Applied multivariate analysis on annual rainfall in the northeast of Algeria

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ABSTRACT

In recent times, there has been a growing interest in understanding precipitation variability and its predictability for periods of a few months to several years. Our work consisted of studying climatic changes in the northeastern region of Algeria based on multivariate analysis of the annual rainfall. Variability of annual rainfall was analyzed using principal component analysis (PCA) and non-hierarchical classification (cluster method). For spatial rainfall variability, due to the complexity of the region, we used the method inverse distance weighted cartography modeling. Results indicate PCA represented the accumulated yearly rainfall of correlated fields on an annual scale, only the years 1971, 1985, 1995, and 2002 had a rather high degree of correlation, translating the homogeneity of annual distribution of precipitation. Cluster method demonstrated the certainty of three groups. The first group was characterized by regions of distinguishable climatic types, such as Mediterranean climate. The second group was characterized by the Tellian Atlas, while the third group was characterized by high plateaus. Spatial analysis of average decade rainfall shows that the isohyet curves of 750 mm in the center of the study region are shifting to the south, and that the Mediterranean regime rainfall affects all the northern region.

Key words | cluster method, northeast Algeria, PCA, rainfall

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INTRODUCTION

The regionalization of climate scenarios in the context of global warming is an essential step for conducting studies on the impacts of climate change. In recent years, significant advances have been made in high-resolution climate modeling, which is gradually approximating the regional scale, providing a remarkable circumstance for studying regional climate behavior. It is well established that the amount or availability of water for agricultural purposes depends on rainfall. An excess or an extended absence of rainfall has been known to cause flooding and drought throughout history, respectively.

The interest in climate variability has increased over time and major efforts have been made to learn about precipitation variability and its subsequent trends (Cannarozzo *et al.* 2006; Wang *et al.* 2010; Li *et al.* 2011; Corona & Montaldo 2018) and regional scales (Tsakiris *et al.* 2007; Ngongondo *et al.* 2011; Khalili *et al.* 2016; Zamani *et al.* 2017). Numerous studies have been carried out to analyze the variability in precipitation throughout the world, specifically in the Mediterranean basin (Donat *et al.* 2013; Nouaceur *et al.* 2013; Altın & Barak 2014; Khomsi *et al.* 2015; Varouchakis *et al.* 2018). Data have shown that the south shore of the Mediterranean basin, adjacent to the north coast of Algeria, is of particular vulnerability.

Algeria, an African country located on the southern Mediterranean shore, has not escaped climate change (Senoussi *et al.* 1999; Nouaceur *et al.* 2017; Mrad *et al.* 2018). Algeria's climate is characterized as semi-arid to arid with an irregular spatio-temporal distribution of precipitation.

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The understanding of the distribution and variation of annual precipitations are necessary for the stock management of water and its use in agriculture. Although the variability in annual precipitation can be quantified and analyzed, it is difficult to define rainy years spatially within a homogeneous region due to the differences of modes of precipitations at the same time geographically, as well as weather alternatives.

To date, the method of detecting changes in rainfall and how to take into account changes to agricultural risk management tools and methods has remained at the heart of the concerns of farmers, livestock breeders, and rural communities in the Algerian basin (Khaldi 2005). Historically, agricultural seasons have been modeled on the rate of mean rainfall. Interpretations of the results have focused on the sequential chronological variations of the annual rains and several major droughts since the 1970s (Habibi *et al.* 2018) associated with the spatial phenomena occurring in the basin (Merabti *et al.* 2018).

To study the temporal variability of rainfall and monitor the temporal evolution of rainfall, several researchers used principal component analysis (PCA), which has been applied in numerous studies discussed above (Kousari *et al.* 2014; Zarei *et al.* 2016a; Merabti *et al.* 2018). However, Medjerab & Henia (2005) used PCA without rotation of monthly data from 220 stations between the years of 1942 and 1990 in northwestern Algeria. The results were validated by factorial discriminant analysis (FDA). In addition, Hebal & Remini (2012) investigated a series of annual, seasonal, and monthly precipitation from 55 stations which covered three major basins (Seybouse, Isser, and Tafna). They observed that the distribution of rains obeyed the following three cases: (1) its distribution increased with altitude, (2) its distribution decreased from east to west, and (3) rainfall decreased further away from the shore.

Different spatial interpolation methods have already been utilized in related fields: generally, the geostatistical approach including Theissen method, inverse distance weighted (IDW) method, spline method, and kriging ordinary method (ESRI 2008).

From a review of the literature, research on spatial interpolation methods of rainfall approved by Naoum & Tsanis (2004), Chen & Liu (2012), Qulin & Xiao (2014), Wu *et al.* (2016), and Yilmaz & Uysal (2017) found that every technique has its preferences and weaknesses in light of its objectives, and subsequently, the ideal introduction strategy shifts for various propositions. The IDW method pays attention to both the smoothness and precision of the interpolation surface. Goovaerts (2000) considers it to be the most suitable interpolation method and to be less accurate than geostatistical approaches for estimating monthly and annual rainfall.

