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CLIMATIC DROUGHT IN THE SEMI-ARID REGION OF DJELFA –ALGERIA (ANALYSES OF THE RAINFALL DATA FROM 1975 TO 2016)

LA SECHERESSE CLIMATIQUE DANS LA REGION SEMI-ARIDE DE DJELFA-ALGERIE (ANALYSES DES DONNEES DE PRECIPITATIONS DE 1975 A 2016)

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ABSTRACT

In the context of sustainable development and the recent climate warming in the semi-arid region of Djelfa whose vegetal production of pastors depends solely on rainfall, analyses of the rainfall data for the last 42 years were mandatory basing on the coefficient of variation CV, the precipitation concentration index PCI, simple linear regression, Mann Kendall test, Sen's slope and finally the homogeneity tests. As results, a drastic variability was recorded for all the monthly and annual rainfall from year to another with no seasonality; namely a strong hydric stress would threaten plants subsistence and cause summer flood that destroys soil. Moreover, an annual decreasing was due to almost of months decreases particularly winter and spring. However, August, September and October recorded slight increases to let expect an eventual autumnal advance in August instead of September. This goes along with trend results whose the maximal decreasing trend was in November, then January. However, the increasing trend was the most in August, and July had also an increasing trend. In fact, the significant decreases were due in part to the abrupt decreases almost in winter then spring. Under the desertification threat, this drought and the drastic hydric stress make a real challenge to development.

Keywords: Climate change, steppe, Mann Kendall, Sen's slope, homogeneity, Coefficient of variation (CV), Precipitation concentration index (PCI).

RESUME

Dans le contexte de développement durable et le réchauffement climatique récent dans la région semi-aride de Djelfa dont la production végétale des parcours dépend uniquement de la pluie, des analyses des données de précipitation des derniers 42 ans étaient obligatoire en basant sur le coefficient de variation CV, l'indice de concentration des précipitations PCI, la régression linéaire simple, le teste de Mann Kendall, la pente de Sen et finalement les tests d'homogénéité. Comme résultats, une grave variabilité a été enregistrée pour tous les mois ainsi que pour le cumule annuel d'une année à l'autre avec l'absence de la saisonnalité ; ce qui indique un grand stress hydrique qui pourrait menacer la subsistance des plantes et causer les inondations estivales qui détériorent le sol. En outre, une diminution annuelle était due à la majorité des diminutions mensuelles, en particulier l'hiver et l'automne. Cependant, Aout, Septembre et Octobre ont enregistré des faibles hausses de précipitation qui laissent présumer une avancée de l'automne au mois d'Aout au lieu de Septembre, aussi Juillet avait une tendance d'augmentation. En effet, la diminution significative était due en partie à la chute brusque des précipitations généralement en hiver et printemps. Sous la menace de désertification, cette sécheresse et ce grave stress hydrique font un vrai défi au développement.

Mots clés : Changement climatique, steppe, Mann Kendall, pente de Sen, homogénéité, coefficient de variation (CV), indice de concentration des précipitations (PCI).

INTRODUCTION

The remaining need for a further explanation of the strange disappearance of the anciently featuring cold and frost in Djelfa in both December and February despite their temperature decreases found by the author's recent research about Djelfa's climate warming (Boubakeur, 2016; Boubakeur et al., 2017) and its eventual attribution to the lack of rain water (Yen et al.,2015) made a starting point to the analysis of precipitation in this regional scale within the context of the IPCC suggestion that the sub-regional variability in precipitation should be analyzed in depth (M. de Luis et al., 2011).

