Meteorological drought in Batna region and its consequence on biodiversity (case of *Cedrus atlantica* Manetti)

Mouhli N., Nedjahi A., Laouer H., Riahi W.

Abstract— Our work is based on the study of meteorological drought in the region of Batna (Algeria) over a period of forty years (1975 to 2014) by using climate data of the National Meteorological Office. In this purpose, Quantification of changes in precipitation at different time scales is determined by applying the standardized precipitation index (SPI) adopted by the World Meteorological Office in 2009. The results demonstrate significantly the presence of several drought periods in duration and severity on the chronology of the used data. On the other hand, Batna region has experienced a warming tendency since 1992. The longest period of drought is from 1998 to 2002 and the most severe years are 1983, 1990, 1993, 1996, 1997, 1999 and 2002. Analysis of this phenomenon is complementary to other previous studies on the decline of Atlas cedar which is an anisohydric species adapted to episodic droughts when are not prolonged, especially if it is associated with strong heat. The approach used is original; it reinforces the idea that the decline of Atlas cedar is directly dependent on prolonged drought.

The decline of carbon sinks from forest cedar of Saharan atlas is related to the mortality of Atlas cedar trees (*Cedrus atlantica* Manitti). In Algeria, the most affected forests by this phenomenon are those of Aures and Belezma since the eighties that scientific and political communities impute to climatic changes. One of major consequences of these climatic changes is drought in its various types meteorological, agricultural, hydrological and socio-economic that affects the environment, the economy and the society.

Index Terms— *Cedrus atlantica*, climate change, decline, Mediterranean, meteorological drought, Standardized Precipitation Index, vegetation season

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1. Introduction

The phenomenon of climate change is preoccupied by the scientific community and the political world in view of the catastrophic consequences on the environment, the economy and the human population. It is linked to the greenhouse effect which induces the increase of temperatures and water deficits [2]. Current climate change significantly affects the Mediterranean forests [22] that cause significant disturbances on ecosystems such as fires, drought, pathogens, invasion of exotic species and storms are expected [9].

Drought is one of the consequences of climate change. It is defined by the World Meteorological Organization (WMO) as a water deficit, linked to an absence of precipitation over an extended period. Drought assessment provides valuable information to address the impact of drought on water and biodiversity. Several indices are used throughout the world to determine and quantify the severity of drought. The standardized drought index (SPI) is the most popular in the characterization of meteorological drought [24].

Drought is generally considered as a natural hazard that progresses slowly and insidiously, it is due to the natural variability of the climate and it can be meteorological, agricultural, hydrological and socio-economic type [20]. The consequences of different types of drought are linked to each other. Moreover, if meteorological drought persists over a period of time, it becomes an agricultural, hydrological and socio-economic drought [20].

Drought affects water supply, which plays an important role in agriculture and industry, and degrades the health of ecosystems by causing serious environmental consequences: soil erosion, destruction of habitats and decline of Forests in general.

The decline of the Atlas cedar is a case that is widely debated in Algeria as in Morocco in order to find the triggering factor in dependence with drought. The cedar trees of the Saharan atlas were influenced by this decline from 1981 and 1982 in the Aures [1], [3] and 1985 in the Oursenis. There was a very high mortality rate, probably affected by drought [1], [3], [14], [23].

Kherchouche (2013) indicated through its dendroclimatological results that the driest periods are in 1978 and 1979 and the longest from 1993 to 2002. These results are followed by those of Slimani (2014) indicating that the dry years are 1978, 1988, 1994, 1997, 1999, 2001 and 2002. The same author shows that the presence of absent rings coincides with the years 1978, 1983, 1988, 1994, 2001 and 2002 in the forest cedar of Touggurt (Belezma, Batna) High water deficit, and even lack of precipitation. These dendroclimatological results indicate only the dry years, but do not identify the beginning and the end of the drought, and thus its severity.

The ISP method consists to determining the dry and the wet episodes in a series of forty years from 1975 to 2014 in Batna region in order to classify the periods identified in drought classes that will reflect climate history and precipitation anomalies. Our objective in this work is to verify the hypothesis of the installation of the meteorological dryness which we consider as causal factor of dieback and to show the beginning and the end of the dry and wet periods, according to the severity and the duration. The analysis of this phenomenon according to the meteorological drought approach is complementary to the other previous works.