The main objective was to be able to determine a regional vector to explain the different phenomena responsible for the rainfall variability of the Constantinois Seybouse Mellegue (CSM) basin. Thus, an entire series of multivariate statistical analyses was adopted based on the determination of the correlative proximities between the observation posts on a monthly scale as well as on an annual scale, which result offers consideration regarding both the early warning of flood disasters that can provide a scientific basis for understanding climate change and improving future climate risk predictions.

For this purpose, 43 years (1970–2012) of rainfall data from 60 rain gauges situated in different parts of the CSM in northeast Algeria were analyzed. This was to clarify the spatial and temporal variability of annual rainfall, which led to the development of this five-part study. The first section introduces the paper and explains the motive behind this work. The second describes the study area and the precipitation data employed. The third describes the methods of PCA and cluster methods to assess homogeneous classes of annual rainfall. These methods helped generate the isohyet maps of years studied, which show a general downward variability and increase in average annual rainfall. The fourth section discusses the results while the fifth outlines the major findings.

STUDY AREA AND PRECIPITATION DATA

The study region, the CSM, covers an area of 44,219 km^2. It is one of the five major hydrographic basins in Algeria, as shown in Figure 1, and includes the watersheds of coastal Constantine (3), Constantine High Plateaus basin (7), Kebir Rhumel (10), Medjerda (12), and Seybouse (14). It occupies the most northeastern part of Algeria and is

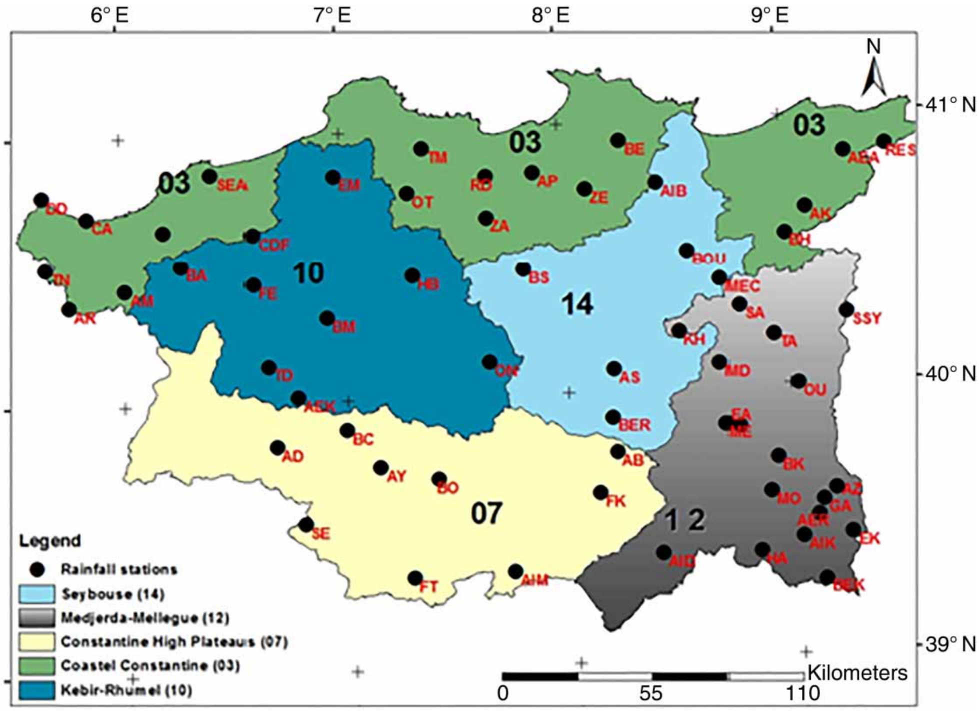

Figure 1 | Location of the Constantinois Seybouse Mellegue (CSM) watershed and ANRH (National Agency of Hydraulic Resources) gauging stations.

bounded by the Mediterranean Sea to the north, the Sahara basin to the south, the Hodna basin to the west, and the Tunisian border to the east.

Rainfall data were obtained from the National Agency of Hydraulic Resources (ANRH) of Algeria, and 60 stations (Table A1, Appendix A) were selected based on the length of available rainfall records and their geographical positions to cover the optimal area of the watershed for a period of 43 years (1970–2012) (Figure 1). In a time series analysis, the hypothesis that observations made through the rain towers were equally distributed and each series of data collection was homogeneous were to be verified. In our study, we applied the double cumulative method. This method has the advantage of being simple, well known within the field, and quickly achievable. The double cumulative method made it possible to detect error, but not correct it, at least not directly (Musy 2005). It was based on the comparison of the progressively cumulative annual totals of the series to be controlled (y(i)) and a reference series (x(i)), which can be either that of a reliable station, or a fictitious series corresponding to a regional average. The results of this method showed the perfect alignment of the cumulative rainfall on the same straight line and gave rise to correlation coefficients (R^2) greater than 95%. This confirmed the homogeneity of the series studied.

