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STUDY OF THE CLIMATE CHANGES IMPACT ON THE SPATIO-TEMPORAL VARIABILITY OF PRECIPITATION IN THE EASTERN PART OF THE SAHARAN ATLAS; CASE OF THE BELEZMA, THE AURES AND NEMEMCHA, AND THEIR BORDERS. GEOMATICS AND GEOSTATISTICAL APPROACH

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Abstract: The survey and the characterization of the climatic variability at the reduced scales prove to be fundamental for understanding the impacts of the climatic changes on the projects of development and the local vulnerability. One of the main contributions of this study is to analyze the spatio-temporal variability of rainfall series in the oriental termination of the Saharan Atlas that integrates three major mountain ranges and their borders to know: The Belezma, the Aures and the Nememchas during 44 years (from 1969 to 2013) with correction methods, rainfall indices, geostatistical analysis and interpolation (inverse Distance weighting). The results show that climate especially show a significant interannual variations in the region of survey between the north slopes area and the South, an alternation of wet and dry periods and a reduction in the values of the rainfall during the last years. Temporal analysis at sites shows that precipitation is stationary in the mountainous regions as stations of Chelia, Yabous, Ain mimoune, Boudella and Ouledchelih, which record maximum values; in contrast the zones of plain stations present minimal values during the study period. The spatial analysis based on interpolation methods revealed variations in rainfall especially during two decades (1989-1998 and 1999-2008) with maximum values. Its variations allow detecting the impact of climate change on all region of study on a latitudinal and altitudinal plan.

Key words: climate change, variability spatio-temporal, massifs, geomatics and geostatistical approach

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INTRODUCTION

The occurrence of climate change can result in important brutal modifications in the climatic patterns (Merf, 2010). In this context, understanding and characterization of the spatio-temporal variability of climate parameters and the trends of their evolution prove to be important for the management and the sustainable protection of the environment (Meddi and Meddi, 2007).

Climate change in recent years has produced in arid semi-arid areas of Algeria, periods of drought, which are characterized by deficient rainfall and very low flows of the river main watershed. During dry periods, surface water resources and, therefore, the stored volumes suffered a sharp decline. It is sometimes difficult to satisfy the demand for drinking water and for that agriculture. To better manage such a situation, knowledge of climate change and its impact on the spatio-temporal variability of precipitation in three major massifs of Belezma, the Aures and Nememechas, and their borders. Through the means of geomatics including digital databases, the volume of generated variables can be analyzed on both spatial and temporal components. In our study area, rainfall has varied considerably over the past decades, especially during the last years provoking some droughts and flooding (case town of Khenchela on 08 June 2015). The occurrence of these extreme events means a likely change in the stationary of the climatic régimes at the local scale. The studies have shown the existence of strong interannual fluctuations of precipitation in mountainous regions and declines in rainfall stations at zones of the plains; especially in the southern region of the study area.

STUDY AREA

The study area is located between 5° 57.8 to 7 ° 15.7 east longitudes and north latitude 35 ° 00.00 to 35 °52.31 north latitude (figure 1), with a surface of 27180 km^2, it is a vast mountainous region of Algeria situated to the east of the Atlas of the Sahara that separates the high plains Constantnoises to the Sahara; it is a distinctly individualized region, it is massively raised above the Quaternary plain of Biskra (Côte, 2003).

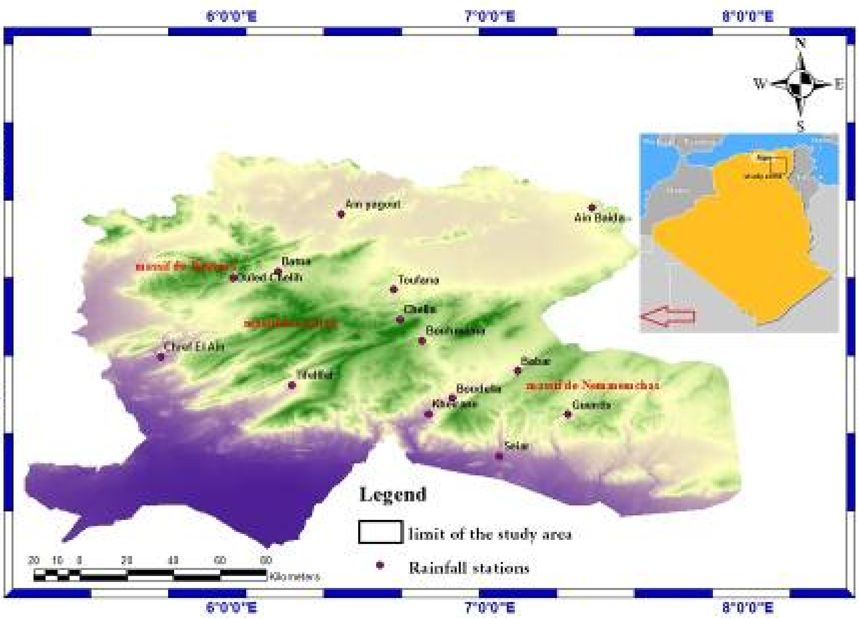

Figure 1. Study area

It contains the three major massifs of Belezma, Nememchas and the Aures with their borders; stands out as a quadrilateral with four angles which are marked by the towns of Khenchela, Batna, Biskra and the Sahara of Nememchas. It is limited at the North by a line drawn from Batna to Khenchela, and to the west by the national street Batna - Biskra (El Kantra), on the south by a line pulled from Biskra to Khanget sidi nadji and the southern limits of Khenchela town, on the east by the Tunisian border coinciding with the periclinal limits of the Nememchas massif. The climate is qualified as semi-arid characterized by a rainy winter, especially in mountainous areas with maximum values of rain between 500-550 mm, which decreases from North to South and may reach 50 mm minimum values. The study area is characterized by geological formations varied from the Triassic to Quaternary.

