cycles had an impact on the annual amounts, duration of rainfall events, their distribution in the hydrological year and their intensities (Groisman et al., 2005). These anomalies generally result either by drought (Trenberth, 2011) or by flooding (Parajka et al., 2010). These are causing economic and environmental damage and sometimes substantial casualties (Jonkman et al., 2003).

Moreover, in recent decades, extreme rainfall events have increased worldwide (Frich et al., 2002; Westra et al., 2013). Rainfall becomes increasingly concentrated in time. This means that higher percentages of total annual rainfall occurred in some very rainy days where an increase of negative impacts on eco-hydrological processes (IPCC, 2014).

Numerous studies of rainfall variability have been undertaken all over the world using various statistical indices to investigate changes in rainfall patterns and analyze trends in extreme events (Philandras et al., 2011; Del Rio et al., 2011; Coscarelli et al., 2012; Huang et al., 2014; Porto de Carvalho et al., 2014; Yang and Lu, 2015).

Regarding Algeria, although that country suffered a drought in rainfall that lasts since the mid-1970s, the number of searches on rainfall changes, especially changes in the concentration and rainfall aggressiveness remains limited. It is only recently that young researchers are trying to invest in this issue. Thus, we note the work of Hamlaoui Moulay et al (2013), Lazri and Ameur (2014); Meddi et al (2014) and Benhamrouche et al (2015).

STUDY REGION AND DATA

The Kebir-Rhumel watershed with an area of 8811 km^2 is located in the Northeast of Algeria (Fig. 1). Bordering the Mediterranean Sea in the north, it stretches to the northern margins of the Highlands south of Constantine. It is drained by two wadis: the Rhumel and the Kebir whose confluence is in the bowl of Beni Haroun dam (capacity: 960.10^6 m^3). Despite the relief of the watershed is described as moderate, mountainous areas up to 1729m peak altitude. In the region prevails the Mediterranean climate characterized by mild, rainy winter and hot, dry summer. It varies slightly from sub-humid to semi-arid north to south with rich water resources from various origins (rain, hail and snow). In general, the snow appears high up in the high mountains. Rainfall that is the main factor that governs the flow of rivers, have a direct effect on the flow. The inter-annual average rainfall in the watershed of Rhumel-Kebir is estimated between 500-630 mm. This region like the entire Mediterranean basin has a high spatial and temporal climatic variability. Intra-annual rainfall is irregular, most rains fall between October and April, while infrequent and local storms occur in the dry season from July to October. Rainfall is relatively abundant in the north in particular years exceeding 1300 mm/year. They significantly decrease in southbound where average annual values are only 250 mm/year (Fig.1).

Rainfall data were collected by the former of the ANRH, National Agency of the Hydraulic Resources service. Because there were too many gaps post-colonial period in the 60’s and where the number of years of observations was too low for statistical purposes, many station series were discarded from the data set. As a result, only 20 rainfall series were selected (Fig.1).