Rainfall analysis shows that the intensity and magnitude of absolute rainfall irregularities are not uniform (Figure 2, left). Indeed, there is variability between north and south, in the mountainous region where average annual rains exceed 1,100 mm. On the coast, the amount of rain varies between 700 and 900 mm. According to the figure, there is a diametric difference between the Tellian or central part, whose rainfall values are above 500 mm, and the interior-oriented highlands, where the average does not exceed 400 mm. The rest of the territory has rainfall between 500 and 700 mm.

The coefficient of variation map (Figure 2, right) reflects the spatial distribution of average rainfall. The figure shows that the regions with high rainfall cover the northern part of the Constantinois western coast and the northern mountains of the Medjerda have a low variability of coefficients of variation around 20% to 30%, while rainfall decreases towards the southern regions of the Mellegue (12) and the highlands, which are characterized by very high coefficients varying between 40 and 45%.

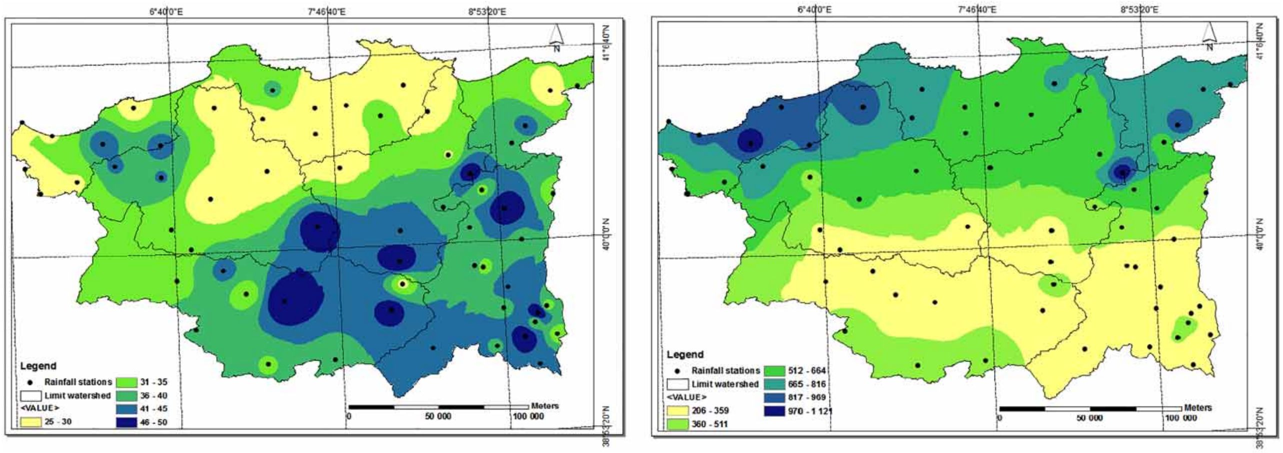

Figure 2 | Spatial distribution of the average annual rainfall (left) and coefficient of variation (right) for the Constantine Seybouse Mellegue basin.

MATERIALS AND METHODOLOGY

Principal component analysis (PCA)

PCA is a factorial method because the reduction in the number of characters, in general, depends on each other. PCA is not affected by subjective selection of certain parameters but by the transformation of the initial variables into new synthetic characters obtained by the combination of linear factors (Laborde 2003). They are ordered in such a way that the variance of the first principal component is the greatest, the variance of the second is second greatest, and so on, whereas that of the last one is the smallest (Héberger *et al.* 1999). Each variance indicates how much information is involved in the corresponding principal component, and the greatest variance represents the most largely compressed information sufficient to replace the original variables (Sang-Min *et al.* 2018). Ghernaout & Remini (2018) have shown this method to identify the homogeneous region in Mina river in terms of precipitation regime.

Non-hierarchical classification (cluster method)

Cluster analysis is proficient at grouping samples or objects into unknown groups and transmission of particular objects to these groups by classification. Cluster analysis has long been perceived as a powerful statistical tool in grouping stations into climatologically homogeneous region districts dependent on the given meteorological parameters (Zhang *et al.* 2001). A number of studies have used this technique to successfully achieve spatial variability annual or monthly rainfall (Dinpashoh *et al.* 2004; Belkhiri *et al.* 2010; Arab Amir *et al.* 2017). The hierarchical clustering routine produces a dendrogram showing how samples can be made and grouped according to their similarity to each other (Belkhiri *et al.* 2010). In the present study, we cut the dendrogram from an area of regions grouping stations with a similar temporal evolution of rainfall and groups with the same characteristic.