In fact, Djelfa is a typical pattern of the north African steppe which is of a great importance due its large area about 375000 km2 whose major part is in Algeria (Djebaili et al., 1989), and to its transitional position between humid North, and the huge desert in the South, giving it a strategic place to protect the fertile North from desertification which threatens also the steppe itself (Bensouiah, 2003; Nedjraoui and Bédrani, 2008; Boubakeur, 2016; Boubakeur et al., 2017). Moreover, the steppe belongs to the Mediterranean basin where the global hydrological cycle is dominated by a very high spatial and temporal variability (Lionello et al., 2006; Norrant and Douguedroit, 2006 in M. de Luis et al., 2011). In addition, the fragility and marginality of its lands and pastors in Algeria (Pouget, 1980; Bensouiah, 2003; Boubakeur, 2016; Boubakeur et al., 2017) makes it more vulnerable to the climate changes that can favor the drought which affects the ecosystem vitality (Landmann et al., 2003 and Bréda et al., 2004 in François and Christian, 2005) through affecting nutrient availability and plant growth (Mingzhu and Feike, 2014). Also, Toby et al. (2014) claimed that projected changes in global rainfall patterns will likely alter water supplies and ecosystems in semi-arid regions- during the coming century.

All these facts make the analysis of climatic drought an obligation in a context of sustainable development and rehabilitation of the steppe ecosystem of this semi-arid region of Djelfa.

DJELFA, STUDY AREA

Due to its semi-arid climate characterizing the steppe, its central location and the fact that it is commonly known as the capital of the Algerian steppe

Figure 1: Central position of Djelfa in the band of Algerian steppe
Source: NEDJRAOUI, 2004 IN BOUBAKEUR, 2016

(DPAT, 2004), Djelfa was already chosen as the typical example of the Algerian steppe in the last researches of the author about climate warming (Boubakeur et al, 2017; Boubakeur, 2016; Boubakeur et al., 2014; Boubakeur, 2009).

Djelfa is located a 300 km south far away from the capital of Algeria, in the middle of Algerian steppe which makes a band between the humid fertile North and the huge Algerian desert (Figure 1).

METHODOLOGY AND METHODS

Data source

The precipitations are measured hourly by both the pluviometer and the pluviograph, then monthly averages are calculated. The synoptic meteorological station of Djelfa, the unique available and reliable station in this region, is located in the highest bare hill (1180,5m), outside of the Djelfa's city (figure2), on the latitude 34°,20’ North and longitude 3°,23’East, in the South-East of the city**,** 3213 m far away from the city center (figure2) (Boubakeur et al., 2017; Boubakeur, 2016; Boubakeur et

al., 2014).

Figure 2: The town-outside situation of Djelfa’s meteorological station
Source: Google earth, 2014 in Boubakeur, 2016; Boubakeur et al, 2017.

Methodology

The analyses focused on annual and seasonal change through annual and monthly rainfall values. As a first step, data times series were pre-whitened to eliminate the perturbations that could err the results of further analyses which focused on variation, variability and seasonality, then the trend and value of change, and finally the eventual abrupt change (homogeneity) during the period of 42 years from 1975 to 2016 which exceeds the conventional period of climate study (IPCC, 2001) and covers the period of the study of climate warming in this same region (Boubakeur et al., 2014; Boubakeur, 2016; Boubakeur et al, 2017). Thus, results of both studies can be confronted and conjugated.

Methods

Pre-whitening (ARIMA Model)

ARIMA model purifies the series before any analysis. It is the combination of two models, the autoregressive model (AR) and the model of moving averages (MA) joined to an integration (I). The auto-regressive model eliminates the auto-correlation of the series which are the internal perturbation. The moving average model eliminates the external ones. The integration makes at a certain degree (***d***) these two former models stationary by eliminating trend and seasonality. Accordingly, we almost note $ARIMA_{(p,d,q)}$ (Dominique, 2005).

Coefficient of Variation (CV)

It is the ratio of the standard deviation S to the mean M. (Hervé, 2010) usually expressed in percentage (Equation 1).

$$CV = \frac{S}{M} \quad (1)$$

It expresses the variability of the series values (Oguntunde et al., 2006; Hervé, 2010).