MATERIALS AND METHOD

Climate data used in this study was collected from the National Agency for water Resources (NAHR) resources, it contains rainfall recorded at 37 pluviometry stations chosen and covering the zone of survey (table1) encompassing a period more 42 years from 1969 to 2013.

These data are fairly homogeneous, a good quality and representative of the study area (figure 2). For modeling cartography the principal tool was used is GIS through the software ARC-GIS 10.1 and for physical parameters (orography, exhibition) the satellite images with average resolution of the 31 North area were exported.

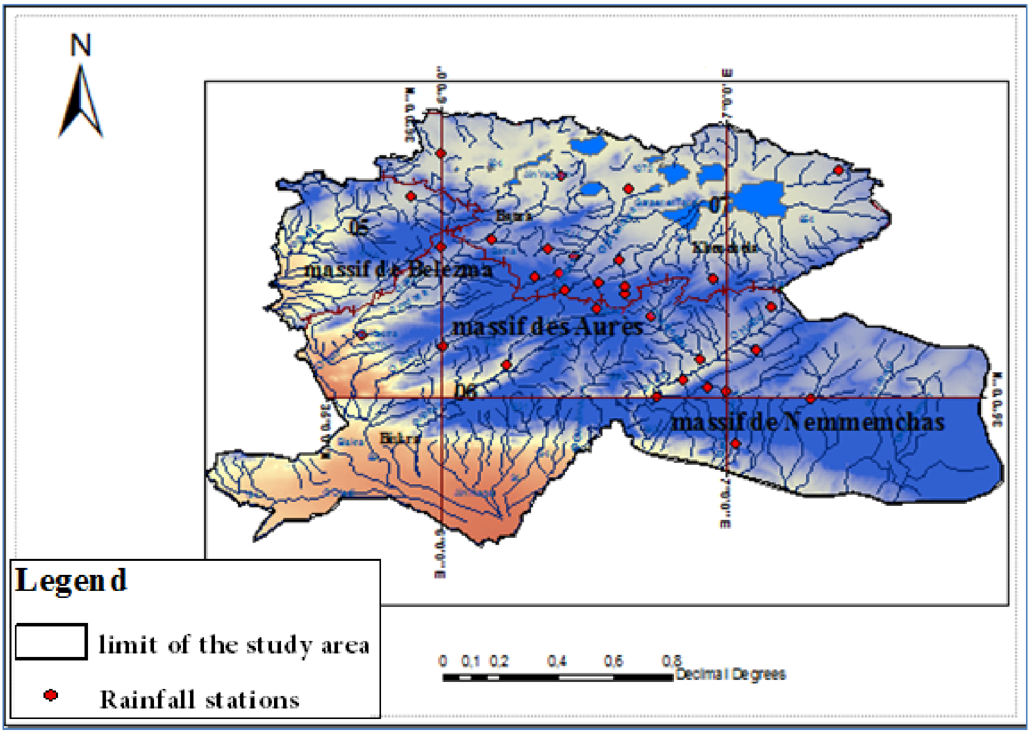

Figure 2. Principal Rainfall Stations

Table 1. Principal characteristics of rainfall stations

Serial N°	name of stations	Latitude	Longitude	Altitude (m)	Period	The annual average of rainfall (mm)
1	Ain Baida	7°23'28"	35°47'49"	1004	1960-2013	384,698113
2	Ain djasser	6°00'53"	35°51'45"	865	1975-2011	297,5
3	Ain Mimoun	6°57'63"	35°25'92"	1180	1970-2005	438,440635
4	Ain Tin	6°26'16"	35°22'53"	1650	1968-2013	430,117043
5	Ain yagout	6°25'53"	35°46'50"	876	1975-2005	326,196666
6	Babar	6°18'49"	35°32'42"	1100	1971-2006	305,223571
7	Baiou	7°06'15"	35°09'39"	1510	1969-2013	353,94
8	Batna	6°19'56"	35°25'49"	1040	1971-2006	366,727778
9	Boudella	6°10'72"	35°34'63"	/	1969-2013	204,26
10	Bouhmama	6°51'11"	35°03'48"	1140	1968-2011	409,631818
11	Bouhmar	6°43'55"	35°17'18"	1275	1968-2011	307,913636
12	Boulhillet	6°32'26"	35°29'36"	859	1968-2013	192,862174
13	Chechar	6°39'57"	35°44'73"	1165	1990-2013	278,416667
14	Chelia	7°00'24"	35°02'25"	1260	1969-2013	453,193333
15	Chref El Ain	6°38'37"	35°22'10"	900	1974-2013	270,105481
16	Djamoura	5°43'19"	35°13'99"	485	1971-2006	143,3
17	Djebel Houara	5°50'57"	35°04'41"	900	1974-2010	330,024324
18	El Mita	5°53'48"	35°42'74"	100	1990-2013	109,955417
19	Fou Toub	6°45'13"	35°11'51"	1160	1969-2013	445,140909
20	Guentis	7°02'55"	34°29'17"	993	1974-2013	224,17
21	Habada	6°25'02"	35°26'19"	1120	1989-2013	289,045833
22	Khanget S Nad	7°18'14"	34°59'36"	/	1967-2013	77,0148936
23	Kheirane	7°09'27"	35°19'20"	560	1969-2013	203,627273
24	KtefEssouda	6°05'32"	35°33'53"	845	1989-2013	191,648
25	Medina	6°41'58"	34°50'13"	1570	1969-2013	441,877778
26	merouana	5°91'	35°63'	1000	1971-2005	322,8
27	Menaa	6°45'53"	34°59'54"	/	1969-2007	241,12162
28	N'Gaous	5°37'97"	35°33'46"	750	1966-2013	246,891667
29	Oued El Ma	6°00'	35°65'	1001	1981-2005	307,8
30	OuledChelih	6°54'51"	35°07'36"	1180	1969-2013	315,63556
31	Seiar	5°55'65"	35°38'64"	450	1969-2013	64,302222
32	Sidi Maancer	6°31'00"	35°19'11"	1112	1969-2013	320,175
33	Tifelffel	6°00'29"	35°10'49"	740	1973-2007	172,34571
34	Timgad	5°37'97"	35°33'46"	1000	1969-2013	280,78478
35	Toufana	6°00'13"	35°39'12"	1040	1967-2013	279,2383
36	Yabous	6°00'44"	35°32'88"	1200	1969-2013	402,34222
37	Zeribet Hamed	6°06'50"	35°36'59"	43	1990-2013	78,7875