According to the study carried out by Medjerab & Hania (2005), one of the most significant advantages of PCA and FDA methods is the possibility of grouping meteorological stations of a region without any a priori hypothesis, in the case where the percentage of the total variance expressed by the significant main components is very high.

RESULTS AND DISCUSSION

Precipitation annual variability

In this context that the variations of the annual cycle of precipitation of the CSM region were studied, applying PCA of the active variables was represented by years (43 years) through annual observation. The results displayed below show that the first component (Figure 3) explained 37% of

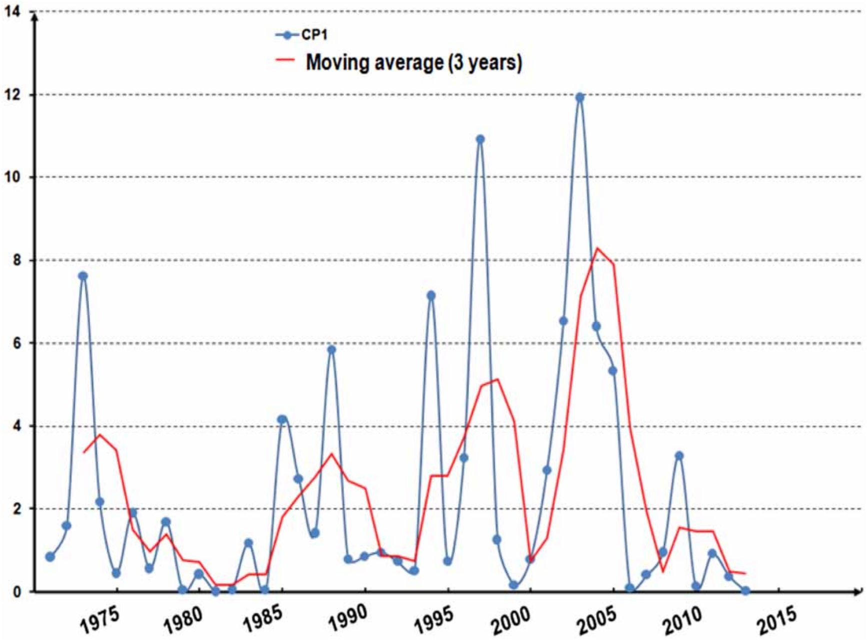

Figure 3 | Chronological projection of the first component C1.

the total variance. This can only be explained by the irregularity of inter-annual rainfall affected by the succession of dry years. However, in the first component projected on the axis of years, a series of three dry periods (1975–1984, 1989–1994, and 2005–2007) interspersed with two humid sequences (1970–1975 and 1996–2001) appeared. These results are in line with a number of previous studies (Hallouz *et al.* 2013; Nouaceur & Laignel 2015; Achir & Hella 2016). Furthermore, the results suggest the evolution of rainfall could have started in 2000, which confirms the increase in rainfall was significantly noticeable since 1997 and that 2004 was characterized by rainfall and exceptional snowfall in all Maghreb countries (Hirche *et al.* 2007). Donat *et al.* (2014) showed that there was a significant increase in intense cumulative precipitation over northern Algeria as well.

The second component (Figure 4), represented 12% of the information and explained the distinction between two major dry periods (1978–1984 and 1995–2002) followed by wet years (1975–1979 and 2001–2006). This confirmed that this axis was linked to the light dominance of the coastal regime affecting the northern and central part of the basin. By this type of temporal analysis, it should be noted that the rainfall patterns explained by the components dominated the basin in a cyclical way, favoring the annual feeding of the rainfall according to the wet or dry sequences of varying length.

Figure 5 shows that the concentration of the most important precipitation values in the Eraguene, Souk El Arbaa, and Mechroha stations can be explained by the influence of the topography. It can be seen that the difference of precipitation in each subcatchment is clear, so that annual precipitation in Erraguene and Mechroha is the highest, with an average annual precipitation of 1,120 and 1,125 mm, respectively, and then El Milia in the Kebir-Rhumel, with a precipitation of 892 mm. The precipitation in Souk-Ahras is 582 mm, and Seguene has the lowest precipitation of 442 mm. A comparison of the average precipitation of each decade compared to the annual total highlights that the decade 1980–1990 is the most correlated with the annual rainfall for almost all the stations.

Referring to the results obtained in Figure 6, this classification revealed three strong forms consisting of groups of stations, more or less homogeneous partitions. The resemblance between these highly homogeneous stations was reflected in the climatic characteristics and being grouped together with similar characteristics, such as geographical location and exposure or influence of the rainfall regime.