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2. MATERIALS AND METHODS

Region of Batna is located in the east of Algeria in the Saharan atlas, between two forest massifs: Belezma and Aures (Fig. 1). These massifs occupy a significant forest area and provide important socio-economic and tourism services for the local population. These massifs are characterized by a rugged topography with high altitudes (Chelia: 2328 m, Tougguert: 2091m) and a semi-arid bioclimate submitted to the action of the Saharan climate. In this area, cedar forest is in danger where Atlas cedar risks disappearing [12].

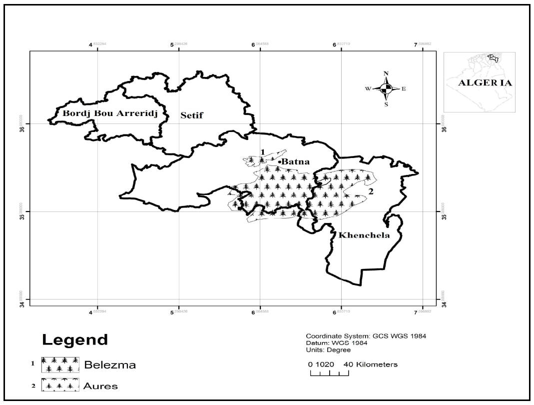


Fig. 1. *Location of Batna (Algeria)*.

The proposed study is based on climate data analysis on 40 years of observation (1975-2014) which is provided from Batna weather station that is located at 35.55 ° N; 6.18 ° E; Z: 1050m and characterized by a semi-arid bioclimate.

The annual mean precipitation is 316.82 ± 102.72 mm (min: 190 mm, max: 584 mm). The mean temperature of maxima is about 14.90 ° C. Snow falls on the mountains of Aures and Belezma (1300m at 2328m of altitude) from November to March. Snowfall is not constant and the number of days varies from year to year. The majority of the winds blowing on Batna region have a south direction, south-east and south-west. In winter the direction of the winds is variable between the North and North-East.

This step is completed by calculating the Standardized Precipitation Index (SPI) adopted by WMO in 2009 which is used for of measuring meteorological drought measurement in order to characterize the precipitation deficit for a given period [21]. This index is used to quantify changes in precipitation values at different time scales. In addition, this index makes it possible to determine the degree of humidity or dryness of a region for a period of time. However, climate data should contains monthly rainfall surveys of over than 20 years [13]. This index allows for the rapid detection and assessment of drought situations [21].

SPI is classified into six categories:

1. if SPI> 2 :extreme humidity;
2. if 1 <SPI <1.99 :strong humidity;
3. if 0 <SPI <0.99 : moderate humidity;
4. if -0.99 <SPI <0 : moderate drought;
5. if -1 <SPI <-1.99 : severe drought;
6. if SPI <-2 : extreme drought.

For this, SPI 6.2 software [21] is used because it is considered very efficient to calculate the SPI indices defined above. This index allows to quantify the severity of the drought for a duration of 1 to 24 months according to the study cases, so, the period covered by SPI index will vary according to the type of drought that makes the subject of the analyzes and applications envisaged. For example, the SPI index will be 1 to 2 months for a meteorological drought, 1 to 6 months for an agricultural drought and 6 to 24 months or more for a hydrological drought [21]. Our choice is limited to the period of 3 and 6 months coinciding with vegetation period of plants and the accumulation of soil moisture.

The purpose of using SPSS software is to define groups of years that are characterized by dry or wet periods. Tree method using the "Decision tree" procedure creates a segmentation model [11] with a tree form. In our case it classifies the observations into drought severity groups according to the ISPs of each month of the year. This is based on the Chi-squared Automatic Interaction Detection (CHAID) method, the khi-square determining node splitting and the modal fusion is calculated using Pearson's method. At each step, CHAID chooses the independent variable whose interaction with the dependent variable is the strongest. The modalities of each predicted value are merged if they do not show significant differences with the dependent variable at a significance level (P-value) is 0.05.

The “Excel 2010” tools allow to plot the ombrothermal diagram and to calculate anomaly indices and temperature trend as a function of time.

7. RESULTS AND DISCUSSION

7.1. Analysis of climate change

The climate of the region of Batna is known by its intra and interannual irregularity. Temperature reaches its maximum during the dry season in summer and its minimum during the winter season. Rainfall falls in winter, spring and even autumn, but in summer (June, July and August) it is occasionally as rain or hail formed in the midst of storm clouds. However, they regress significantly and constitute, with the increase in temperatures, a dry period from June to September according to the ombrothermal diagram (Fig. 2).