Methods

Methods Study of rainfall and climatic variability

The index of Nicholson

For the analysis of the climatic hydro parameters, in order to detect the changes in rainfall regimes, we conducted the calculation of annual averages of precipitation and the index of Nicholson. The survey of the indexes of Nicholson plays a very important role in the determination of seasonal variations. Nicholson et al., (1988) cited by (Paturel et *al*., 1997*)* have defined an index which is calculated every year on the period studied, thus:

$$I_i = \frac{x_i - \bar{x}}{\partial}$$

Where:
I i: rainfall index
Xi: Height of rain of the i year (in mm),
$\bar{x}$: average height of rain over the period of study (in mm),
∂: standard deviation of the height of rain over the study period.

The averages annual precipitations

They determine a centered variable reduced **(**Lamb, 1982; Servat et al., 1998**),** the interannual mean of a series corresponds to the index zero (0) according to the method of Nicholson. A normal period is a period during which a similar fluctuation occurs one part and on the other of the x-axis. In this case, the annual average is substantially equal to the average of total rainfall. During the wet period, the annual average is higher than the average of total rainfall. Finally, the dry period is a period or annual average is less than the total rainfall average.

Study of Rainfall-Altitude

As the spatial distribution of precipitation depends on the environment and topography (Fouchier et al.) and given that the studied territory is complex so the pluviometric gradient became very variable depending on the places (Descroix, 2001; Alexandre et al., 1999**)**. For this reason, we studied the relationship between altitude and the interannual mean of precipitation during the period of study aimed to distinguish the relationship height-rainfall throughout the region, from North to South and from East to West using the software ARC-GIS 10.1 to trace the curve of growth using satellite image and map of interannual rainfall.

Study of spatio-temporal variation in rainfall

Realization of interpolation maps

Inverse Distance weighting (IDW) is a fast and accurate deterministic interpolator. There are very few changes to operate on the parameters of the model. It may be a good way to achieve a first look at an interpolated surface. However, there is no assessment of forecast errors.

The IDW interpolation gives more weight to nearby values than to distant. To predict a value for any location without measure, IDW will use the measured values that surround the location of the prediction. These nearer measured values to the site of the prediction have more influence and carry the predicted values than those most faraway.

Therefore, IDW supposes that every measured point has a local influence that decreases with the distance. It weighs the nearest points in the site of the bigger prediction than those most faraway, from where the name of the inverse weighed distances.

The study of the spatio-temporal variation of rainfall is done using different data of rainfall stations which cover the zone of study, these rainfall stations, are also added to rainfall measures from sensor Meteosat to fill existing gaps. The available data have been classified into four (4) decades (1969-1978; 1979-1988; 1989-1998; 1999-2008), and the last period is 5 years (2009-2013), based on the available data. The resulting database is exported in the ARC-GIS software 10.1 in order to precede to a type (Inverse Distance Weighted) IDW interpolation to generate thematic maps (map of interpolation).

RESULTS AND DISCUSSION

Annual fluctuation of rainfall with the index of Nicholson

The reduction of the number of pluviometry stations from 37 to 10 stations will be necessarily to calculate the index of Nicholson, five on the slopes north of the study area and five on the South side. The selected stations cover well the study area taking into account the differences of altitude and exposure. The Nicholson index values are represented in table 2.

Table 2. Principal characteristics of rainfall stations

Stations	Exposure	Study period	Normal period	Humid period	dry period
Ain Baida	Northeast	1960-2013	1969-1978	1989-2013	1960-1968 1979-1988
Ain Tin	North	1968-2013	1968-1978	1979-1998	1999-2013
Boulhillet	North	1968-2013	/	1989-2008	1968-1988 2009-2013
N'Gaous	Northeast	1966-2013	1966-1978	1999-2013	1979-1998
Yabous	Northeast	1969-2013	/	1969-1978 1989-2013	1979-1988
Bouhmama	South East	1968-2013	1989-1998	1999-2013	1968-1988
Cheref Alain	South West	1974-2013	1989-1998	1999-2013	1974-1988
Gentis	South East	1974-2013	/	1989-2013	1974-1988
OuledChlih	South West	1969-2013	2009-2013	1969-1988	1989-2008
Seiar	South East	1969-2013	/	1969-1978	1979-2013

This work is particularly aimed to characterize the spatio - temporal variability of precipitation, through the analysis of the annual rainfall series provided on the period 1969-2013 and distributed on the survey zone represented by 10 stations in order to determine the impact of climate change during the years of study. Initially, the graphic representation of Nicholson indices of rain permitted to emphasize the succession of periods of dry and wet years. In general, the curves of the moving averages are a good indicator of large interannual fluctuations. Ozer et al., 1995 have identified three distinct periods. For the northern part of the study area (figure 3), the period of 1989 to 2013 is characterized by an overall wet rainfall; the 1979 to 1998 period corresponds to dry a period. Finally, the period from 1969 to 1978 records a normal period. The recent period from 1989 to 2013 is characterized by a stronger Interannual variability than those of the two previous periods. In the southern part (figure 4), the period between 1969 to 1978 is dry, followed by a wet period of 1978 to 1988, the period of 1989 to 1998 period was normal, and then there was the return to the wet period between the years 1999-2013 with a signifiant increase in the values of the rainfall.