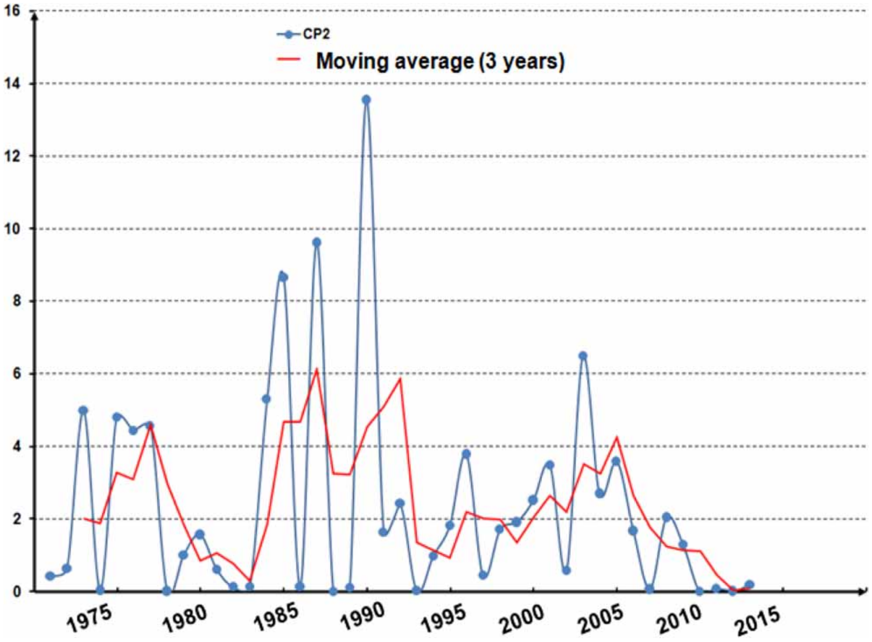

Figure 4 | Chronological projection of the second component C2.

In general, the cluster classification results are grouped into three categories, characterizing as:

- Group 1 (GR1) is a summary of all stations located in the Tellian mountainous part of the basin and stations near to the Mediterranean, although this grouping is strongly linked to two sub-watersheds that were subjected to different rainfall regimes. One coast is influenced by a continental climate while the other coast is influenced in the north by the penetration of marine wetland air.
- Group 2 (GR2) highlights strong individualized forms. We note that the east is made up of strong forms, grouping the stations Ain Roua, Tahar, Ramdan Djamel, and El-Milia by the influence of altitude and by their exposure to wind and rain.
- Group 3 (GR3) is a grouping with all the stations more or less localized to the high altitudes of the south with important altitude drought present.

In parallel to the observations made by Beniani & Achite (2016), it was found that the three zones can be influenced by their geography: coastal zone, sub-arid zone, and the arid zone in the south. Consequently, in stations exposed to rainfall, there was an increase in precipitation as a function of altitude with a gradient variation from east to west, similar to the observation made by Medjerab & Hania (2005).

Spatial variability of rainfall

Based on a PCA graph, we have mapped the average annual decadal rainfall for 1970–1980, 1981–1990, 1991–2000, and 2001–2012, shown in Figure 7, to detect the different changes between these decadal years in the distribution of annual precipitation.

In the decade 1970–1980 (Figure 7, top left), the increase in rain was recorded in the region of the extreme northeast and northwest with average rainfall ranging between 900 mm and 1,050 mm. This area is indeed very hilly as it is crossed by the Tellian Atlas, and the northern maritime trade winds promote the formation of clouds and consequently heavy rainfall in this area. This is in contrast to the southern region where the rainfall decreased with average measurements ranging between 180 mm and 370 mm.

The decade 1981–1990 highlighted rainfall deficit recorded in 1980, with a decrease of 25% for the stations located in the north. We registered that the 750 mm isohyet