Precipitation concentration index (PCI)

An indicator of rainfall concentration and rainfall erosivity (Oliver, 1980 in Francis and Tsunemi, 2013), assesses also the seasonal and annual regularity of the rainfall by the formulae (2,3 and 4) (Michiels et al., 1992 in Francis and

Tsunemi, 2013; Milan et al., 2016; M. de Luis et al., 2011). The interpretation is done up to table 1.

$$PCI_{seasonal} = 25 * [\sum Pi^2/(\sum Pi)^2] \quad (2)$$
$$PCI_{supra\ seasonal} = 50 * [\sum Pi^2/(\sum Pi)^2] \quad (3)$$
$$PCI_{annual} = 100 * [\sum Pi^2\ / (\sum Pi)^2\ ] \quad (4)$$

Pi = rainfall amount of the ith month; for season scale, winter (D-J-F), spring (M-A-My), summer (Jn-Jl-A), autumn (S-O-N); and on supra-seasonal scales, wet (October to March) and dry (April to September) seasons (M. de Luis et al., 2011).

Table 1: Interpretation of the precipitation concentration index (PCI)

PCI value	Interpretation
<10	Uniform precipitation distribution
11 to 16	Moderate precipitation distribution
16 to 20	Irregular distribution
>20	Strong irregularity of precipitation distribution

Source: Francis and Tsunemi, 2013

Methods of accessing trends and values of variation

a - Simple linear regression and representation by chronologic curves

Jacques et al. (2000) recommended the chronologic curves, for their efficiency showing trend and evaluation of the change rate during the period of study (ΔP) and its significance by regression method (Soltani and Soltani, 2008; Hirsch et al., 1991 in Hossein and P. Hosseinzadeh, 2011).

$$\Delta P = Tg\alpha * \text{study period years number (42 years)} \quad (5)$$

b - Man kendall test

It is a non-parametric test for identifying trends in time series (Khaled H. et al., 1998; Sheng yue et al., 2002; Oguntunde et al., 2006; Hamed, 2009; Drápela and Drápelová, 2011; Hossein and P. Hosseinzadeh, 2011; Milan et al., 2013).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \quad (6)$$

$$\mathrm{Sgn}(xj-xk) = \begin{cases} 1\ if\ (xj - xk) > 0 \\ 0\ if\ (xj - xk) = 0 \\ -1\ if\ (xj - xk) < 0 \end{cases} \quad .(7)$$

Where n is the number of the observations in the studied time series.

In cases where the sample size n>10, the standard normal variable Z is then computed (Equation 8)

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (8)$$

$$VAR(S) = \frac{[n(n-1)(2n+5)-\sum_{t=1}^{m} ti(ti-1)(2t+5)]}{18} \quad (9)$$

With (m) is the number of tied groups (a tied group is a set of sample data having the same value), and (t_i) is the number of data points in the i^{th} group.

While positive values of Z indicate increasing trends, negative values of Z Show decreasing trends. The rate of trend is significantly and clearly given by Kendall's tau (Equation 10) (Kendall, 1938; Kerridge in Mirella, 2006).

Kendall’s tau = [number of concordant pairs – number of disconcordant pairs]/ 0.5n(n-1) (10)

c - Sen's slope estimator

Positive values of the slope show increasing trend (Drápela K., Drápelová I., 2011; Hossein and P. Hosseinzadeh, 2011; Milan et al, 2013). If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non parametric procedure developed by Sen in 1968 (Hossein and Hosseinzadeh, 2011). The slopes of all data pairs are calculated by the equation (11). If there are n values x_j in the time series, we get as many as N = n (n – 1) / 2 slope estimates Q_i . The Sen’s estimator of slope is the median of these N values of Qi (Drápela and Drápelová, 2011).

$$Q_i = \frac{x_{j-}x_k}{j-k}, \qquad i = 1,2, \dots \dots, N \quad (11)$$

Homogeneity Test

It consists on dividing the time series into characteristic sub-series according to change in homogeneity (Nicholson et al., 2000; L’Hote et al., 2002) denoting the abrupt change point inside the time series. We used test of Pettitt, SNHT (Standard Normal Homogeneity Test), Buishand test, and Von Neumann test.

RESULTS AND DISCUSSION

Variabity of Rainfall

The rainfall average was 317, 51 mm/ year. Thereby, this region is still semi-arid and belonging to the steppe whose isohyets are limited between 100 and 400 mm/ year (Le Houérou et al., 1977; Nedjraoui and Bedrani, 2008). Months' averages are very low and very approximate to each other (table 2), therefore, the non-seasonality of the rainfall in Djelfa.

