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# MULTIDIMENSIONAL ANALYSIS OF PRECIPITATION IN CENTRAL-NORTHERN REGION OF ALGERIA

# ANALYSE MULTIDIMENSIONNELLE DES PRÉCIPITATIONS DANS LA REGION NORD-CENTRE D'ALGÉRIE

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## ABSTRACT

The problems of water quality and quantity have the potential to affect users of the resource at the watershed scale. Watershed management is considered as an effective approach that brings together all water users around the core related issues in order to develop planned and concerted actions in a consensual manner to serve the general interest. In the central region of northern Algeria, there has been a severe and persistent drought in recent years due to a recurring problem, in time and space, of the availability of this resource. The spatial and temporal variability study remains one of the first tools of water resources manager. At the first stage, the study of spatial variability of the average monthly precipitation in central-northern Algeria, by a synthetic visualization of similarities between the response profiles of the seventy measuring stations, highlighted two rainfall gradients: a strong gradient between the northeastern and the southwestern regions of the study area, and a small gradient between regions of low and high altitudes. The link between the variables revealed three synthetic indicators; a big wet season where almost all precipitations are recorded, a short spring and a dry summer. At the second stage of this study, a temporal analysis of annual rainfall series recorded from 11 rain-gauging stations, through trends, ruptures and the standardized precipitation index showed a trend towards precipitation decrease over the whole study area with an average of 20% over the observation period 1910-2010. The analysis of the standardized rainfall index shows that the drought that rages on this region of Algeria is a consequence of the rate of years with mildly dry which is 44% and that of severe dry represent 9%. The persistence and severity of the drought in recent years in the study area is reflected in the increase in the rates of years with mildly dry in the order of 13%, on one hand, and by decreasing year rates of the mildly wet of 12%, 4.5% for the moderate wet, 3% for the very wet and 5% for the extremely wet, on the other hand.

**Keywords:** Spatiotemporal variability, precipitation, response profiles, variables links, dry, Algeria.

## RESUME

Les problèmes de qualité et de quantité de l'eau peuvent affecter les utilisateurs de la ressource à l'échelle du bassin versant. La gestion des bassins versants est considérée comme une démarche efficace qui fédère tous les usagers de l'eau autour des enjeux qui y sont liés afin de développer des actions planifiées et concertées de manière consensuelle au service de l'intérêt général. Dans la région centrale du nord de l'Algérie, il y a eu une sécheresse sévère et persistante ces dernières années en raison d'un problème récurrent, dans le temps et dans l'espace, de la disponibilité de cette ressource. L'étude de la variabilité spatiale et temporelle reste l'un des premiers outils des gestionnaires des ressources en eau. Dans un premier temps, l'étude de la variabilité spatiale des précipitations mensuelles moyennes dans le nord-centre de l'Algérie, par une visualisation synthétique des ressemblances entre les profils de réponse de soixante-dix stations de mesure, a mis en évidence deux gradients pluviométriques : un fort gradient entre le nord-est et le sud-ouest de la région d'étude, et un faible gradient entre les régions de basse et haute altitude. La liaison entre les variables a fait apparaître trois indicateurs synthétiques; une grande saison humide où la quasi-totalité des précipitations sont enregistrées, un printemps court et un été sec. Dans un second temps, l'étude temporelle des séries pluviométriques annuelles enregistrées à partir de 11 stations pluviométriques, par le biais des tendances, les ruptures et l'indice pluviométrique standardisé, a montré une tendance à la baisse des précipitations sur l'ensemble de la zone d'étude avec une moyenne de 20% sur la période d'observation 1910-2010. L'analyse de l'indice pluviométrique standardisé montre que la sécheresse qui sévit sur cette région de l'Algérie est une conséquence du taux d'années à faible sécheresse qui est de 44% et celui de sécheresse sévère qui est de 9%. La persistance et la sévérité de la sécheresse ces dernières années sur la région d'étude se traduit par l'augmentation des taux d'années à sécheresse modérée de l'ordre de 13% d'une part, et d'autre part par la diminution des taux d'années légèrement humides (12%), modérément humides (4.5%), très humide (3%) et extrêmement humide (5%).

**Mots clés :** Variabilité spatio-temporelle, précipitations, profils de réponse, liens variables, sec, Algérie.

## INTRODUCTION

Precipitation is the primary source of water supply for streams and ground water recharge, it influences flow variability at different time scales. The drought phenomenon is considered as one of the most critical climatic hazards for many areas of the world including the Mediterranean region. The main impacts of this phenomenon are identified through affecting human activities, controlling the water resource policies, and constraining the economic development of territories (AMS Statement, 2004). Several studies exist in the literature that focus on the drought phenomenon in terms of dry spells found from daily precipitation, frequently utilizing statistical models dependent on Markov chains (Douguedroit, 1980; Berger & Goosens, 1983; Conesa & Martín-Vide, 1993; Gómez Navarro, 1996; Anagnostopoulou *et al.*, 2003). As announced in many researches, the hydrological time series from various regions exhibit critical non-consistency or non-stationarity, because of the climate change impact as well as large-scale of human activities on the systems of water resources. For instance, various recent investigations in the USA have identified some trends in stream flow (Smith & Richman, 1993; Pupacko, 1993; Changnon & Kunkel, 1995; Lettenmaier *et al.*, 1994; Lins & Slack, 1999; Olsen *et al.*, 1999; Douglas *et al.*, 2000). North of Morocco; breaks were detected during the most complete measurement period: 1935-2004. In addition, dry and non-dry years were categorized by applying the Standardized Precipitation Index (SPI). It appears that the break period is recorded between 1968 and 1984. The "eastern region" of study location has experienced the largest reduction in rainfall, or 30% compared to the "Atlantic region" (Sebbar*et al.*, 2011). In Tunisia, the spatial distribution of rainfall is very different from north to south of the country. The cyclonic and durable rains at the north part, for the three winter months, are essential cause of some heavy daily rains, while the short and stormy nature of the autumn and spring rains seems to be the dominant condition in the center and south of the country (Zahar & Laborde, 2007). In northern Algeria, where a Mediterranean-type climate prevails, rainfall is characterized by high spatial and temporal variability. They are also the most highly explanatory factor of the hydrological regimes of rivers (Mebarki, 2003). The regionalization of precipitation reveals three distinct regions characterized by different rainfall patterns, with a similarity between the central and eastern regions. The intensity of average annual rainfall increases in two main directions, from west to east and from south to north. The intra-annual variability of precipitation is greater for coastal stations than that of inland stations. This is due to a clearer distinction between the dry and rainy seasons for coastal stations, while the amplitude of rainfall is lower for the continental stations due to the thunderstorms during summer season (Hassini*et al.*, 2008). In northwestern Algeria, the Tafna watershed at Beni Bahdel, rainfall values have dropped considerably since 1974-1975. This deficiency, estimated by 27% compared to the wet period, leads to a 69% decrease in water flow. On the other hand, it has been established that the dry period is characterized by greater flowability compared to the wet period (NekkacheGhenim *et al*., 2010).

During the last twenty years, Algeria has experienced a severe and persistent drought with a rainfall deficit (Medejerab & Henia, 2011). Studies on annual precipitation variability are very important for any agricultural development project and hydraulic planning. They have also a considerable concern in climate change investigations (Meddi, 2009). Knowledge on evolution and variability of climate in arid and semi-arid regions is required to anticipate the consequences on the habitats and societies of these regions, and thus define policies of sustainable adaptation strategies (Sarr, 2008).