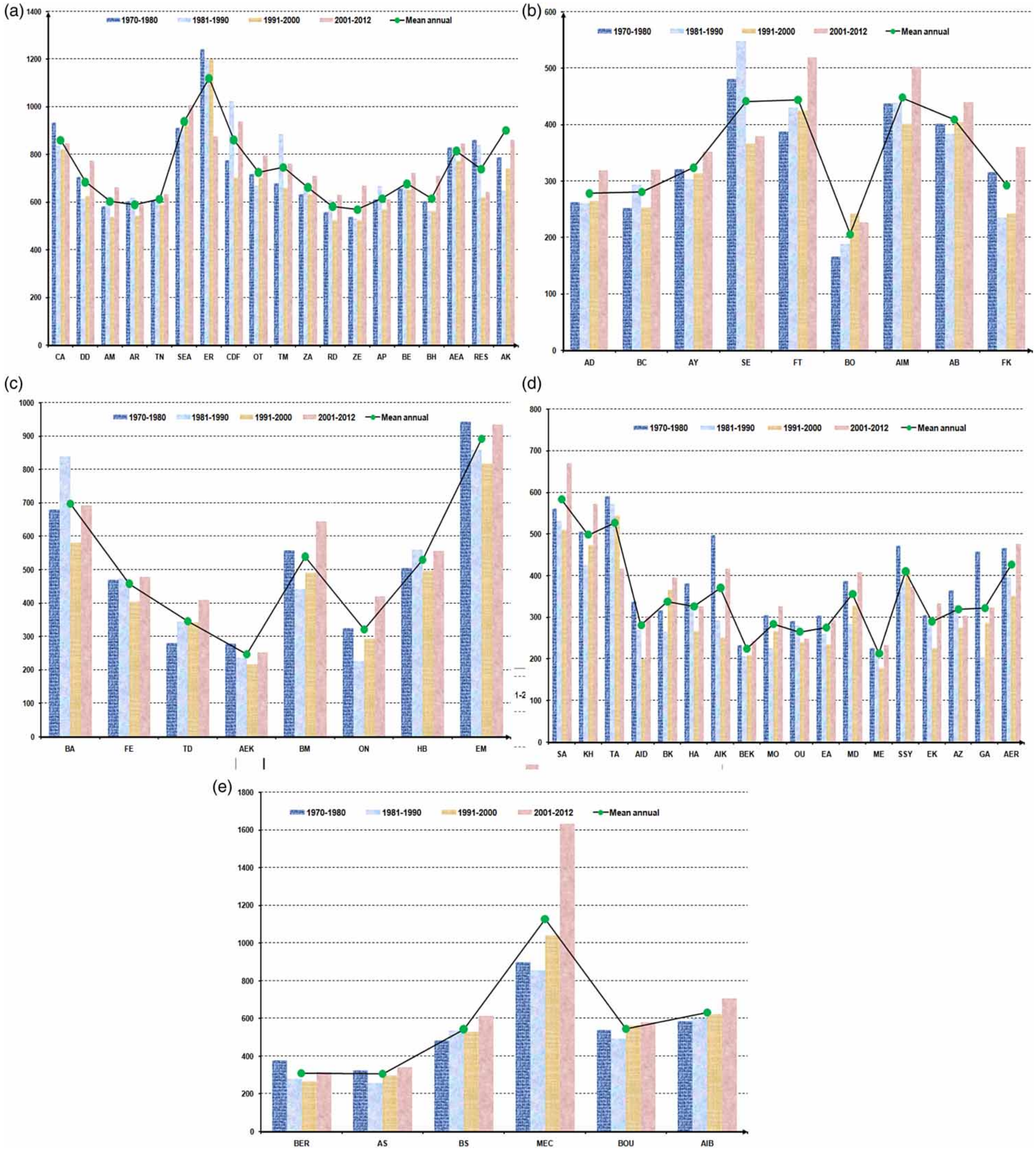

Figure 5 | Correlation between decade and average annual rainfall in each sub-catchment CSM study area: (a) coastal Constantine (3), (b) Constantine High Plateaus basin (7), (c) Kebir Rhumel (10), (d) Medjerda (12), and (e) Seybouse (14)).