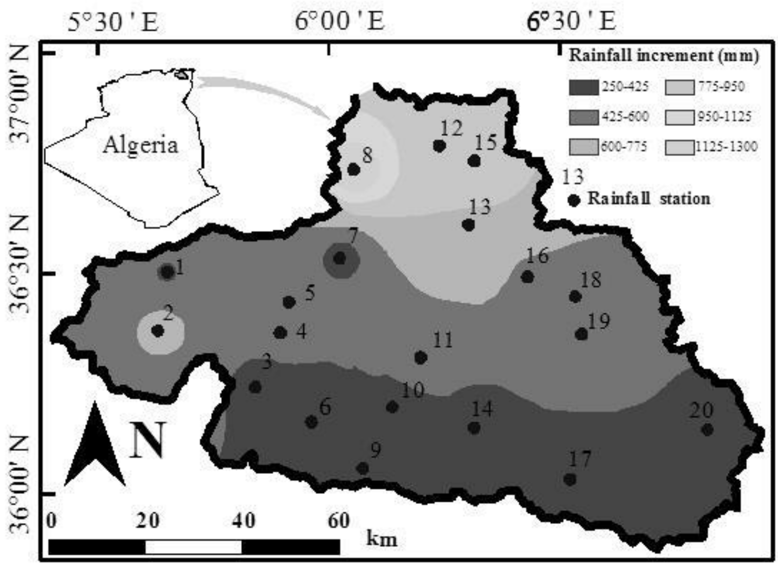

Figure 1 : Location of Kebir-Rhumel watershed in Algeria and meteorological stations used in this study

Table 1 : Basic information of Kebir-Rhumel watershed

N°	Station name	Data series	Coordinates		Average annual rainfall (mm)
			Latitude	Longitude	
1	Beni Aziz	1970-2004	05°39'E	36°28'N	770
2	Chebabta	1971-2013	05°38'E	36°19'N	710
3	Belaa	1970-2011	05°51'E	36°12'N	990
4	Koudiat Tendart	1977-2013	05°55'E	36°19'N	635
5	Ferdjioua	1972-2010	05°57'E	36°24'N	580
6	Tadjenanet	1970-2011	05°59'E	36°07'N	845
7	Mechta Serradj	1970-2011	06°03'E	36°30'N	350
8	Ouled Messaouda	1970-2011	06°05'E	36°43'N	585
9	Ain El Kebch	1972-2001	06°06'E	36°01'N	955
10	Chelghoum Laid	1977-2012	06°10'E	36°10'N	375
11	Boumalek	1970-2011	06°14'E	36°17'N	830
12	El Milia	1969-2010	06°17'E	36°45'N	885
13	Hamala	1970-2001	06°21'E	36°34'N	660
14	Teleghma	1970-2006	06°21'E	36°07'N	750
15	Settara	1970-2011	06°20'E	36°43'N	905
16	El Kheneg	1978-2009	06°29'E	36°28'N	580
17	Fourchi	1970-2010	06°36'E	36°21'N	775
18	Hamma Bouziane	1970-2009	06°35'E	36°25'N	460
19	Constantine	1970-2008	06°21'E	36°24'N	555
20	Ouled Nacer	1968-2010	06°53' E	36°07' N	320

The data collected are a set of daily rainfall series for the period post-1968. They include less than 5% of gaps. These are replaced by the values of the station which has the best correlation. The data were tested for their quality control. The suspect data were cross-checked with those of nearby stations (some are not used in this study). Data were aggregated according to hydrological year from September to August. The selected stations are described by the geographical coordinates, number of years of observation and statistical characteristics (Table 1).

METHODOLOGY

Monthly rainfall heterogeneity was studied using the modified version of the Precipitation Concentration Index developed by Oliver (1980) and modified by De Luis et al. (1997).The PCI of a rainfall year can be derived from monthly rainfall data and calculated using equation (1).

$$PCI = 100.\frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \qquad (1)$$

where P_i is the rainfall amount of the i^{th} month, calculated for each of the rain gauge and for each year within the study period. As described by Oliver (1980), annual PCI values below 10 indicate a uniform monthly rainfall distribution in the year; values from 11 to 15 indicate a moderate rainfall concentration whereas values from 16 to 20 denote irregular distribution. Values above 20 correspond to climates with substantial monthly variability in rainfall amounts.