In this study, we focus on the variability of precipitation with respect to space and time in northern central Algeria. For a synthetic visualization of similarities between the rainfall response patterns, seventy gauging stations were used in order to deduce one or more synthetic variables capable of explaining this variability in space. Temporal analysis also focuses on the study of trend and breaks in annual totals in order to characterize rainfall variability over time.

## REGION OF STUDY

The study area covers 38190 km$^2$ in north-central Algeria (Fig.1). It lies between the latitudes **35,8140 N** (35°48’50.4’’N) and **36,9330 N** (36°55’58,8’’N) and the longitudes **2,8380 N** (2°50’16.8’’E) **and 5,08 E** (5°4’48’’E). Geographically, it is constituted by the Tellian Atlas in the northern part, culminating at 2608m in the Djurdjura massif and the Biban chain in the south. The two chains are separated by plains which constitute the most fertile lands of the country.

The climate of the northern Algeria is characterized by cold, wet winters and dry, hot summers, and may be called semi-arid Mediterranean. Winter in North Africa is dominated by polar air masses. Polar low pressure flowing from west to east, of these areas, encounter wetter tropical air masses and thus generate rainfall, often in the form of showers. As summer approaches, the air masses of the Sahara rise to the north and slow down the polar air masses of Europe generating hot summers and dry rare stormy precipitations. The precipitation decreases generally, from north to south and from east to west because of the weakening of cyclone routes (Ghernaout, 2014). Rain showers depend mainly on altitude, latitude and exposure and are highly variable over time.

According to Sogetha-Sogreah (1962), the study region is subject to Tellian Atlas climate, with very rapidly increasing of continentality degrees away from the sea. The average annual temperature decreases from 17°C to 10°C due to orographic effect. The average monthly amplitude increases from 16°C to 20°C from the north to the south of this region, mainly due to the low temperatures observed in winter. White frosts can be observed for 1 to 50 days a year from November to March and the snow persists more than 20 days a year on the heights above 1000 m altitude.

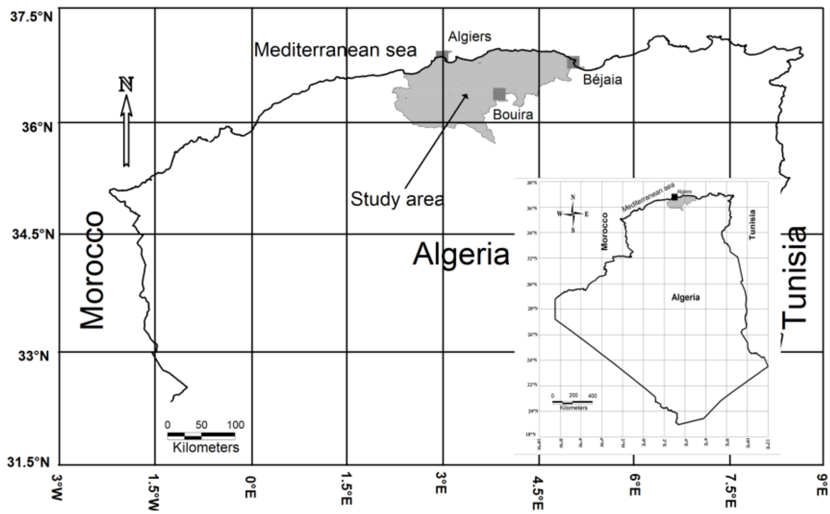


**Figure 1: Location of the study area**

## MATERIALS AND METHOD

Seventy (70) rain gauging stations were selected for this study. These stations are well distributed over the whole of the study region, ranging from 1910/1911 to 2004/2005 for some and from 1968/1969 to 2006/2007 for others. They have some gaps that do not exceed 10% at temporal scale. The observed rain gauging stations are shown in figure 2. For the purposes of the Principal Component Analysis (PCA), the monthly average precipitations (in mm) are considered as the analysis variables, and the seventy (70) rainfall stations are the statistical individuals. The details of the data are presented in table.1.

**Table 1: Characteristics and precipitation data of rain gauging stations (coordinates UTM WGS84).**

*Pmean,an: average annual rainfall (mm), Z(m): altitude of rain gauging stations*