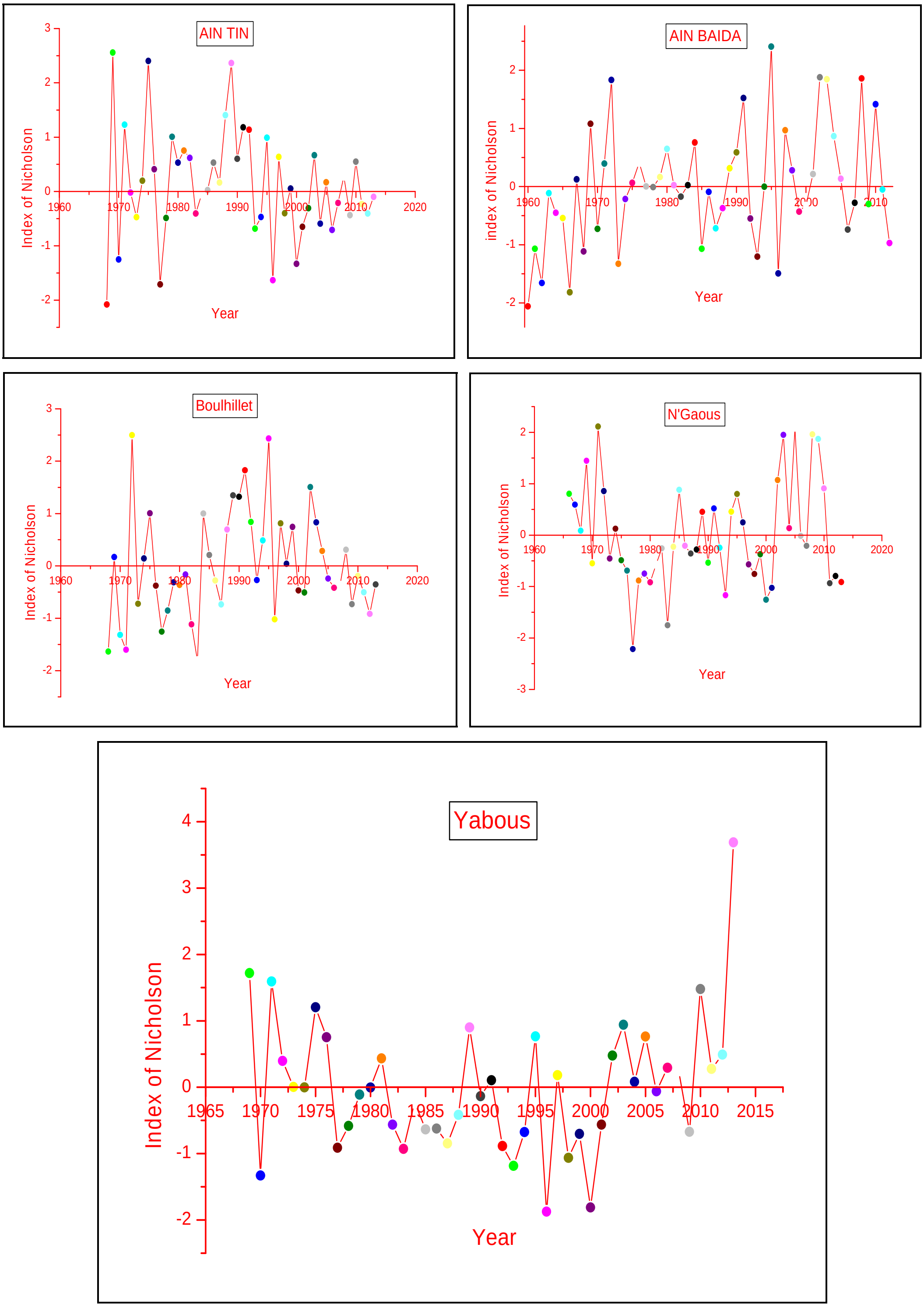

Figure 3. Fluctuations of rainfall by applying index Nicholson (North Stations)