Table 2: Extemes and mean of rainfall values from 1975 to 2016

Months and Annual Average	Minimum	Maximum	Average
January	0,8000	117,0000	30,6975
February	0,3000	74,0000	29,2390
March	1,0000	75,1000	28,1905
April	0,0200	87,0000	29,2895
May	1,4000	122,0000	34,4857
June	0,0000	74,0000	20,0829
July	0,0000	47,0000	11,1243
August	0,3000	77,8000	21,1683
September	0,7000	96,0000	31,9927
October	0,7000	117,0000	26,5762
November	1,0000	80,5000	28,5357
December	2,5000	97,1000	26,1341
Annual average	13,4583	42,5000	26,4791

Furthermore, the extent of variation between the max and the min is very wide for all months to exceed 70 mm and more than 100 mm for the wet seasons autumn and winter (table 02), namely a drastic variation, and variability (figure 03). So a great and remarkable impact on the steppe pastors production in a context of an entire dependency to rainfall (Yan et al. 2015; Hellal et al., 2014).

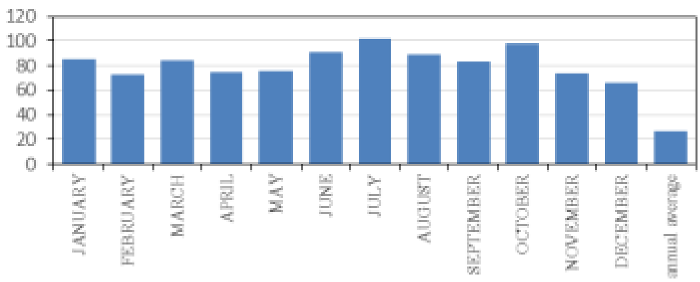


Figure 3: the rain fall variability CV%

The variability of the rainfall from a year to another for all months exceeds 65%, and for the annual average is 26, 61 % (figure 03). As an aberration, the July variability of 101, 7% indicates that standard deviation is greater than the mean of precipitation. Also variability is the highest in summer.

Regularity and seasonality of the rainfall distribution

According to figure 04 interpreted by the table (01), a general moderate precipitation distribution is shown by the annual precipitation concentration index, and tend to the irregularity. However, a Strong irregularity of precipitation distribution was recorded for the year 2000 and 2001, an irregular distribution for 2015, but for 2011and 2016 the precipitation distribution is uniform. So, rainfall distribution during the year is irregular with no seasonality.

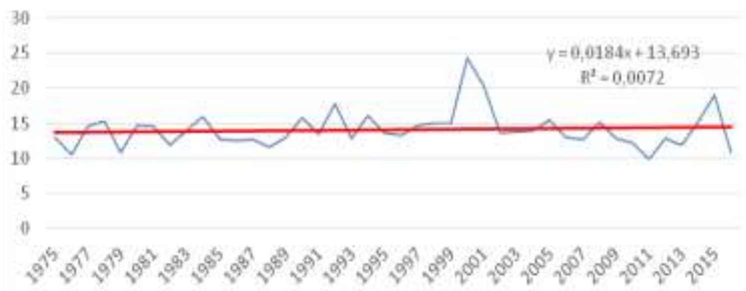


Figure 4: Annual precipitation concentration index (PCI annual)

Trends and values of rainfall variation

Diminution is the general aspect of rainfall evolution during the last forty-two years except for August, September and October. In fact, the high reduction was for the annual cumulative rainfall (figure 05) with a speed of Tg(α)= -2,1938 mm/year, to give then a total diminution ΔP = -92,1438 mm which is of a high influence in terms of plants hydric need and growth, soil nutrient availability (Mingzhu and Feike,2014).

The accentuated fluctuation from a year to another revealed by the CV (Figure 03) is again proved by figure 05. Rainfall amount fell drastically from its maximum 510 mm in 1976 to less than half (272 mm) in the next year, after that to nearly the third 175mm in 1978, and then a sudden increase for the four successive years which are again followed by a decline and so forth (figure 5).