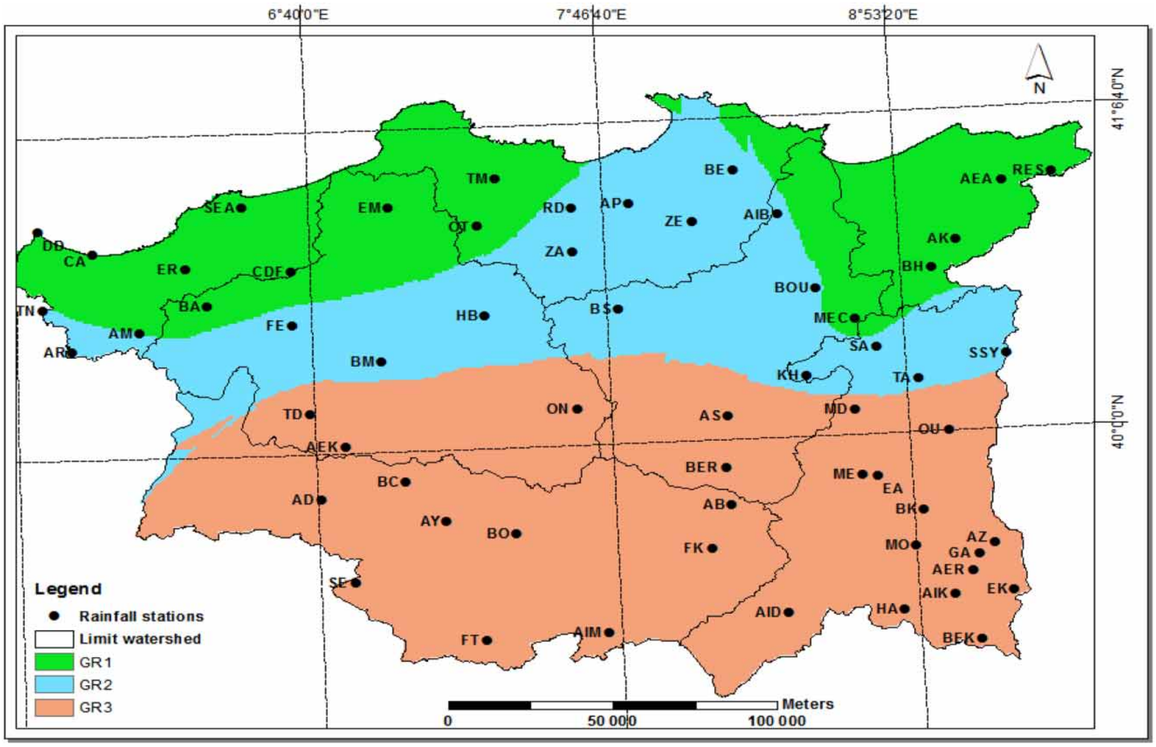

Figure 6 | Station clusters for annual rainfall of the CSM region.

curve, which was at the center of the CSM in the years 1970–1980, has completely migrated to the south, and this shift has affected the entire region of Algeria (Figure 7, top right). Medjerab & Hania (2011) observed the importance of drought during the decade of the 1980s in the Tellian and coastal regions, regions which are usually very well watered, and where the practice of market gardening and cereal production is carried out without irrigation.

The decade 1991–2000 shows a perceptible increase in rainfall, but it does not yet return to the level of excess of the previous decade. Low rainfall values of isohyets (300–400) were located in the southern parts of the basin (Figure 7, lower left).

The map of the isohyet values of the decade 2001–2012 highlights the significant rains recorded during these years. Noteworthy are the regions of highest elevation which incurred 820 mm to 950 mm of rain (Taher, Jijel) as well as those regions of lowest elevation, which experienced between 280 mm and 400 mm of rain (Oueld-Naceur, Ain Yagout, Timgad). Some of these zones presented rainfall indices reaching values ranging between 1,000 and 1,200 mm (Figure 7, lower right). This increase is due to the floods that occurred in the northeast in 2001 and 2002 that caused losses in economic and environmental infrastructures.

Local geographic features, such as the coastal escarpment, its orientation, the presence of relief features, the exposure of the slopes or the direction of the local winds, also influenced the formation of intense precipitation events (Boudevillain *et al.* 2009; Tramblay *et al.* 2013). However, altitude influenced the increase in precipitation for the areas exposed to the rain-bearing wind. Other factors, such as the distance of the station from the sea and the position of the relief features relative to the summit also played an important role in the formation of the rains. Lionello (2012) showed that precipitation in the Mediterranean basin was influenced by local characteristics such as elevation and topography.

The decline in rainfall in northeastern Algeria during the 1980s was explained by the climatic factors that generate precipitation. Several authors have previously shown that this variation of the Mediterranean rainfall