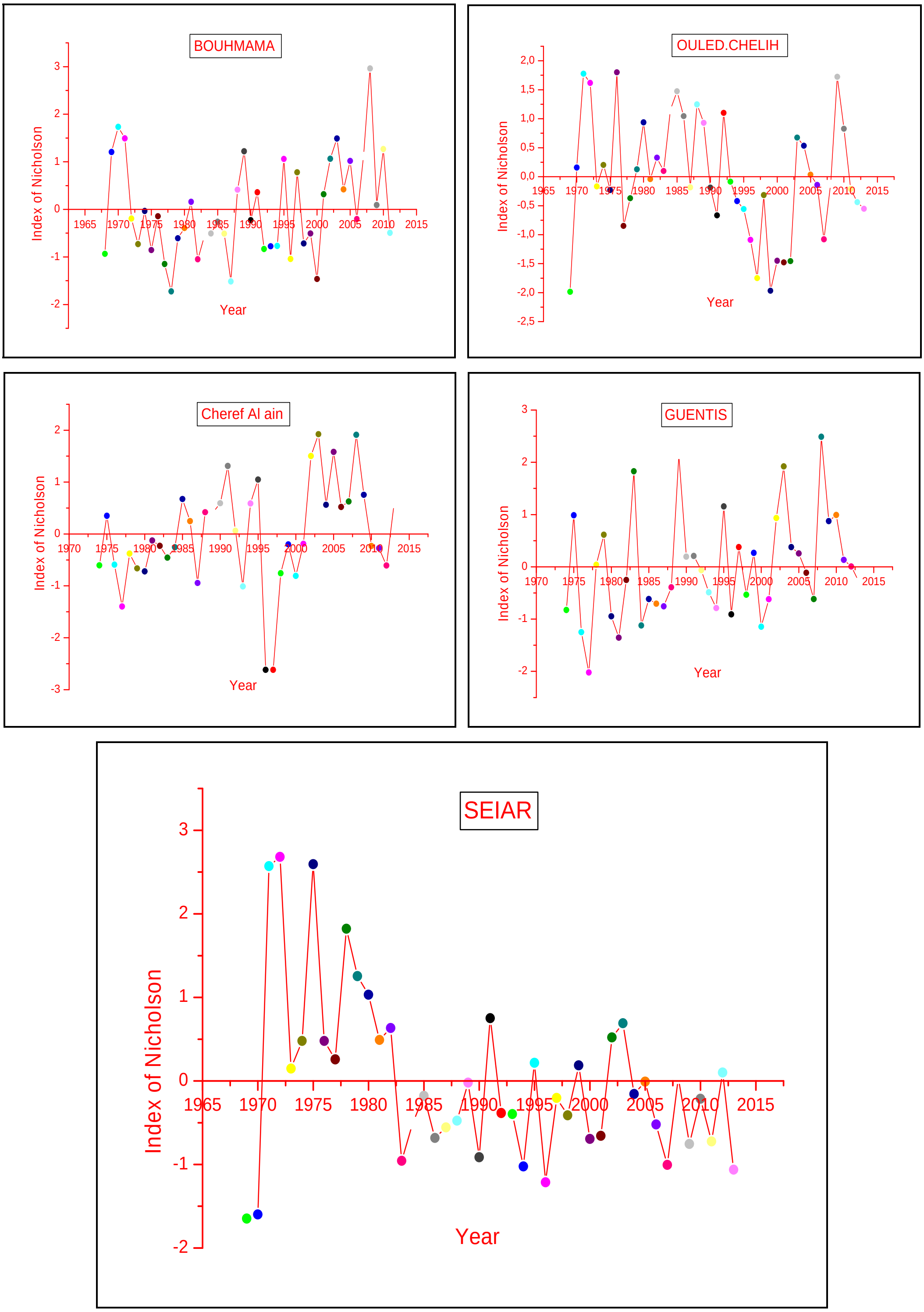

Figure 4. Fluctuations of rainfall by applying index Nicholson (South Stations)

Observed rainfall altitude in the study area

In this study, the spatial distribution of the rain is controlled by two parameters:

- the hypsometric distribution: the most watered sectors are the most elevated, according to an altitudinal gradient;

- the relief orientation: that of the NE-SW is perpendicular to the disrupted flow of the NW (figure 5).

According to these two parameters, this study emphasizes three distinct areas of rainfall:

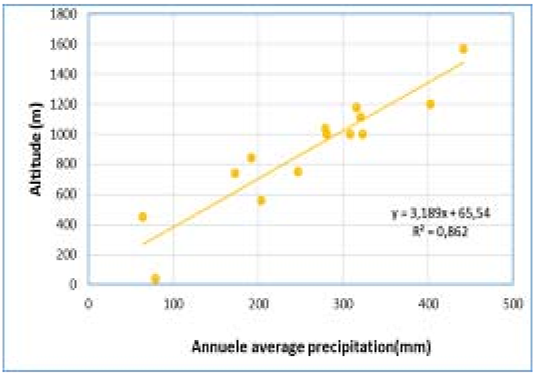

Figure 5. Curve of increase in rainfall with altitude

The wet sector

This corresponds to the mountains and peaks over 1500 m and oriented East-West. We mention the Mahmel, the Chelia, Ichemoul, Sasha. They receive rainfall between 300 and 500 mm/year. This is well presented and confirmed in the map considered by (Chaumont et Paquin, 1971) who admit in the sector of the Mahmel and Ichemoul a rainfall of 500 to 600 mm per year. More recent studies have shown that the same sector is well watered (Djabaïli., 1978) and this is because the effect of altitude as well (it is the highest sector of Aures) by exposure to the flow of the North-west sector.

The medium wet sector

This corresponds to the north face of the massif and it is represented by three stations which are: Ain Baida, Boulhillet, FoumToub. It extends more deeply to the West and covers the mountain ranges of Ich -Ali with an altitude ranging between an1809 to 2009 meters and the entire forest of Sgag. In this sector, the average of rainfall rangies between 400 and 800 mm/year. This character is explained mainly by their exposure to the North influence and thus an ubac situation. Similarly, to the Oued El Ma station located at the same latitude but in the Belezma mounts and receives virtually the same total of precipitation with 455 mm/year.

The dry sector

For this one, the average rainfall rangies between 100-300 mm/year and spread as well to the West and South of the study area. It is represented by Seiar stations with 239 mm/year, Ketef-Essouda with 182 mm/years and Chachare with 130 mm/years. Geographical considerations explain the brutality of this contrast. Indeed, the position altitudinal and latitudinal of this sector generates sometimes a reduced precipitation to its simplest depression

The analysis of a series of rainfall on 37 stations and the realization of the growth curve, confirmed the orographic character of this phenomenon. Rainfall decreases from North to South parallel to the altitude. With a high altitude, North receives annual average quantities greater than

550 mm (figure 5), which characterizes especially the peaks of the massifs of Chelia. At the base of these mountains, the rainfall is 300 mm to 400 mm per year. On the South of this area, rain decreases gradually, it is the case of the massif of the Ben Melloul with 200 to 300 mm/year and the Aures drop receiving only 200 mm per year, and up to 100 mm/year.