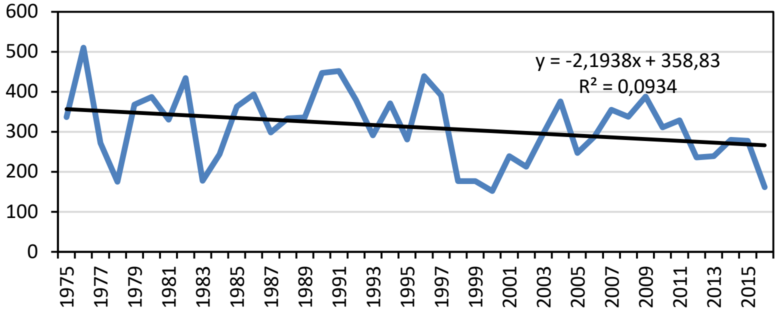


Figure 5: annual cumulative rainfall (mm)

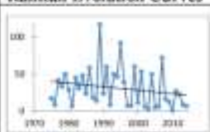
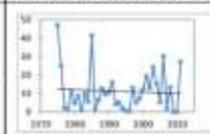
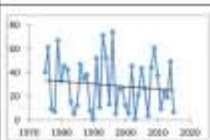
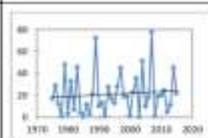
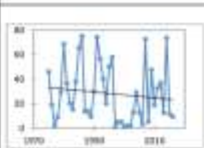
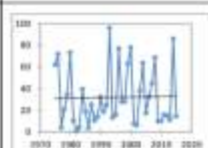
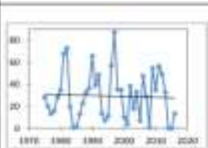
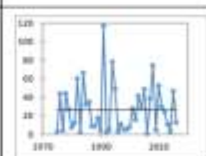
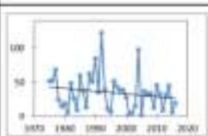
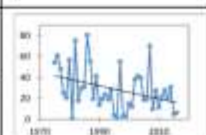
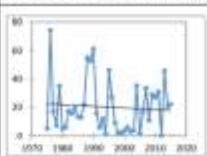
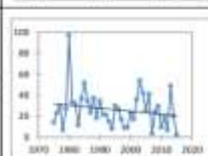
Months	Rainfall Evolution Curves	Months	Rainfall Evolution Curves
January Y= -0,4782X+984,48 R^2=0,045		**July** Y= -0,0685X+147,72 R^2=0,0043	
February Y= -0,2153X+458,75 R^2= 0,0146		**August** Y=0,158X-294,07 R^2= 0,01	
March Y= -0,2411X+509,24 R^2= 0,0154		**September** Y=0,0498X-67,41 R^2= 0,0005	
April Y= -0,0806X+190,11 R^2=0,002		**October** Y=0,0154X- 4,1462 R^2= 0,00005	
May Y= -0,4099X+852,51 R2= 0,0367		**November** Y= -0,6214X+1268,5 R^2= 0,1323	
June Y= -0,1124X+244,23 R^2= 0,0054		**December** Y= -0,2885X+601,73 R^2= 0,0399	

Figure 6: Months' rainfall evolution from 1975 to 2016

This annual diminution is decreasingly due to decreases in November (-26.0988 mm), January (-20.0844 mm) and May (-17.2158 mm), then February, March and December, and finally April, June and July with a slight decrease less than 5mm. Contrarily, an increase was recorded for August (+6.636 mm), September (+2.0916mm) and October (+0.6468mm) (figure 6) (figure 7).

Significant fluctuations were marked by months. Basing on the coefficient of determination (R^2), the maximal fluctuation is in October (R^2 =0.00005) and September (R^2 =0.00005) (figure 6), namely autumn as a critic season for plants is marked by a drastic hydric stress.

For the tendency, P value was greater than Alpha for all months except November and the annual average (Figure 8).