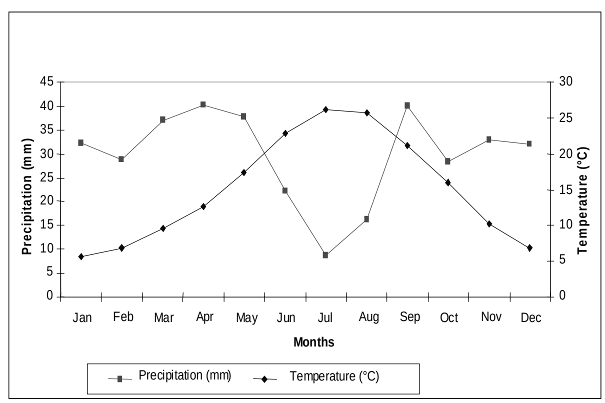


Fig. 2. Ombrothermal diagram.

7.2. Temperature anomalies and tendency

The evolution of temperatures through the period of 1975-2014 in the study region is represented by the following graph (Fig. 3).

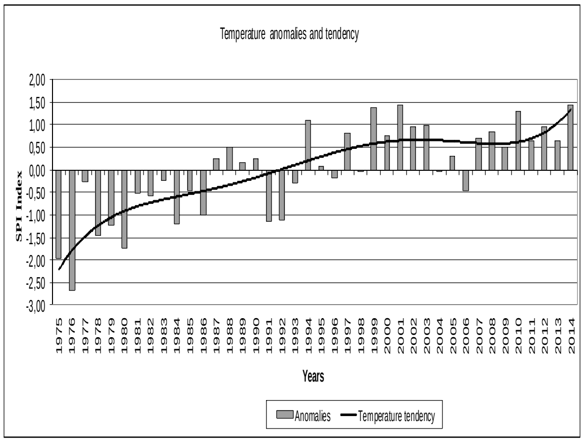


Fig. 3. Temperature anomalies and trends of the period 1975 at 2014 (Batna).

In the warmest years, the anomaly is positive. It becomes negative for the coldest years. This mode of presentation is frequently used to visualize the trend of temperatures. Our graph illustrates two sub-periods:

1- One, cold that dates between 1975 at 1991,
2- The other, warm from 1992 to 2014

The previous results show a trend towards a warming of the climate in the region; this is clearly distinguished between the two sub-periods. Positive anomalies would be increasingly higher as we approach the end of the series.

7.3. Drought at regional level

In this regard, we have tried to demonstrate the installation of dry periods in other stations adjacent to Batna as Setif and Bordj Bou Arreridj (Fig. 1), which are located on the same semi-arid bioclimatic stage, thus, the climate data of this localities covers only 32 years (1982 to 2014).

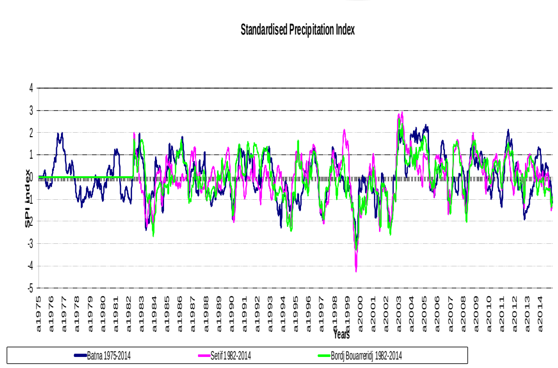
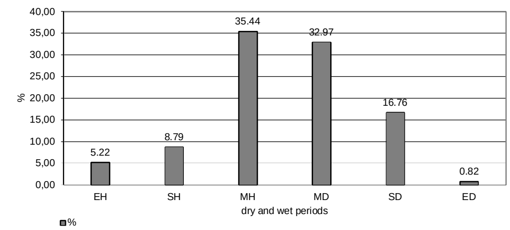


Fig. 4. *Installation of drought periods at the regional level (Setif, BBA and Batna)*.

Fig. 4 illustrate the evolution of precipitation at the regional level, where dry periods are practically comparable to those of Batna. The severity of the drought characterizes the period 1999-2000 whose values oscillate between -3.5 at Batna and -4.2 at Setif. However, in terms of duration, the periods recorded in Batna are the longest as those of Bordj Bou Arreridj and Setif.