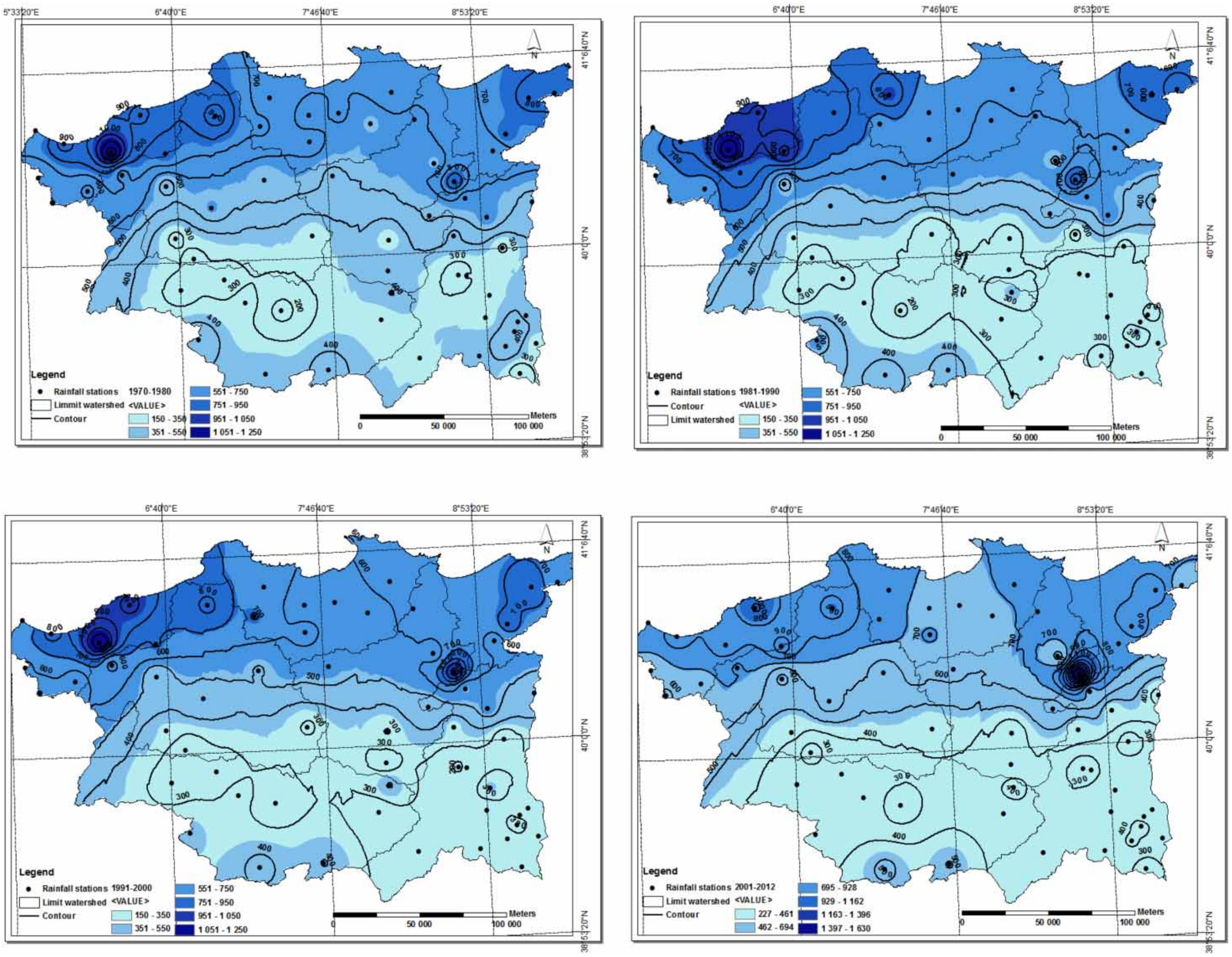

Figure 7 | Spatial variability of annual decade rainfall in CSM region: 1970–1980 top left, 1981–1990 top right, 1991–2000 lower left, and 2001–2012 lower right.

regime is determined by general atmospheric circulation, particularly the North Atlantic Oscillation (NAO) (Cassou 2004; Salameh 2008; López-Moreno *et al.* 2010; Singla *et al.* 2010; Raymond *et al.* 2016). Since 1980, the NAO index has been positively increasing. The inverse correlation between a rise in the index and decline in rainfall in the Mediterranean basin as well as northern Algeria can be affirmed. According to Hoerling *et al.* (2012), the warming of the oceans facilitated the emergence of anticyclone systems, mostly centered on the Mediterranean basin, which explains an ecological shift towards drought conditions in the 20th century. Meddi *et al.* (2010) revealed a link between the NINO4 and NAO climatic indices and precipitation in northwestern Algeria before and after 1970.

CONCLUSION

Northern Algeria has a contrasting topography and significant variations of climatic factors in its northern part, influenced by the Mediterranean climate. Data from this study indicated that over the course of the last century, northeast Algeria has experienced a succession of periods of rain deficits and excess without correlating to the well-studied hydrologic cycles. PCA showed the lasting nature of drought observed in the northern region from 1976 to 1980. It also highlighted the return to a wet episode from 2002 to 2010. The analysis of rainfall over time and space was based on annual rainfall measurements at rainfall stations. The coastal plain area was subject, as noted above, to the Mediterranean influence in the northern part of the study region. In this respect, the annual regime taken individually for each year was markedly different from the monthly distribution and from the correlation between the precipitations of the annual total. This showed that the rainfall variability is also greater and different between years than in the space between stations, hence the diversity of rainfall regimes, the annual dry and wet periods, and the geographical extent of the basin's climate.

The rainfall isohyet map depicts areas of high rainfall, ranging from Jijel to Collo, as well as within the highest elevation ranges such as the Edough massif in the northeast. The rain reached more than 1,800 mm on the Collo massif in the decade 2001–2012. The isohyets of 600 mm to 800 mm sweep across all the rest of the Tellian Atlas with rainier regions in the extreme east of Algeria. The High Plains are surrounded to the north by the 450 mm isohyet. The rainfall decreased to 200 mm in the south in 1981 to 1990.

The influence of elevation on the geographic distribution of rainfall is varied. There was an increase in precipitation with an increase in altitude in the stations exposed to wet flows, with a change in gradient from west to east. In any event, altitude is not always the most influential factor in the geographical distribution of precipitation. Other factors, such as the position of relief features to the sea and the morphology of the orography also play an important role.

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