The distribution of rainfall in Algeria has three rules according to (Seltzer, 1946)**:**

- the height of rain increases with altitude, but it is higher on the slopes sprinkled by the humid winds than on others;
- it increases from the West to the East.
- it decreases as we move away from the coast.

However, the character (decrease from North to South) reflects a relative manner of this phenomenon. Relief plays a large role in the spatial distribution of the rains. Indeed, oriented from the NE to the SW, vertically to the origin of the prevailing rains, this relief creates an asymmetry between the slopes exposed to the North and the slopes exposed to the South. The first masks the second. The slopes masking are those exposed to the North and therefore more than the slopes covered exposed to the South. This phenomenon is well distinguished in the completed maps (from figure 6 to 10).

The Spatio-temporal variation in rainfall

The distribution of the mean values of the period (1969-2013) revealed inequality in the spatial distribution of rainfall in the study area (from figure 6 to 10). A decrease in the annual heights is observed, from North to South following a gradient (axis) north-east / south-west. This spatial distribution is explained by the effect of exposure and orography, due to the absence in the area south of wet carrier air masses, why mountainous regions receive more water than those in plain areas either north or south especially. Variability of the rain over the decades 1969-2013 (1969-1978, 1979-1988, 1989-1998, 1999-2008) and the last five years 2009-2013 is strongly influenced by drought years 1979-1998 in the northern part and the years 1974-1988 in the southern part. The interpretation of the figure below to shows:

During the Decade 1969-1978, through the map of this decade, rainfall decreases from North to South parallel with the altitude, the North with elevate altitude receives annual average quantities greater than 450 mm. This range features especially the tops to Khenchela and Chelia. At the base of these mountains, the rainfall is only 200 mm a300. The South of the study area recorded minimum values, it contains two parts; the South Eastern part or the massif of the Nemmemchas receives values from 100 mm to 200 mm/ year, as the station of Chachar gets 200 mm, Guentis 152 mm, however the Southwest part records values less than 100 mm/year as the station of Mita 50 mm and Ketef Essouda 80 mm (figure 6).

During the Decade 1979-1988, a remarkable variable increase in the values of precipitation, especially in the areas of Plains north and South (South West) and they are observed with values between 250 mm and 490 mm (figure 7).

During The Decade of 1989-1998, a significant increase in the values of the minimum and maximum rainfall, but watered region is very limited compared to the previous decade, the maximal values are limited in the regions which have altitudes more than 1500 m as the case of Djebel Chelia that receivies 534 mm. The North East plain area recorded important values with 350 mm (figure 8).