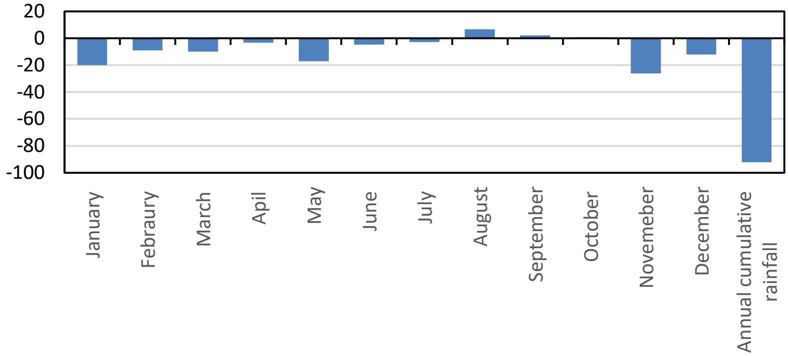


Figure 7: rainfall change during the period 1975 to 2016

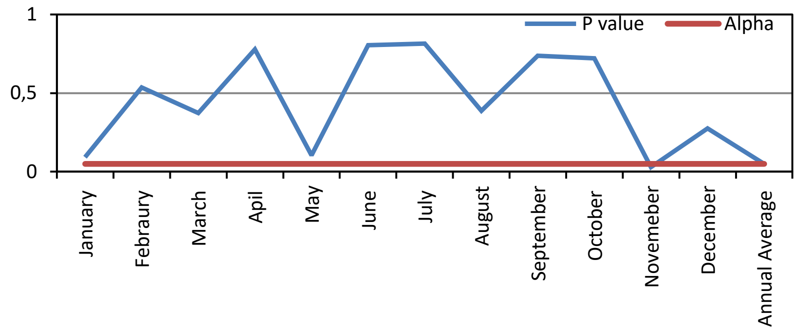


Figure 8: P value and Alpha for revealing tendency

Therefore, there is no tendency except for November and the annual cumulative rainfall which have both a tendency for future decrease from year to another to enforce the drought after an advanced wet autumn that is expected to start in

August to October. Hence, the November's drought interrupts the already started vegetative cycle.

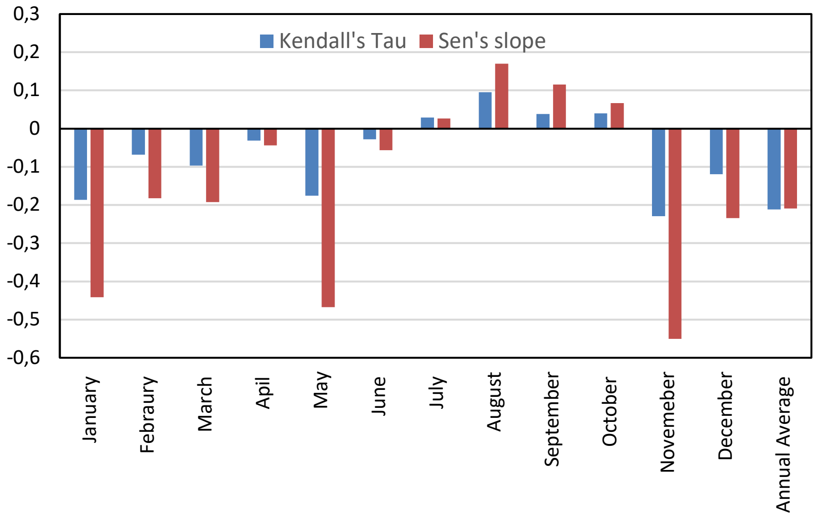


Figure 9: Kendall's tau and Sen's slope

The quasi-resemblance in direction of evolution between figure 07 and figure 9 indicates that change and change trend are compatible. However, despite the decrease, July had an increasing trend, means that despite it had a slight decrease, the increasing pairs were more than decreasing pairs by an amount of Kendall's tau = 2.86% (figure 09), which also can be revealed through the July's curve (figure 06) where ups are more than downs. The sen's slope indicates the same increase with a value of 0.0265 for July, this indicates a supposed increase of ΔP= Sen's * 42years = 1.113 mm for July.