To evaluate the relative impact of different classes of magnitude of rainfall, especially the contribution of the largest daily event to the total amount, we used the concentration index (CI) proposed by Martin-Vide (2004). The CI is based on the fact that the contribution of daily rainfall events to total amount is generally well described by a negative exponential distribution (Brooks and Carruthers, 1953; Martin-vide, 2004; Zhang et al., 2009). The method consists of aggregating daily precipitation events into increasing (1 by 1mm) categories and determining the relative impact of the different classes by analyzing the relative contribution (as a percentage) of progressively accumulated precipitation, Y , as a function of the accumulated percentage of wet days, X, as defined by the following equations:

$$Y_j = 100.\frac{\sum_{i=1}^{j} P_i}{\sum_{j=1}^{N} P_j}$$

and

$$X_j = 100.\frac{\sum_{i=1}^{j} n_i}{\sum_{j=1}^{N} n_j}$$

where P_i and n_i are the precipitation and the number of wet days (respectively) falling into the i^{th} classe, and N is the total number of classes. These percentages are related to exponential curves (Jolliffe and Hope, 1996). Riehl (1949), Olascoaga (1950) and Martin-Vide (2004) showed that such functions are on the kind:

$$Y = aXe^{bx} \tag{4}$$

where a and b are constants that can be determined by means of the least-squares method in the following equations :

$$\ln a = \frac{\sum X_1^2 \sum \ln Y_1 + \sum X_1 \sum X_1 \ln X_1 - \sum X_1^2 \sum \ln X_1 - \sum X_1 \sum X_1 \ln Y_1}{N \sum X_1^2 - (\sum X_1)^2} \tag{5}$$

$$b = \frac{N \sum X_1 \sum \ln Y_1 + \sum X_1 \sum \ln X_1 - N \sum X_1 \ln X_1 - \sum X_1 \ln Y_1}{N \sum X_1^2 - (\sum X_1)^2} \tag{6}$$

N is the number of classes

The parameters a and b thus defined are used to adjust the empirical couples of values (X_j ,Y_j) defined above and the normalized daily precipitation concentration index can be defined as follows:

$$CI = \frac{S}{5000} \tag{7}$$

where S is the area delimited by the exponential curve, and the li

$$S = \left(\frac{10000}{2}\right) - Z \tag{8}$$

with Z being the definite integral of the exponential curve $aX.e^{bx}$ between 0 and 100 (the range of allowed values for X), i.e. the area under the curve.

$$Z = \left[\frac{a}{b}\, e^{bx}\left(x - \frac{1}{b}\right)\right] \qquad (9)$$

The annual trend of annual rainfall, PCI and CI series was analyzed by using the statistical non-parametric Mann–Kendall test (Mann, 1945; Kendall, 1975). This procedure detects the direction of trend patterns in hydrological variables. For a time series (x_i) of n values, each value x_i is compared with all corresponding x_j to compute the sign, the indices i and j take the respective values i = 1,2,. . . , n-1 and j = i + 1, i + 2, i + 3,. . . ,n. The Kendall's S-statistics is based on the sum and variance computation. In this study, an error risk of 5% is accepted to reject the null hypothesis H_0, that means the trend series is no monotonic against the alternative hypothesis H_1, the trend is monotonic. Thereby, the Mann-Kendall test is expected to be less affected by the outliers because its statistic is based on the sign of differences rather than on the values of the random variable (Helsel and Hirsch, 1992).

RESULTS

Spatial and temporal patterns of annual rainfall, PCI and CI

The mean annual rainfall values range from 250 mm (at Ain El Kebch station,code n°9) in the south of the watershed) to 1300 mm (at Ouled Messaouda station, code n°8) in the north of the watershed. Despite the latter relatively high value, most of the catchment area receives less than 600 mm rainfall (Fig. 1).

The spatial distribution of average PCI in the study period is shown in Fig. 2a. Interannual distribution of rainfall amounts in space and time shows that stations in the study area have concentrations values between 14.25 and 19.20, which denote for the entire region a seasonal rainfall distribution. In six stations, the PCI is less than 15, indicating moderate concentration while for the other stations; the rainfall pattern is rather irregular. The study does not reveal any evidence of stations with very high concentration in the regime, i.e., mean PCI>20. There is a close relationship between amounts of rainfall and concentration of indices. For instance, stations with higher mean rainfall had relatively lower concentration indices and vice versa. Note that the highest value of the PCI (19.20) was recorded in the Ain El Kebch station (code n°9) that accumulates the lowest rainfall value.