| Stations | Longitude (degrees) | Latitude (degrees) | Z (m) | Observation period | Pmea, an (mm) | *Summer rainfalls (mm)* |
|---|---|---|---|---|---|---|
| 90104 | 3°15'12.4198" E | 36°4'27.9646" N | 750 | 1973-2002 | 348 | 28.63 |
| 90201 | 3°2'1.2977" E | 36°15'50.5047" N | 790 | 1910-1993 | 475 | 20.76 |
| 90202 | 3°10'30.8477" E | 36°23'0.4349" N | 875 | 1969-2004 | 580 | 22.76 |
| 90203 | 3°18'31.2946" E | 36°24'45.3721" N | 450 | 1910-2006 | 485 | 53.73 |
| 90205 | 3°3'55.2492" E | 36°14'53.3777" N | 659 | 1974-2006 | 330 | 17,27 |
| 90208 | 2°54'39.2347" E | 36°8'10.6436" N | 928 | 1910-1993 | 523 | 31.28 |
| 90301 | 3°3'55.2492" E | 36°14'53.3777" N | 659 | 1971-2006 | 501 | 32.84 |
| 90302 | 3°11'41.7349" E | 36°14'4.6495" N | 600 | 1910-2004 | 405 | 31.55 |
| 90303 | 3°21'25.1901" E | 36°23'13.5879" N | 641 | 1910-1993 | 495 | 40.17 |
| 90304 | 3°21'25.1901" E | 36°23'13.5879" N | 370 | 1945-1955/1969-2004 | 486 | 19.86 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 90314 | 3°34'12.2828" E | 36°8'43.7819" N | 850 | 1975-2005 | 441 | 22.17 |
| 90401 | 3°34'44.7894" E | 36°18'27.7552" N | 782 | 1969-2006 | 384 | 12.81 |
| 90402 | 3°38'2.7329" E | 36°23'19.9851" N | 782 | 1969-2004 | 537 | 19.10 |
| 90403 | 3°45'20.5793" E | 36°28'42.5427" N | 520 | 1910-2008 | 657 | 40.44 |
| 90405 | 3°41'4.3806" E | 36°32'10.7909" N | 178 | 1927-1955/1970-1975 | 686 | 14.26 |
| 90406 | 3°29'30.9088" E | 36°33'15.9296" N | 520 | 1969-2008 | 722 | 24.04 |
| 90413 | 3°33'9.1617" E | 36°25'35.2244" N | 831 | 1969-1996 | 524 | 17.10 |
| 90419 | 3°28'54.4126" E | 36°29'24.1274" N | 820 | 1973-2008 | 704 | 23.85 |
| 90502 | 3°35'3.5937" E | 36°37'28.3748" N | 50 | 1986-2008 | 710 | 22.27 |
| 90503 | 3°31'57.3572" E | 36°39'0.5628" N | 425 | 1969-2006 | 739 | 20.74 |
| 90505 | 3°42'40.0099" E | 36°44'34.7860" N | 27 | 1968-1998 | 412 | 24.51 |
| 90506 | 3°46'26.4548" E | 36°35'32.5036" N | 415 | 1968-2008 | 744 | 22.09 |
| 90508 | 3°40'22.7266" E | 36°44'19.6852" N | 29 | 1952-1979 | 744 | 28.13 |
| 90510 | 3°43'3.3264" E | 36°48'37.9721" N | 27 | 1971-1996 | 679 | 23.50 |
| 90512 | 3°41'46.9082" E | 36°38'23.6525" N | 235 | 1973-2008 | 672 | 19.30 |
| 150101 | 3°42'16.4859" E | 36°8'43.2501" N | 882 | 1980-2005 | 430 | 29.77 |
| 150103 | 3°49'2.5830" E | 36°13'20.4193" N | 730 | 1980-2005 | 361 | 22.69 |
| 21112 | 2°50'41.9693" E | 36°15'25.8931" N | 880 | 1979-2005 | 487 | 20.39 |
| 50103 | 3°33'3.9967" E | 36°02'08.2958" N | 830 | 1975-1999 | 297 | 15.87 |
| 11104 | 3°8'56.4441" E | 35°53'25.4707" N | 1250 | 1975-2005 | 306 | 19.33 |
| 11404 | 2°50'51.0277" E | 36°06'53.0910" N | 932 | 1980-2005 | 476 | 25.35 |
| 150204 | 3°54'5.4294" E | 36°22'34.1319" N | 520 | 1913-1992 | 386 | 38.19 |
| 150503 | 4°25'17.8652" E | 36°27'29.8375" N | 280 | 1923-1992 | 456 | 33.38 |
| 1501004 | 4°41'30.2426" E | 36°40'27.1817" N | 100 | 1902-1992 | 705 | 28.95 |
| 20810 | 4°6'2.0889" E | 36°52'53.5647" N | 150 | 1970-1995 | 852 | 26.49 |
| 20902 | 4°26'8.4478" E | 36°44'10.0681" N | 820 | 1935-1954/1968-1995 | 1173 | 33.86 |
| 20909 | 4°29'32.0499" E | 36°44'08.7246" N | 1000 | 1971-1996 | 1190 | 34.9 |
| 21501 | 4°23'7.5825" E | 36°38'22.1086" N | 215 | 1969-1996 | 925 | 31.82 |
| 21503 | 4°17'0.4775" E | 36°41'10.9671" N | 450 | 1969-1996 | 834 | 29.26 |
| 21504 | 4°22'15.4055" E | 36°44'49.0462" N | 430 | 1920-1955/1968-1996 | 956 | 24.26 |
| 21601 | 4°18'25.6358" E | 36°49'49.1040" N | 630 | 1923-1955/1968-1997 | 1060 | 25.82 |
| 21603 | 4°17'12.7002" E | 36°44'36.8910" N | 155 | 1973-1993 | 712 | 20 |
| 21607 | 4°14'45.5784" E | 36°48'04.8721" N | 320 | 1965-1996 | 937 | 19.15 |
| 21701 | 4°5'51.3057" E | 36°33'23.7542" N | 400 | 1971-1996 | 801 | 24.18 |
| 21705 | 4°11'59.0103" E | 36°38'19.5543" N | 1004 | 1916-1962/1967-1996 | 992 | 37.74 |
| 21712 | 4°13'11.4264" E | 36°34'47.6921" N | 760 | 1973-1996 | 827 | 30.6 |
| 21801 | 4°2'23.1116" E | 36°38'18.2022" N | 650 | 1940-1943/1969-1996 | 842 | 27.18 |
| 21804 | 3°58'39.4183" E | 36°44'17.6059" N | 48 | 1971-1996 | 700 | 22.03 |
| 21805 | 4°4'11.0356" E | 36°47'09.2241" N | 470 | 1971-1996 | 820 | 29.96 |
| 21901 | 3°57'8.0616" E | 36°31'0.2019" N | 350 | 1968-1996 | 726 | 28.57 |
| 21902 | 3°49'52.9479" E | 36°32'19.1419" N | 450 | 1970-1996 | 691 | 21.85 |
| 21903 | 3°57'17.7843" E | 36°32'45.5788" N | 250 | 1946-1949/1968-1996 | 755 | 29.33 |
| 21905 | 3°53'39.7641" E | 36°34'4.0567" N | 240 | 1970-1996 | 594 | 18.67 |
| 21906 | 3°46'5.0556" E | 36°33'58.5783" N | 570 | 1968-1996 | 748 | 21.76 |
| 21911 | 3°53'28.0802" E | 36°30'4.0095" N | 500 | 1972-1996 | 656 | 23.67 |
| 21918 | 3°54'58.3482" E | 36°40'42.4509" N | 75 | 1972-1994 | 752 | 16.81 |
| 22002 | 3°51'18.0710" E | 36°49'2.7434" N | 30 | 1968-1996 | 772 | 25.34 |
| 22005 | 3°48'28.0944" E | 36°48'30.2568" N | 250 | 1969-1996 | 780 | 24.23 |
| 20502 | 2°57'54.5119" E | 36°44'3.5100" N | 250 | 1971-1993 | 678 | 25.69 |
| 20509 | 3°2'44.9912" E | 36°44'49.8289" N | 140 | 1951-2010 | 756 | 25.39 |
| 20511 | 2°53'15.9837" E | 36°41'38.0066" N | 150 | 1952-2007 | 638 | 20.92 |
| 21201 | 2°48'31.7395" E | 36°39'39.9116" N | 10 | 1958-2007 | 540 | 17.97 |
| 21233 | 2°46'2.6278" E | 36°38'4.2909" N | 125 | 1981-2007 | 586 | 13.80 |
| 21407 | 2°56'47.3330" E | 36°40'34.3489" N | 170 | 1952-1959/1969-2007 | 587 | 17.75 |
| 20602 | 3°21'7.6621" E | 36°36'25.5380" N | 130 | 1906-2005 | 777 | 24.46 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 20603 | 3°22'54.0981" E | 36°35'58.9891" N | 475 | 1969-1994 | 728 | 32.15 |
| 20604 | 3°28'50.6089" E | 36°36'30.9069" N | 630 | 1968-1994 | 741 | 22.66 |
| 20607 | 3°19'46.4766" E | 36°39'11.4715" N | 62 | 1952-1962/1970-2005 | 676 | 28.70 |
| 20627 | 3°17'19.2475" E | 36°38'41.3844" N | 67 | 1973-2005 | 600 | 14.98 |
| 20632 | 3°19'46.4766" E | 36°39'11.4715" N | 62 | 1972-2005 | 614 | 19.07 |