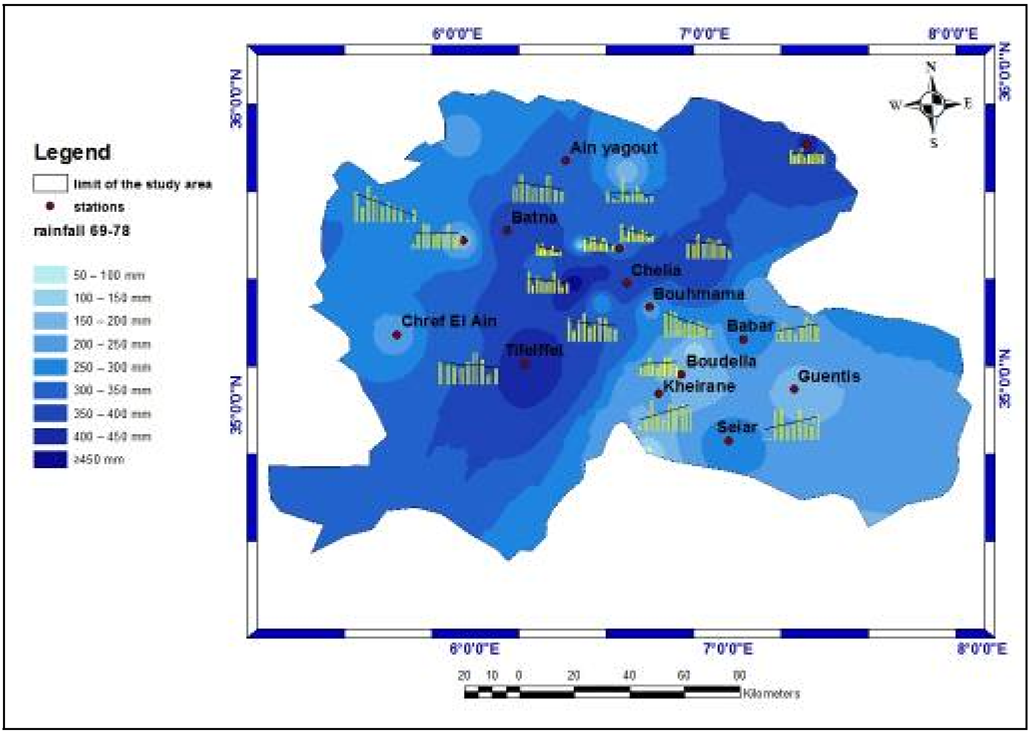

Figure 6. Variability of rainfall during the Decade 1969-1978

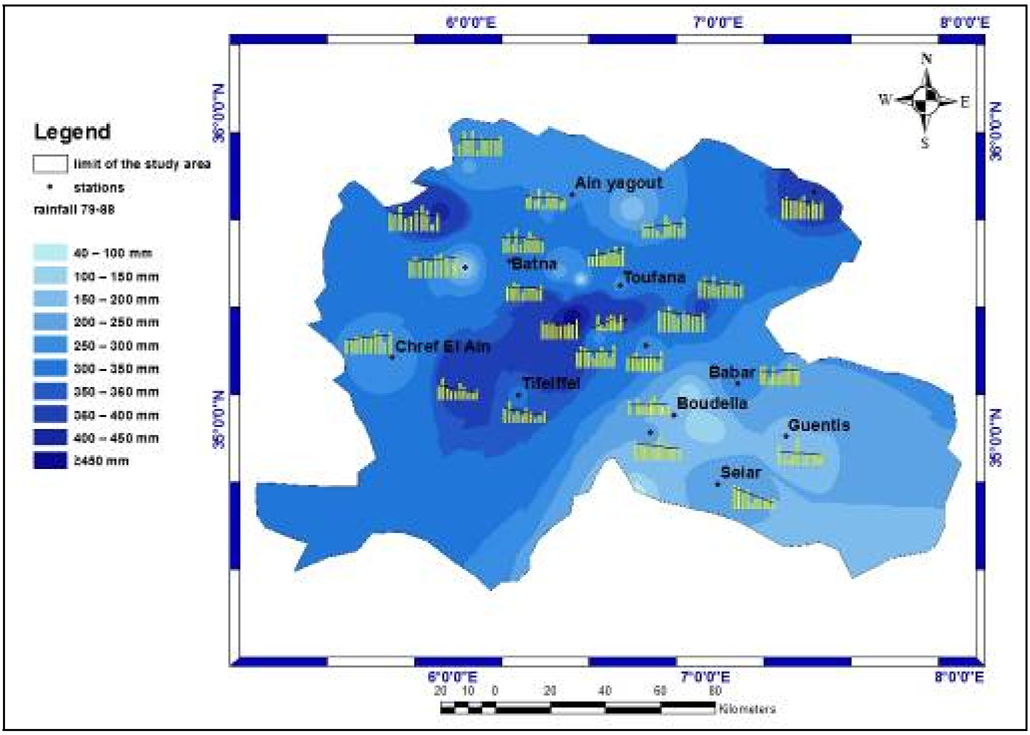

Figure 7. Variability of rainfall during the Decade 1979-1988

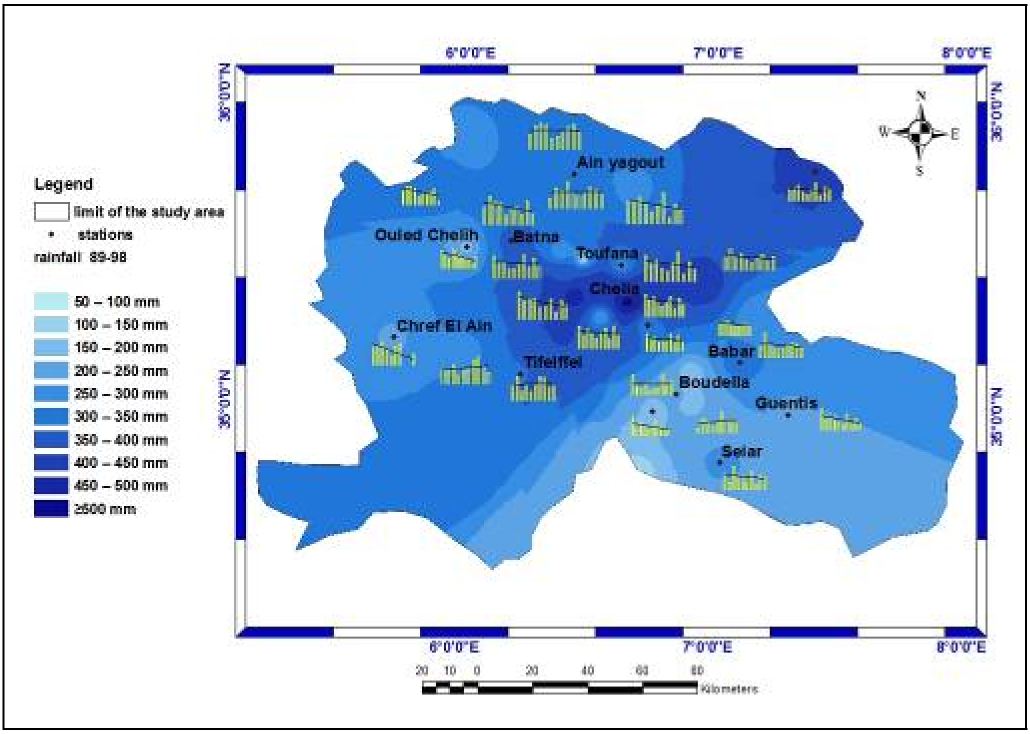

Figure 8. Variability of rainfall during the Decade of 1989-1998

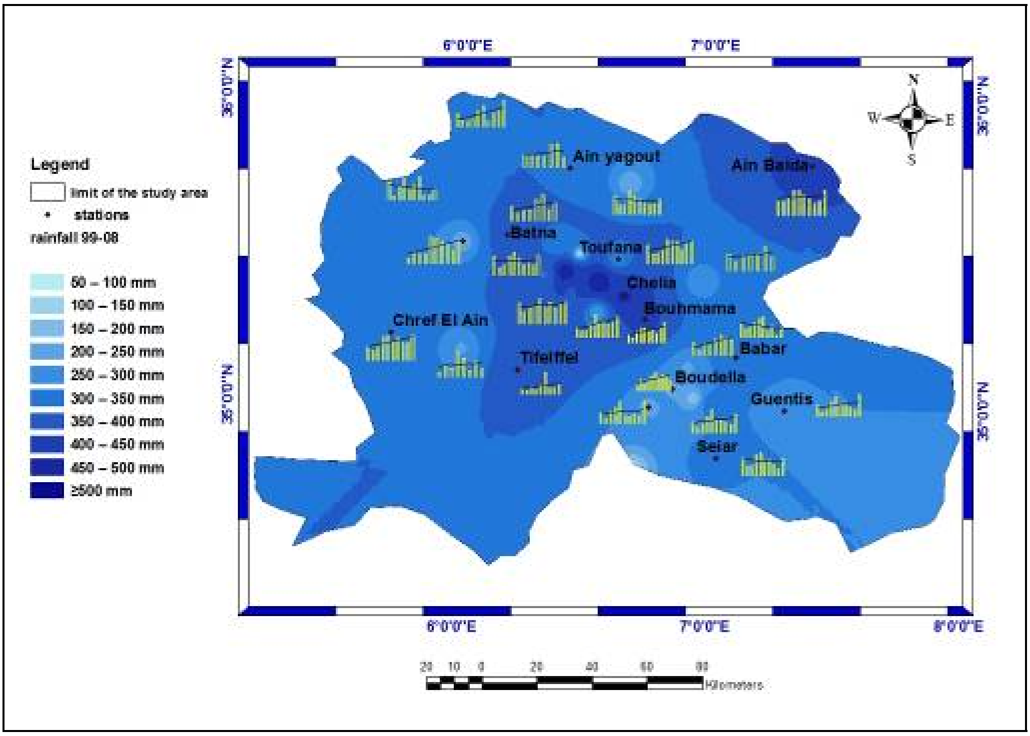

Figure 9. Variability of rainfall during the decade 1999-2008

During the decade 1999-2008 is rainy compared to the Decade (1969-1978, 1979-1988) with 500 mm as maximum and important value in mountainous areas, with 400 mm in the Plains North - East and the average values in the North West is 300 mm. The minimum values are recorded 75 mm in the South-East with 75 mm (figure 9).

During the past five years (2009-2013), the southern part has recorded important values of precipitation compared to the four previous decades with average and maximum values in the southwest part, the region of Tifelffel with a value of 550 mm, Chelia with 400 mm, other parts have average of 350 mm values and the South East region recorded the minimums with 59 mm (figure 10).

A general analysis of maps of interpolations shows the important spatio - temporal variation of precipitation in our study area, reflecting a decline in general rainfall, this is expressed especially from North toward the South.