7.4. Drought at regional level

The PSI results identify the dry and wet periods of the 40-year data series from 1975 to 2014 at Batna station. After the calculation, we obtained SPI indices of each month in number of 468. The following graph (Fig. 5) clearly shows the percentage of distribution of the wet periods compared to the dry periods. The frequency of the dry months is 50.55% (SM: 32.97%, SF: 16.76%, SE: 0.82%) and that of the wet months is 49.45% (HE: 5.22% 8.79%; HM: 35.44%).



EH: Extreme Humidity, SH: Strong Humidity, MH: Moderate Humidity;

MD: Moderate Drought, HD: Strong Drought, ED: Extreme Drought

Fig. 5. Frequencies of deferential classes of drought.

7.5. Determination of dry and wet periods

Fig. 6 illustrates the history of the dry and wet periods in Batna region between 1975 and 2014, these drought periods differ in severity and duration, some years are characterized by drought indices down than - 2 representing extreme droughts. In addition, it appears that a significant number of years are classified in the strong drought class with ISPs between -1 to -1.99.

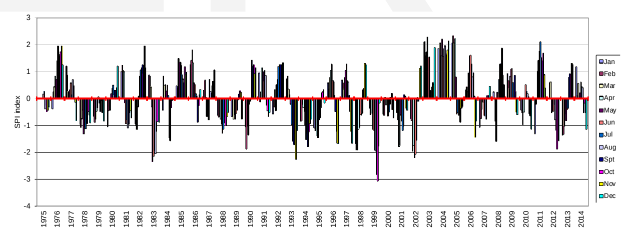


Fig. 6. Standardized precipitation index over the period 1975-2014 in Batna.

Classes of severity by years:

1- Moderate drought: 1975, 1977, 1979, 1980, 1986, 1987, 1989, 1991, 2000 and 2005
2- Strong drought: 1978, 1981, 1982, 1984, 1988, 1990, 1994, 1995, 1996, 1997, 2001, 2006, 2008, 2010
3- Extreme drought: 1983, 1993, 1999, 2002,

According to the duration of the drought, two droughts types are distinguished; Long (several years) or short from one year to a few months:

1- Short duration: 1975, 1979, 1983, 1984, 1986, 1987, 1990, 1991, 1996-1997, 2005, 2006-2007, 2008, 2009, 2011

2- Long duration: 1977-1980, 1981-1982, 1988-1990, 1993-1995, 1998-2002.

7.6. Grouping years according to ISP

The classification of years in groups dominated by dryness or moisture in function of their ISP of each month (n) is represented in Fig. 7. The classification tree highlights four groups that are displayed in the diagram by nodes; the driest one is represented by node 4 with 12 years dominating by months of moderate, strong and extreme droughts. Tends that nodes 2 and 3 combine the years with wet months. Finally the node1 regroups the eleven years which are characterized by a dominance of the drought and moderate humidity.

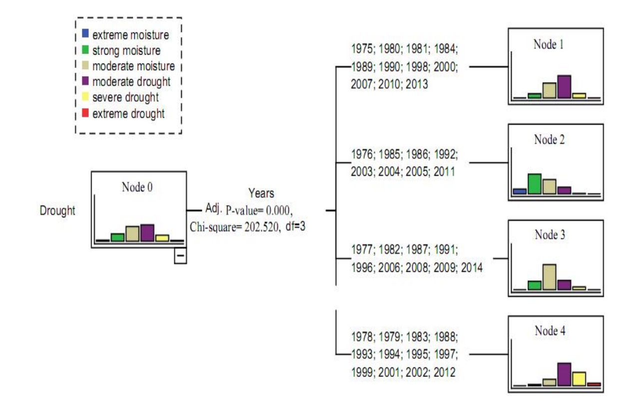


Fig. 7. Grouping of years according to ISP (wet and dry).

7.7. Classification of groups of years according to the severity of the drought

It is very interesting to highlight groups of years that are dominated by one or more drought classes. Fig.8 includes three nodes that clearly describe the severity of drought. The group of years which has recorded a great severity of drought is represented by the node3 by regrouping seven years; 1983, 1990, 1993, 1996, 1997, 1999 and 2002. In this group, the drought represents 55 months (22.8%) spread over seven years, this informs us about the deficit of these years in precipitation. The impact on nature is very important mainly as drought in this group (node3) has been repeated every three years from 1990 to 1999, and drought indices have fallen below -2.