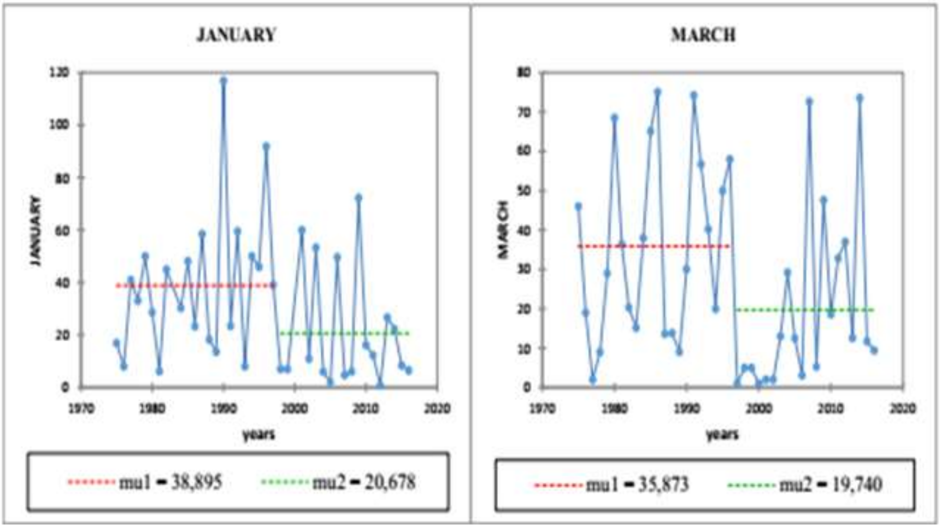
The increasing trend was the highest for august with 9.52 % of kendall tau to mean that increasing pairs exceed decreasing with 9.52 %, then October (3.97%) and September (3.78%) to confirm the advance of autumn to August or probably moreover to July. The Sen's slope goes along with the Kendall's tau to indicate the maximal speed of increase in August (0.1699 mm/ year), then September, October and finally July (Figure 09).

Decreasingly, the decreasing Kendell's tau values were for November, January, and December to give birth to a dry winter-that, hence, would advance to start in November- then May, March and April also February to give place to drought in spring which would threaten the seasonal species and the plants blooming. Also the annual average marked a significant decreasing trend with a Kendall's tau = - 21.15 % (figure 09).

Sen's slope goes a long with the direction of Kendall's tau, hence it had its maximum in November (-0.55 mm/year) to confirm the severe drought of this month that would be the first month of an advanced dry winter whose January is the last moth and marked a speed drying. In second position, May marked a speed drought to express a dry spring and then December, March, February. Finally, April and June.

Abrupt Change of Rainfall

Basing on the homogeneity tests, abrupt decreases were in January, March, November and the annual rainfall values (figure 10). This indicates that the most important decreases were not continuous and they were in a part due to abrupt decreases. The max was in November in 1989 from an average of 41.040 mm to 21.589mm means an abrupt decrease of 19.451mm, and January in 1997 from 38.895mm to 20.678mm means an abrupt decrease of 18.217 mm (figure 10). Therefore the autumn and winter had dried abruptly in ancient time in 1990th. Comparatively, March which indicates spring had dried abruptly in 1996 from 35.873 to 19.740 means an abrupt decrease of 16.133mm. Finally, the annual average decreased abruptly in 1997 from 29.472 mm to 23.378mm with an amount of 6.094 mm.