Precipitation CI values were estimated for all stations throughout the Kebir-Rhumel watershed during the study period. The spatial distribution of average CI is shown in Fig. 2b. Mean CI values range between 0.482 and 0.640. Only one station (Ferdjioua, code n°5) recorded a mean CI value lower than the threshold of 0.5 while the highest value is recorded at the Ain El Kebch station (code n°9).

By observing the spatial distribution of CI on Kebir-Rhumel watershed (Fig. 2b), the study area can be divided in two parts: over 80% of the catchment area is subjected to a low concentration of 0.50 to 0.575while a small area undergoes a daily rainfall contrast relatively pronounced where daily intensity is critical. In this sitting located south of the basin, CI reached the threshold of 0.65.

Spatial distribution trends in annual rainfall, PCI and CI values

The annual values of rainfall, concentrations PCI at monthly scale and concentrations CI at daily scale have varying temporal trends that can be characterized as spatially heterogeneous between stations (Fig.3). The results show the number of rainfall stations that present trends (positive and negative) for two different significance levels. Annual rainfall in the Kebir-Rhumel watershed experienced an increasing MK trend in 14 of the 20 stations studied. These trends are statistically significant at a 5% level for 1 station (Tadjenanet, code n° 6) and 10% level for 2 stations (Belaa, code 3 and El Kheneg, Code n° 16). The other stations, or 6 out of 20 exhibited a negative trend, statistically significant at a 5% level for only one station (Hamala, code n°13).

For PCI trends, they are statistically significant at a 5% level only for 2 stations (Ferdjioua, code n°5 and Hamala, code n°13 witch experienced respectively a decreasing and an increasing MK trends). On the remaining 18 stations where trends are not significant, 12 were positive and 6 negative. These are located south of the watershed.

The concentration MK trends in daily scale CI are increasing in 15 of 20 stations, of which 12 are statistically not significant. Only Hamala station, code n°13 experienced a trend statistically significant at a 5% level and below, Belaa, code 3 and El Kheneg, code n° 16 at a 10% level.

DISCUSSION AND CONCLUSION

In Algeria, rainfall is low. Nearly 90% of the land area receives annually less than 100 mm. Wetlands receiving more than 900 mm/year occupy only 0.40% of the land area (FAO, 2003). Generally rainfall decreases from east to west and north to south. In this study conducted over 20 rainfall series of the Kebir-Rhumel watershed, the mean annual rainfall varies from 250 to 1300 mm. Over 2/3 of the catchment area receives in mean less than 600 mm of rain. This surface is concentrated in the south of the basin. The highest recorded rainfall within the watershed occurred at Oued Messaouda station (2108 mm) in 1984-85, while the least was recorded at Teleghma station (62 mm) in 1998-99. The rate between the maximum and minimum values of 34 shows the magnitude of the rainfall variability in the watershed. This variability is also found in the spatial and temporal distribution. It is translated by the values of the concentrations recorded. Although seasonality is reflected by the interannual average values (14.25 <PCI <19.20 and 0.482<CI <0.640), the fact remains that for particular years, rainfall distribution is very irregular like the station of Beni Aziz that recorded a PCI of 33.47 and a CI of 0.76 in 1995-96. During this year, rainfall in February reached 52% of the annual total. Overall, the high rainfall areas register concentrations (daily and monthly) relatively low and vice-versa (Li et al., 2011).