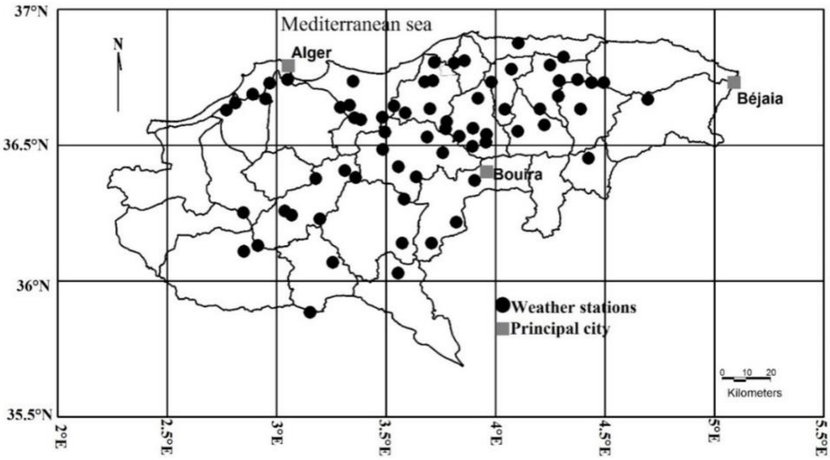


**Figure 2: Location of rainfall gauging stations.**

For spatial analysis, the PCA is a data analysis technique particularly suitable for the study of rainfall patterns. It allows viewing the information contained in a table of quantitative data and concentrate information in a small number of new variables (return to a space of reduced dimension by minimally deforming reality). Therefore, this method is suitable to obtain the most possible relevant summary of initial data due to the application of variance - covariance matrix (or that of correlations) that allows for this relevant summary, as we mainly analyze the dispersion of the considered data. From this matrix, factors (principal components) that are sought, are extracted by proper mathematical process (Davis, 1984; Ghernaout & Remini, 2018). These factors allow to perform and interpret the desired graphics in this low-dimensional space (the number of selected factors), the least distorting the overall configuration of individuals according to the set of initial variables (so replaced by factors). In spite of requiring a bit more calculations, this method is applied using available data of monthly precipitation by forming under "R" software an initial rectangular matrix with monthly rainfall values of the seventy (70) rain gauging stations on row and on column the twelve (12) months of observations. The steps of the principal component analysis are:

- Creation of the raw data matrix;
- Calculation of statistical parameters;
- Transformation of raw data to reduce centred data;
- Determination of the correlation matrix of the reduced centred data;

- Determination of the eigen values, percentages of explained variance;
- Determination of eigen vectors;
- Determination of the principal components (factors) PC;
- Determination of the correlation matrix (factors - variables);
- Links study between axes and variables (average monthly precipitation).

The PCA is combined with the hierarchical classification (by k-mean) for identification of homogeneous regions in term of rainfall regimes that can be summarized as follows (Arthur &Vassilvitskii, 2009):

- Choose K object thus forming K clusters;
- Re(assign) each object (O) to cluster Ci of center of gravity Mi such that the distance to the center of gravity is minimal d(O, Mi) = min;
- Recalculate Mi of each cluster (the center of gravity);
- Go to the step two if you have just made an assignment.

In temporal analysis, numerous techniques are employed for change-point investigation, the non-parametric techniques (Servat et al., 1997), the fuzzy based technique(Yu et al., 2001) and a wide range of Bayesian methods (Chernoff & Zacks, 1963; Lee & Heghinian, 1977; Berger, 1985; Paturel et al., 1997; Perreault et al., 1999, 2000a,b).

The Kendall testis used to analyze patterns in annual precipitation series (Yue & Wang, 2004). The test of significance depends on the accompanying formula:

$$Z_{\tau} = \tau\sqrt{\frac{9n(n-1)}{2(2n+5)}} \tag{1}$$

The null hypothesis is not accepted at significance level áif $|z_{\text{ô}}| > z_{\text{á}}/2$, with $z_{\text{á}}/2$ is the critical value. On account of a upward trend, the null hypothesis (ô = 0) is not accepted when the auxiliary variable $z_{\text{ô}}$is higher than the threshold value $z_{\text{á}}$ ($z_{\text{ô}} > z_{\text{á}}$). $z_{\text{ô}}$ is smaller than $|z\alpha|$ in case of a significant downward trend ($z_{\text{ô}} <$ -zá).

It is hypothesized that the rainfall time series contain an sudden change that partitions the time series in two sub-periods. The Pettitt change point technique which is non-parametric derived from the Mann-Whitney test is utilized to test forth occurrence of the sudden change; it is especially helpful when there is no hypothesis for the location of the change point (Tarhule & KoWoo, 1998). The absence of rupture in the series ($x_i$) with a size N constitutes a null hypothesis (Pettitt, 1978). Applying the test suggests that for an instant t comprised between 1 and N, the time series ($x_i$-$x_j$), i = 1 to t and j=t + 1 to N, belong to the same population. The tested variable is the maximum of the absolute value of the variable $U_{t,N}$ characterized by:

$$U_{t,N} = \sum_{i=1}^{t}\sum_{j=t+1}^{N} D_{ij} \tag{2}$$

With:

$$D_{ij} = \operatorname{sgn}\left(x_i - x_j\right)$$
$$sng\left(x\right) = 1 \text{ if } x > 0$$
$$sng\left(x\right) = 0 \text{ if } x = 0$$
$$sng\left(x\right) = -1 \text{ if } x < 0$$

The most noteworthy change point can be detected at time t where $\left|U_{t,N}\right|$ is greatest. The estimated significance probability p(t) for a change point (Pettitt, 1979; Kiely, 1999) can be expressed as:

$$p\left(t\right) = 1 - e^{\frac{-6U_t^2}{N^3+N^2}} \tag{3}$$

The change point is critical at time t with a significance level of α when the probability p(t) surpasses(1-α). The study of drought and its persistence in time can be approached by the Standardized Precipitation Index (SPI), computed using the accompanying formula (McKee, 1993):

$$SPI = \frac{X_i - X_m}{S_i} \tag{4}$$

With $X_i$ is the total precipitation of the year i; $X_m$ and $S_i$ are, respectively, the mean and the standard deviation of annual precipitation for a given series of data. The calculation of this index allows identification of drought severity considering different classes. This classification is given in table 2.

**Table 2**: **Drought classification by SPI value (McKee, 1993)**

| SPI | Class |
|---|---|
| >2 | Extremely wet |
| 1.50 to 1.49 | Very wet |
| 1.0 to 1.49 | Moderately wet |
| 0 to 0.99 | Mildly wet |
| 0 to -0.99 | Mildly dry |
| -1.00 to -1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2 or less | Extremely dry |

The drought events in every class and drought attribute such as duration (D) and drought magnitude (DM) is given by:

$$DM = -\sum_{i=1}^{D} SPI_i \tag{5}$$

Thus, each drought class can be depicted utilizing two characteristics: drought duration (D) and drought magnitude (DM).

## RESULTS AND DISCUSSION

### Spatial variability

The PCA is a descriptive method that aims to produce the essential information contained in a quantitative data table in graphical shapes. The search for the axis, such that the sum of the squares of the distances of "n" points to this axis is minimal or that the sum of the squares of the projections of the points on this axis is maximum, is achieved by calculating the first axis (principal component 1) (Duband, 1982). We used this method of data analysis to highlight the similarities between statistical individuals (rain gauging stations) in terms of rainfall profile as well as the link between variables (average monthly precipitations). A summary of the basic statistics of active observations is given in table.3.