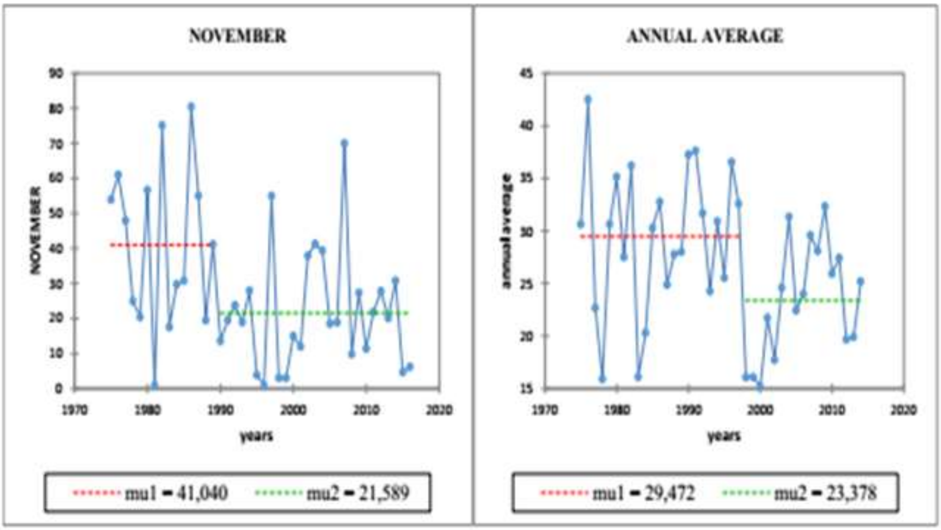


Figure 10: Abrupt changes by homogeity tests from 1975 to 2016

CONCLUSIONS

Djelfa, a typical example of the hyper-sensible semi-arid steppe in Algeria, marked a strange disappearance of the featuring frost and cold despite the cooling of December and February (Boubakeur, 2016; Boubkeur et al., 2017) to give hence an urgent need for the analysis of rainwater availability in a such where rain is the limiting factor of pastors vegetal production and hence decide the persistence and future of this ecosystem already vulnerable and exposed to desertification.

The present research analyzed first the rainfall variability as an important feature of semi-arid climates likely increased by climate changes (Nnyaladzi and Brent, 2010), then regularity and seasonality, variation values, trend and finally the abrupt changes basing on the rainfall data for last 42 years. Therefore, an average of 317.51 mm/ year was found to indicate the semi-arid aspect of this region. A weak monthly rainfall (< 32mm/ month) with a drastic fluctuation and variability from a year to another (extent of variation > 70mm, CV_{annual}=26. 61 % and CV_{months}> 65%) was observed particularly in wet seasons autumn and winter. This hydric stress would threaten the subsistence of both annual and seasonal endemic vegetal species by coincidence of drought or floods to the sensible stages in their life cycles (blooming, germination, hatching, etc.). A maximum variability was in July (CV= 101, 7%) and it is the highest in summer which is the season of soil drought and land bareness; Therefore, this would cause the eventual flood, then soil drifting and many damages that accelerate the desertification of pastors. All this would be forced by the remarkable non-seasonality of rainfall during the year.

Moreover, a general diminution aspect was observed (ΔP_{Annual} =-92. 1438 mm) to explain the strange disappearance of cold and frost in both December and February; on the contrary, IPCC (2007) declared a non-significant decrease since 1950 for global annual land mean precipitation. Exceptional increases were for August (ΔP=+6.636mm), September (ΔP=+2.0916mm) and October (ΔP=+0.6468mm) to indicate an eventual advance of autumn to August particularly before the most significant drought in winter ($\Delta P_{November}$ = -26.0988 mm, $\Delta P_{January}$=-20.0844mm) which could interrupt the started life cycles due to climate warming (Boubakeur, 2016; Boubakeur et al., 2017) especially for annual species. This is not comparative to the IPCC declaration of increasing precipitation since 1901 over the mid-latitude land areas of the Northern Hemisphere (IPCC, 2014). The decreasing tendency was only for November's and the annual rainfall. Unlike July, all months' and annual variations and trends were compatible to have a maximal decreasing trend in November (Kendall's Tau = -22.93%, Sen's slope = -0.55), then January (Kendall's Tau = -18.63%, Sen's slope = -0.4417). However, the increasing trend was the most for August (Kendall's Tau = 9.52 %, Sen's slope = 0.1699). The significant decreases were due in part to the abrupt decreases in 1990th particularly in winter as wet season and spring as a season of blooming. So, this drought is both continuous and abrupt with an aridity context featured by a drastic fluctuation that would affect all the life aspects and soil evolution through mineralization of soil organic matter to diminish its fertility in this vulnerable and hyper-sensible area at the edge of the huge Algerian desert and exposed to desertification.

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