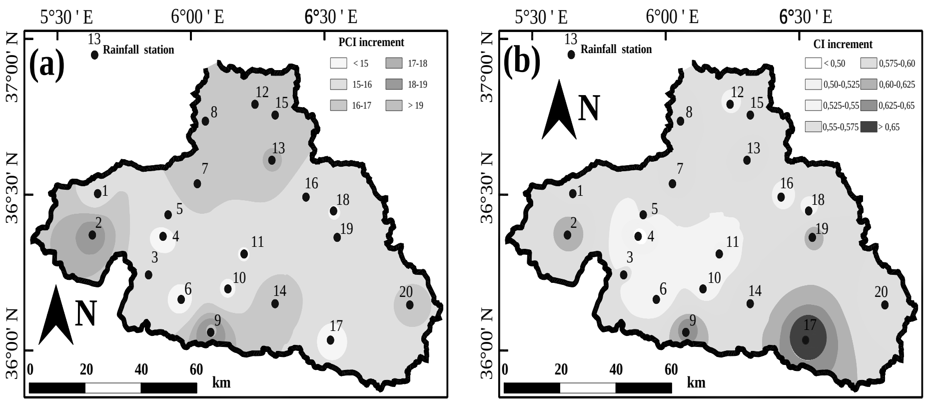

Figure 2 : Spatial distribution of PCI (a) and CI (b) in Kebir-Rhumel watershed, Algeria

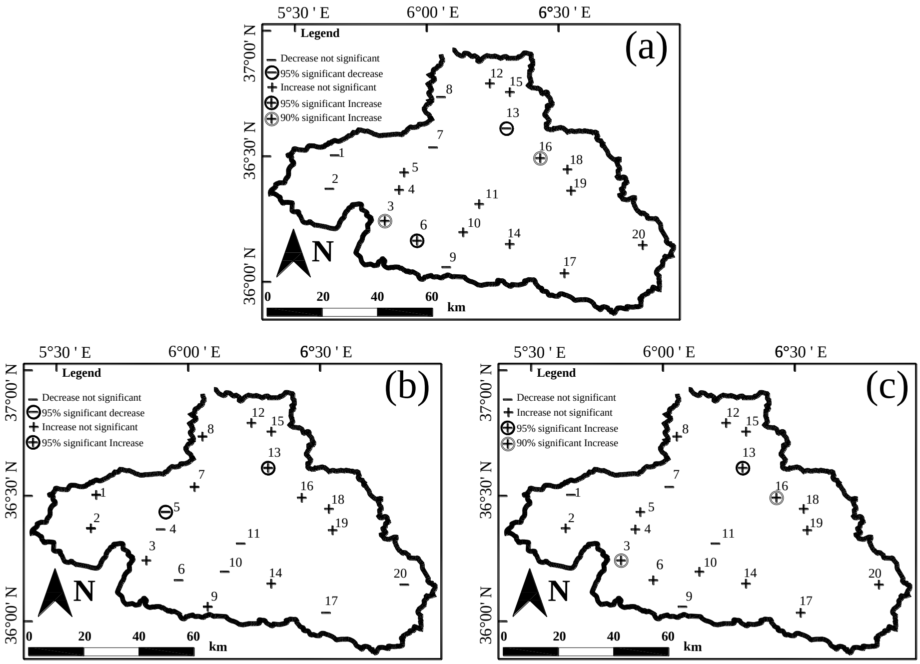

Figure 3 : Spatial distribution for trends of annual rainfall (a), PCI (b) and CI (c) in the Kebir-Rhumel watershed, Algeria

Despite the drop in rainfall announced in recent decades in various regions in Algeria (Ghenim and Megnounif, 2013), 70% of the stations studied in the Kebir-Rhumel watershed show upward trends. The stations with negative trends have their own specificities. Some are located between the mountains or in their southern flank; the others are located at low altitude near river beds. This positive trend is more pronounced in the evolution of CI more than the PCI since the respective percentage of stations having this trend is 80 and 65%.

This appears to contradict the growing evolution of rainfall since the regularity of these is more or less assured by the abundance of rainfall. In fact, the trends as well as concentrations and rainfall are very few statistically significant. The positive trends of rainfall are insignificant. In addition, as a result of climate change, they are the result of brief and intense events. Dry periods thus become longer.

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