**Table 3: Basic statistics of active observations (average monthly precipitations)**

| | *Min (mm)* | *Median (mm)* | *Mean (mm)* | *Max (mm)* |
|---|---|---|---|---|
| September | 12.93 | 30.66 | 31.67 | 54.49 |
| October | 23.92 | 57.72 | 57.76 | 102.28 |
| November | 27.95 | 84.47 | 78.85 | 129.59 |
| December | 38.41 | 106.89 | 105.63 | 222.10 |
| January | 9.81 | 92.47 | 91.89 | 173.56 |
| February | 28.41 | 85.95 | 82.29 | 174.89 |
| March | 23.39 | 74.36 | 75.11 | 157.03 |
| April | 26.65 | 62.91 | 65.60 | 121.52 |
| May | 20.88 | 40.48 | 41.86 | 69.57 |
| June | 5.93 | 12.27 | 13.02 | 30.20 |
| July | 0.990 | 4.325 | 4.601 | 16.540 |
| August | 2.300 | 7.395 | 7.499 | 14.400 |

The PCA software is performed under “R” by the package FactoMiner. The projection results of rainfall data on the factorial axis PC1 and PC2 are shown in figure 3. The contribution of the individuals (rain gauging stations) to the formation of the first PC is illustrated in figure 4. The results of PCA indicate that the first and second PC explains 64.51% and 15.88% of the variance respectively. Three main groups of stations are distinguished in this study area; the first is located in the northeastern zone with a high annual rainfall of 890 mm, the second is in the southwestern with a low annual rainfall of 445mm, while the third is located between the two mentioned groups with an annual rainfall 687 mm.

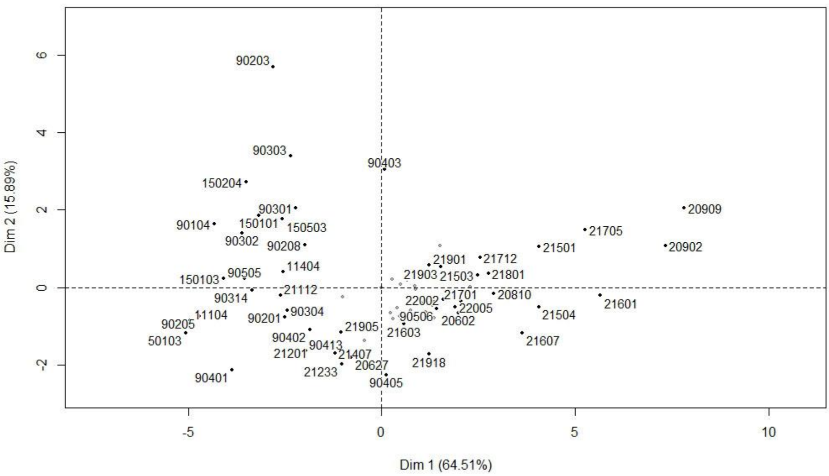


**Figure 3: Variables projection (rain gauging stations) on PC1 and PC2**

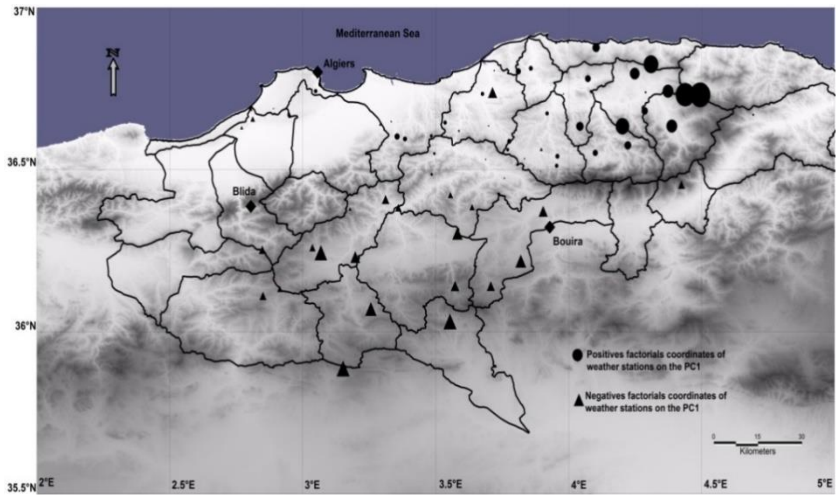


**Figure 4: Contribution of rain gauging stations to the formation of PC1**

Analysis of the source database is required to explain the significance of the two axes. We notice a high correlation between average annual precipitation and the coordinates of the first axis where $R^2$= 0.996 as shown in figure 5, the annual rainfall varies between 300 and 1190 mm recorded at 50103 and 20909 rain gauging stations, respectively.

The northern and northeastern zones receive more annual rainfall than the southern and southeastern ones. This direction represents the first synthetic variable that explains 64.51 % of the variance.

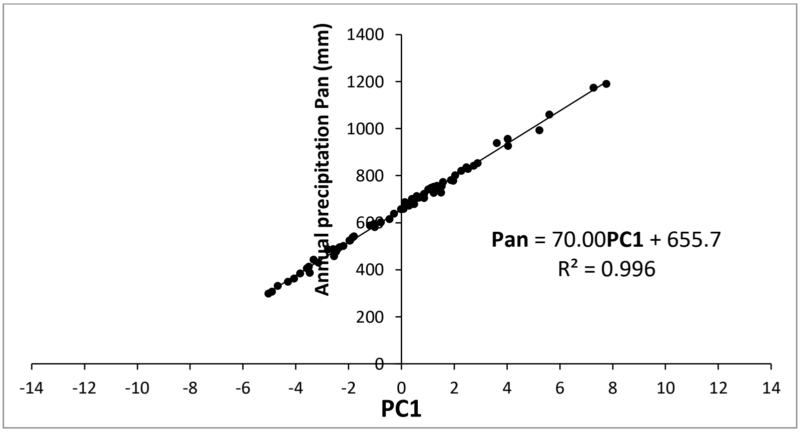


**Figure 5: Correlation between average annual precipitation and PC1**

The first axis of the multidimensional analysis shows that the northern regions of the study area receive more rain than the southern ones. Similarly, the regions that are exposed to the northwestern and northeastern fluxes receive more rain than the regions with south-facing aspect. The eight months period from September to May records 85% of total rainfall, with a maximum of 55% of the total annual precipitation registered during the four months period from December to March.

The results show a strong north-south precipitation gradient, which reflects the particular topography of the study area. It is worth mentioning that the massifs of Djurdjura and Chrea that lie from east to west play a role of mask towards the atmospheric flux that comes from the north. Hence, the regions that are located in the south of this topographic barrier receive less precipitation that the ones that are located in the northern side. The difference in average inter-annual precipitation between these two regions is important considering the short distances between them. The northern region receives an average annual precipitation of 650 mm; the southern one receives only 400 mm.

Regarding the second synthetic variable, as shown in figure 6, a very significant correlation is observed between the contribution of rainfall stations for PC2 and summer precipitation (from June to August). The high-altitude stations and those exposed to the North stream receive an average of 31.5 mm during the summer. The other stations receive an average of 20 mm over the same observation period. This axis therefore, presents the second synthetic variable explaining only 16% of the rainfall variability.