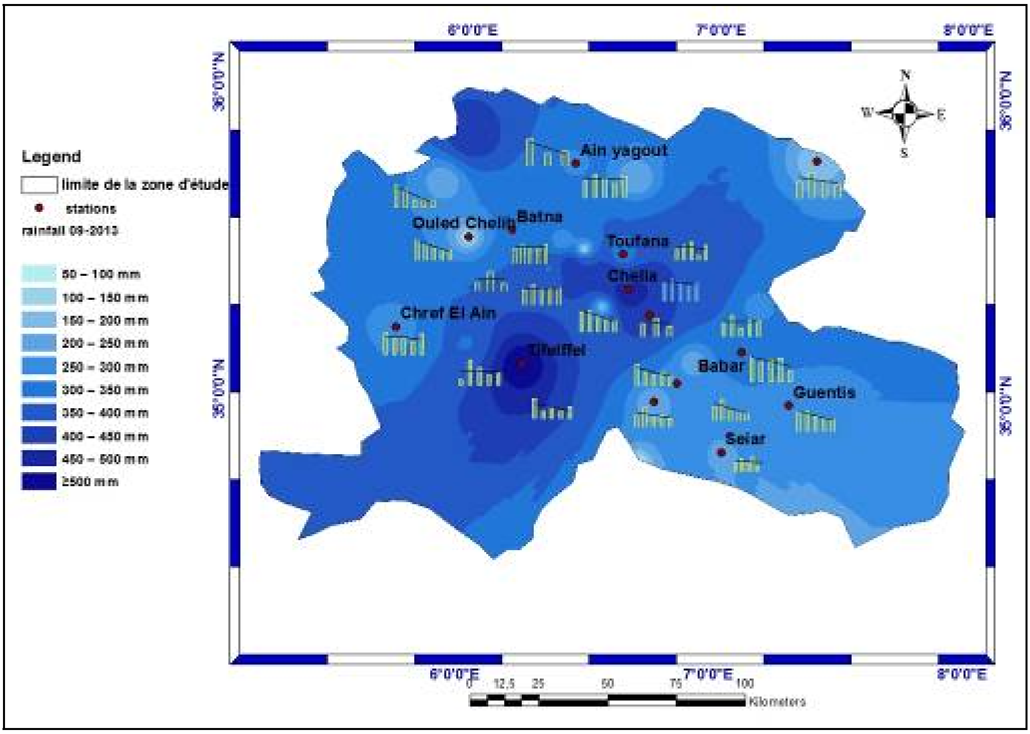

Figure 10. Variability of rainfall during the decade 2009-2013

CONCLUSION

The compilation of data mapping and on rainfall has helped to detect a spatio - temporal variability in the study area. Thus, this variability of rain over the decades, 1969-1978, 1979-1988, 1989-1998 and 1999-2008 with the last five years 2009-2013, is strongly influenced by the droughts of the years 1974 and 1988, it reflects the great heterogeneity in the distribution of rains during these periods.

Warming is now unequivocal and established fact in the study area and its impact on the precipitation translates into strong interannual fluctuations rains and a sliding trend. The results of this study are an important data base for climate risk assessment but also of vulnerability to climate change.

In this context, improvement and intensification observing systems are needed to have sufficient data and more efficient in order to better characterize this climat mosaic and to reach forecasts necessary to a precise vision of the socio-economic and environmental risks in order to contribute to a better adaptation to the probable effects of climate change.

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