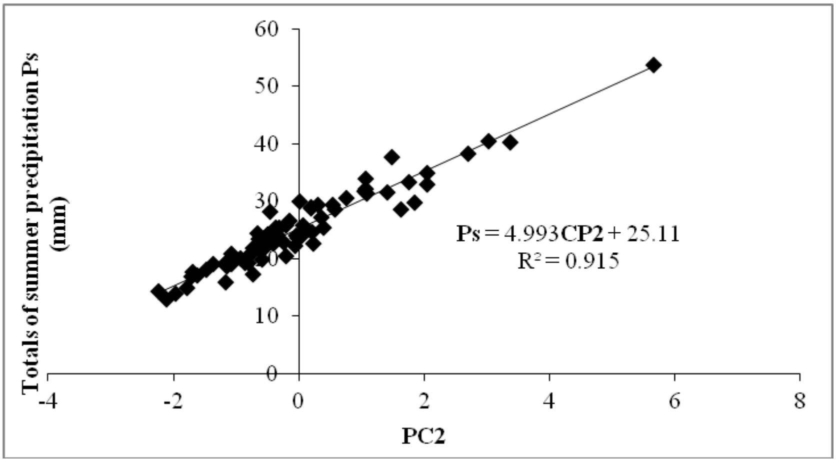


**Figure 6: Correlation between totals of summer precipitation and PC2**

The projection of the variables on the two main axes (figure 7) shows a grouping of the variables from September to May around the first factorial axis. Their correlation coefficients exceed 0.7. Thus, this group forms the great wet season, where most (86%) of the precipitation is recorded, and then there is a dropout of the other months (from June to August) which constitute the dry season.

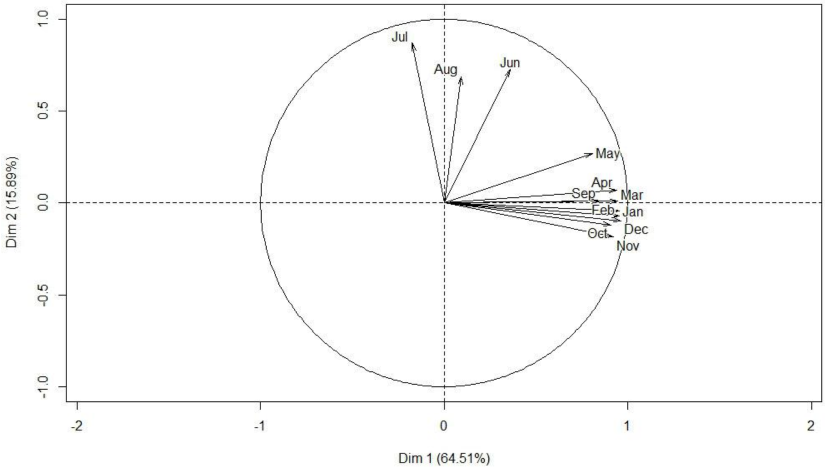


**Figure 7: Projection of variables (months) on PC1 (Dim1) and PC2 (Dim2)**

The Hierarchical classification by K-mean allowed us to identify two main groups of homogeneous regions in term of rainfall regimes (figure 8) that categorizes a group with almost all stations north and northeast of the study area, and a second group south of the study area.

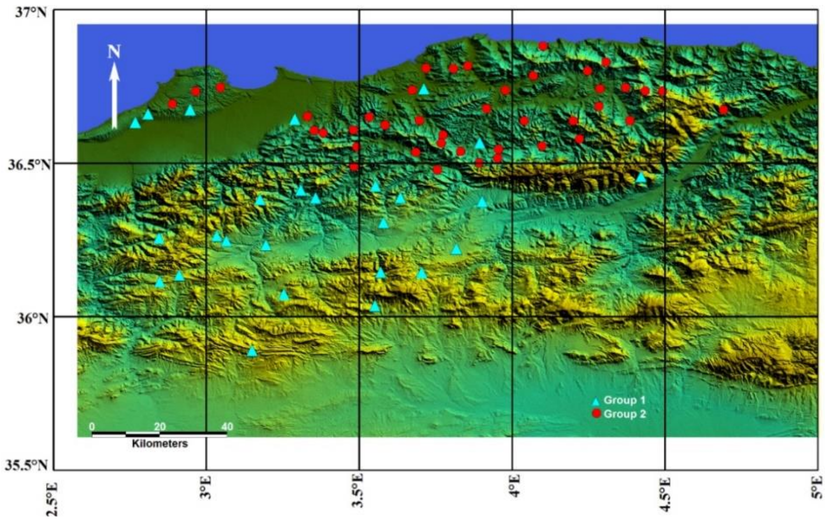


**Figure 8: Groups of homogeneous regions in term of rainfall regimes**

The global test of the study area is divided into two sub-regions (two groups) as shown in table 4. The correlation report between the quantitative variables (which are the monthly average of precipitation) and the class variable are significant as the P-values are below the 5% threshold. The most representative stations of the two groups are given in table 5. We retain station 90304 as representative of group 1 and station 22005 as representative of group 2. The most remote stations of the groups1 and 2 are categorized separately in table 6.

**Table 4: The division of global test results**

| | Correlation ratios | P-value |
|---|---|---|
| December | 0.61 | 1.50E-15 |
| November | 0.60 | 5.37E-15 |
| February | 0.59 | 5.96E-15 |
| March | 0.59 | 1.27E-14 |
| October | 0.57 | 4.53E-14 |
| January | 0.56 | 8.78E-14 |
| April | 0.53 | 8.14E-13 |
| September | 0.52 | 2.28E-12 |
| May | 0.35 | 7.51E-08 |
| Jun | 0.07 | 2.54E-02 |
| July | 0.06 | 3.64E-02 |

**Table 5: Representative stations of both groups 1 and 2**

| Group 1 | Val | Group 2 | Val |
|---|---|---|---|
| 90304 | 1.139645 | 22005 | 0.8209006 |
| 90505 | 1.307620 | 21903 | 0.8740582 |
| 90314 | 1.314922 | 22002 | 1.2210115 |
| 21112 | 1.428946 | 90506 | 1.2215282 |
| 90201 | 1.434425 | 21503 | 1.2541921 |

**Table 6: Most remote stations for both groups 1 and 2**

| Group 1 | Val | Val | Group 2 |
|---|---|---|---|
| 90203 | 8.430338 | 20909 | 10.929427 |
| 50103 | 7.094334 | 20902 | 10.136201 |
| 11104 | 6.954588 | 21601 | 8.487604 |
| 90205 | 6.644159 | 21705 | 8.377425 |
| 90104 | 6.516155 | 21501 | 6.957172 |

## Trends of drought characteristics

This study collected long-term annual precipitation records, and station information of the study area, only 11 stations of the investigated stations have complete high-quality records. Table 7 lists the rainfall stations and their characteristics. In general, the study area shows a trend towards decreased precipitation rates. A detailed statistical analysis on annual precipitation at all rainfall gauging stations allowed determining the years of rupture of the 11 listed stations. As shown in table 8, we point out three main rupture periods: The year 1938, around the year 1959, and 1971 with a high significance level. However, only three series of annual total present ruptures during the year 1970.

**Table 7: Characteristics and statistics of the rainfall stations**

| Station | SC | RY | Lre (years) | SA (m) | Pan (mm) | CV |
|---|---|---|---|---|---|---|
| MAHELMA FERME | 20511 | 1950-2010 | 61 | 150 | 641.69 | 0.27 |
| HAMIZ BARRAGE | 20602 | 1906-2002 | 96 | 130 | 773.23 | 0.27 |
| ZAIANE EL ESNAM | 150204 | 1913-1992 | 79 | 520 | 385.54 | 0.28 |
| AKBOU | 150503 | 1923-1992 | 70 | 280 | 456.35 | 0.22 |
| EL KASER | 1501004 | 1902-1992 | 91 | 100 | 705.3 | 0.3 |
| EL OMARIA | 90201 | 1910-1998 | 90 | 790 | 477.81 | 0.38 |
| BERROUAGHIA | 90208 | 1910-1993 | 83 | 928 | 549.62 | 0.25 |
| BENI SLIMANE | 90302 | 1910-2005 | 96 | 600 | 401.9 | 0.25 |
| BIR RHABALOU | 90303 | 1910-1993 | 84 | 641 | 495.23 | 0.24 |
| DJEBAHIA | 90403 | 1910-2008 | 99 | 520 | 657.35 | 0.3 |
| LAKHDARIA | 90417 | 1910-1993 | 84 | 820 | 760.24 | 0.27 |

*SC: Stations codes, RY: Records years, Lre: Length records, SA: Station Altitude, Pan: Mean annual precipitation, CV: Coefficient of variation*

**Table 8: Rupture periods and trend (*PCP: Pettitt change point, RD: Rainfall deficit)***

| Stations | Z τ | - Z α | P-value % (bilateral) | Trend | PCP | P-value % | RD % |
|---|---|---|---|---|---|---|---|
| 20511 | -1.69 | -0.57 | 9.17% | Negativetrend (non-significant) | 1984 | 4.98 | 15.46 |
| 20602 | -2.61 | -0.73 | 0.91% | Negative trend | 1971 | 0.39 | 19.49 |
| 150204 | **0.22** | **-0.66** | **82.57%** | NO trend | 1926 | 73.43 | ***** |
| 150503 | -2.57 | -0.61 | 1.03% | Negative trend | 1973 | 1.76 | 16.01 |
| 1501004 | -5.32 | -0.70 | 0.01% | Negative trend | 1959 | 0.01 | 27.87 |
| 90201 | -2.85 | -0.69 | 0.44% | Negative trend | 1960 | 0.61 | 23.63 |
| 90208 | -1.69 | -0.67 | **9.14%** | Negative trend (non-significant) | 1970 | **9.51** | 30.30 |
| 90302 | -3.10 | -0.72 | 0.20% | Negative trend | 1938 | 0.43 | 19.06 |
| 90303 | -3.38 | -0.67 | 0.07% | Negative trend | 1952 | 0.23 | 16.21 |
| 90403 | -3.49 | -0.73 | 0.05%. | Negative trend | 1938 | 0.01 | 25.17 |
| 90417 | -3.11 | -0.67 | 0.19% | Negative trend | 1938 | 1.08 | 17.27 |

We notice a trend towards decreasing in annual precipitation. This negative trend is significant for 9stations (P=5%). This trend was not highly significant for MAHELMA FERME (20511) and BEROUAGHIA (90208) stations, with 640 and 540 mm of average annual precipitation, respectively (P>0.05). ZAIANE EL ESNAM (150204) station, which presents the lowest average annual precipitation (385 mm), does not show any trend because of the drought conditions prevailing in this area. The station 150204 (3°54'5.4294"E, 36°22'34.1319"N) placed on 520 m altitude, has a low annual rainfall of 385 mm, similar to two other stations 150103 (3°49'2.5830"E, 36°13'20.4193"N) and 150101 (3°42'16.4859"E, 36°8'43.2501"N) located in the same area, having elevations of 730 m and 882 m, and 361 mm and 430 mm of average annual rainfall, respectively. The altitude effect clearly appears here; the three stations are situated in the south (behind) of Mount Djurdjuraa with a height of 2308 m. In Algeria, it rains every time polar air penetrates on altitude (Pedelabord & Delannoy, 1958).All the rainfall gauging stations that recorded a trend towards a decrease in precipitation present ruptures. Consequently, in contrast to the stations recording 400 mm of an annual precipitation, the stations that present annual totals exceeding 600 mm present a strong tendency towards a decrease in precipitation.

We notice a tendency towards 20% decrease of precipitation over the whole study area. Trend in this region can be divided into two main groups. In southern (group I), the durations of mild, moderate, severe and extreme droughts increase. Trend in northern of the study area, group II (20511, 20620, 1501004,150503 and 90208), where the durations of mild drought decrease, while the durations of moderate, severe and extreme droughts increase.

In table 9, the standardized precipitation index shows a situation dominated by moderate drought. All measuring stations have an average of 44% of years period of moderate drought. The highest rate (54%) is recorded at the Akbou depicted Station (150503). As for the rate of severe drought and high humidity; they respectively are 11% and 13%. The rate of years with extreme humidity is higher than that of years with extreme drought in all the measuring stations.

On all measuring stations, the average rate of years with mildly dry drought is 44%, while the rate of years with mildly wet is 27.20 %. Table 10 shows that three durations are longer than 9 years and having a drought magnitude greater than 7.18. The calculation results for drought, before and after the year of rupture for annual precipitation recorded at eight stations are illustrated in figure 9.

**Table 9: Frequency of years according to SPI classes**

| | 90201 | 90208 | 90302 | 90303 | 90403 | 90417 | 20602 | 205011 | 150204 | 150503 | 1501004 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of years | 90 | 83 | 96 | 84 | 99 | 84 | 97 | 61 | 80 | 70 | 91 |
| N EW | 7 | 3 | 3 | 2 | 4 | 3 | 6 | 2 | 1 | 3 | 3 |
| NVW | 2 | 4 | 4 | 4 | 3 | 5 | 2 | 3 | 4 | 3 | 8 |
| NMW | 11 | 11 | 9 | 6 | 9 | 9 | 5 | 3 | 8 | 4 | 4 |
| NMIW | 30 | 18 | 26 | 23 | 26 | 19 | 28 | 17 | 25 | 17 | 26 |
| N MID | 37 | 39 | 39 | 37 | 43 | 36 | 41 | 29 | 31 | 38 | 34 |
| NMD | 2 | 5 | 12 | 8 | 11 | 7 | 12 | 5 | 8 | 4 | 11 |
| NSD | 0 | 3 | 2 | 4 | 2 | 5 | 1 | 2 | 2 | 1 | 5 |
| NED | 1 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 0 |
| NEW(%) | 7.78 | 3.61 | 3.13 | 2.38 | 4.04 | 3.57 | 6.19 | 3.28 | 1.25 | 4.29 | 3.30 |
| NVW(%) | 2.22 | 4.82 | 4.17 | 4.76 | 3.03 | 5.95 | 2.06 | 4.92 | 5.00 | 4.29 | 8.79 |
| NMW(%) | 12.22 | 13.25 | 9.38 | 7.14 | 9.09 | 10.71 | 5.15 | 4.92 | 10.00 | 5.71 | 4.40 |
| NMIW(%) | 33.33 | 21.69 | 27.08 | 27.38 | 26.26 | 22.62 | 28.87 | 27.87 | 31.25 | 24.29 | 28.57 |
| NMID(%) | 41.11 | 46.99 | 40.63 | 44.05 | 43.43 | 42.86 | 42.27 | 47.54 | 38.75 | 54.29 | 37.36 |
| NMD(%) | 2.22 | 6.02 | 12.50 | 9.52 | 11.11 | 8.33 | 12.37 | 8.20 | 10.00 | 5.71 | 12.09 |
| NSD(%) | 0.00 | 3.61 | 2.08 | 4.76 | 2.02 | 5.95 | 1.03 | 3.28 | 2.50 | 1.43 | 5.49 |
| NED(%) | 1.11 | 0.00 | 1.04 | 0.00 | 1.01 | 0.00 | 2.06 | 0.00 | 1.25 | 0.00 | 0.00 |

***NEW:** number of years with extremely wet; **NVW:** number of years with very wet ; **NMW:** number of years with moderately wet; **NMIW:** number of years with mildly wet; **NMID:** number of years with mildly dry; **NMD:** number of years with moderately dry; **NSD:** number of years with severely dry; **NED:** number of years with extremely dry.*

**Table 10: The most severely dry in the study area**

| Station | Duration (years) | Magnitude | Period |
|---|---|---|---|
| 90202 | 15 | 9.24 | 1980-1994 |
| 90303 | 12 | 8.89 | 1960-1968 |
| 90417 | 11 | 7.99 | 1977-1987 |
| 1501004 | 9 | 7.18 | 1960-1968 |

A more detailed analysis of the rainfall index, compared with the years of breakage of the annual totals of different measuring stations, shows an average increase of 12.5% for mildly dry (MILD), 7.43% for years with moderately dry (MD), 3.69% for years with severely dry (SD), 1.21% for years with extremely dry (ED). The persistence of drought in recent years throughout the study area is reflected in a high rate of years with mildly dry, which is around 44% and 9% for a moderately dry. On the whole region, there is an overall trend towards increasing the frequency, duration and magnitude of different drought classes. An observation on all measuring stations indicates that climatic crises are the result of cumulative years of mildly, moderate and severely dry than years of extreme dry. However, there is a decrease in the rate of years with extreme and mildly wet.

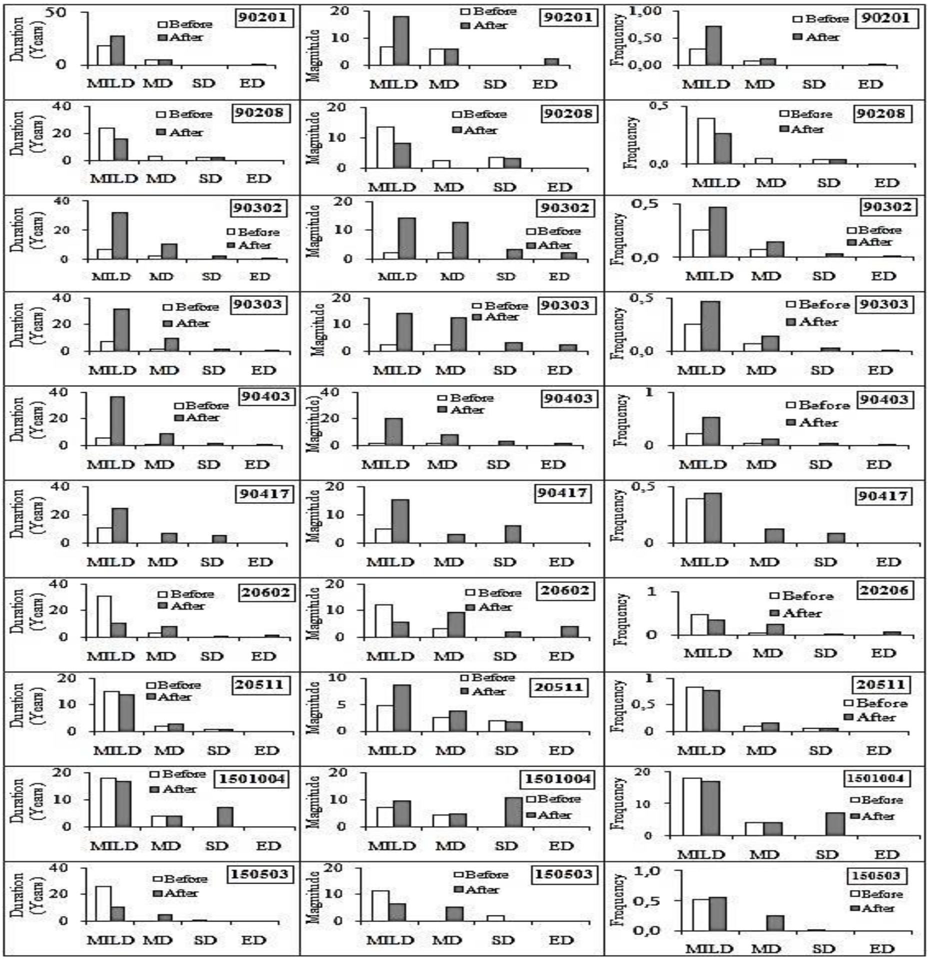

**Figure 9: Trend in the study area**

## CONCLUSIONS

As a conclusion, the study is focused on the variability of precipitation in space and time in central region of northern Algeria. Principal component analysis has proved to be a reliable regionalization tool even though it was applied to a territory showing rather complex physiography and high precipitation variation. The temporal analysis is also focused on the study of trend and breaks in annual totals in order to characterize rainfall variability over time.

It appears from this multidimensional descriptive study that the regions in the north of the study area are more watered than those located in the south, so the regions exposed to the North-West flow and North-East receive more rainfall than those with less exposure because stations in these regions have a good correlation in terms of annual totals with PC1. Most of the precipitations are recorded during the eight months of the year (September to May) when 86% of the precipitation is measured. There is a clear correlation between some variables, which are the average monthly precipitation from December to March (that represents the winter season) with 55% recorded rate of precipitation. A strong North-South precipitation gradient that reflects a particular topography of the study area, in fact the Djurdjura and Chrea (Algiers) mountains that lodge from east to west to the north of the study area, play a role of mask against the North atmospheric flow. As a result, the regions behind this topographic barrier receive less precipitation, and the difference in average inter-annual rainfall between the North, North-East and South regions is considerable, taking into consideration the short distances that separate them. The north region receives an average annual rainfall of 650 mm, while the southern region receives only 400 mm on average. On a seasonal scale, especially in summer, the drops of cold air escaping from the region of low pressure in Island, which often reach Algeria and which proceeds towards the east associated with the region topography, make the summers drier for the regions at lower altitudes and less exposed to this flux from the north than those at higher altitudes and more exposed, the differences in precipitation in summer between these two regions are of the order 12 mm. Three major seasons have emerged from this study, a wet season from September to March and a dry season from June to August (summer), separated by a short intermediate season of two months (spring). The two main dimensions of variability are the inter-annual mean precipitation for the first synthetic variable that is PC1. The very significant correlation of precipitation in summer with PC2, thus this one represents the second synthetic variable.

The correlation analysis between the variables showed a strong seasonality of rainfall. A tendency towards a decrease in annual precipitation reached a mean of 21% for the whole study area. The analysis of the rainfall behavior over the period 1910-1992 reveals two outstanding facts in the precipitation evolution: the year 1938 constitutes a pivotal year in rainfall dynamics and the northern Algeria has experienced a tendency towards dry conditions since 1970, which is worsened during the decade 1990-2000. The PSI values showed that the persistence and the severity of drought during the last decades in the study area was the result of substantial increase in mildly and moderately dry years.

Finally, the alarming results and findings of this study indicate that the semi-drought is reaching wet and sub-humid areas. Hence, adoption of advanced water resources management policies, development of planned modification and adaptation of strategies to deal with this risk is regarded as necessary and urgent actions for the safety of soil, cropland and human activities.

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