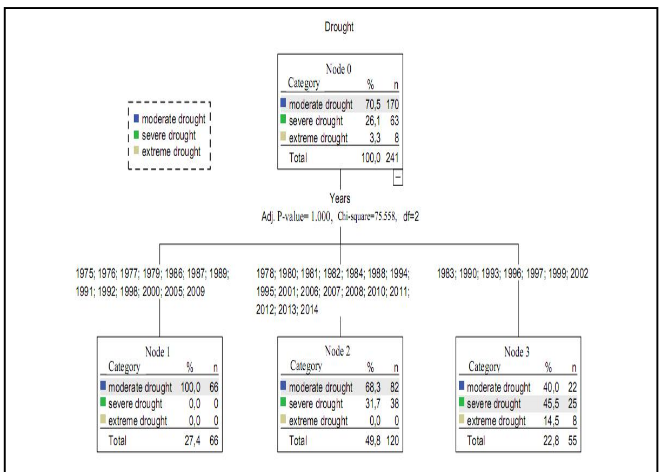


Fig. 8. Classification of groups of years according to the severity of the drought.

The group of the second node is composed by years of strong and moderate drought, with 120 dry months (49.8%) which represents 17 years. In this case, the impact is greater on nature, because droughts are repeated every two to three years, rainfall remains a deficit, but the values of the index do not fall below -1.99. The groups of node 2 and 3 thus have a strong impact on biodiversity by causing a large water deficit; this situation generates a veritable physiological imbalance.

7.8. *Distribution of drought by season of vegetation*

The Atlas cedar vegetation season begins in March and is contained until October, when the demand for water to meet the physiological needs of trees increases. Fig. 9 illustrates well the distribution of drought by years and vegetation season. Although, summer, autumn and spring seasons are characterized by dryness indices forming two groups of nodes. Node4 has a large number of years (19 years) characterized by moderate, severe and extreme droughts with 112 months, node3 with only 16 years of moderate drought.

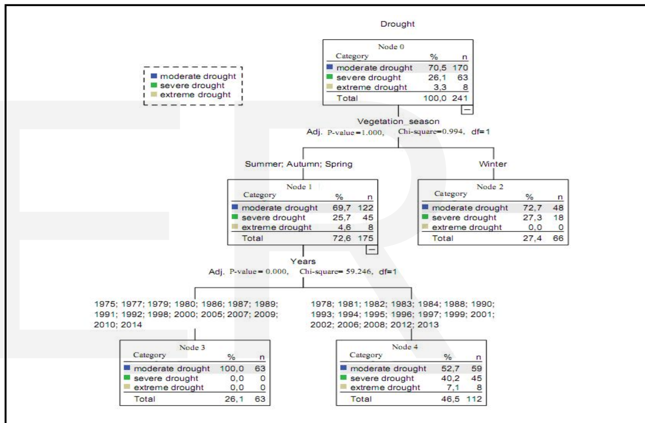


Fig. 9. Distribution of drought by season of vegetation.

These drought indices indicate that there has been no precipitation for a long period since 1978 to 2013 and is repeated at least every two years (node4). The appearance of its droughts during the growing season influences the photosynthesis and the transpiration of trees like cedar which regulates mediately its stomatal transpiration [17]. This causes a physiological imbalance and mortalities of whole or partial subjects.

7.9. The impact of drought on the vegetation (Atlas cedar) of Aures

After determining the periods of drought by the ISP method for the period 1975-2014, it is obvious that this drought had an impact on biodiversity as the case of the decline of the Atlas cedar. The results of research in pedology, entomology, sylviculture and others predict, a priori, the drought as a triggering factor of dieback [8], [1], [10], [3]. Although all the results obtained are interesting, the assessment of the water deficit and the severity of the drought may have a great contribution to explain the recent decline observed.

Historically, the decline of cedar is not new in Aures. According to several authors, cedar forest knew two episodes of very high mortality in 1880 and 1979. According to Delartigue (1904) and Boudy (1952, 1955), in 1880 two thirds of trees died, the remaining third was Consisting of old trees in decline process.

These authors attributed this phenomenon to a severe drought combined with a very severe cold that struck the region in 1879, however it was, a very cold and dry year in Europe [15]. The

Fig.10. Deserted woods released from cedar forest of Chelia (Aures) in 2008.

second episode took place in 1979 following a very intense drought where annual precipitation decreased to 50% of the annual average [1].

Thus, the health status of Atlas cedar in Algeria deteriorated from the 1980s onwards; It is linked to the massive decline in Aures (Chelia, Belezma), which account for one third of the area occupied by Atlas cedar in Algeria. The assumed causes are multiple, but the most probable according to many authors is the prolonged drought [3], [7], [16], this situation affects cedar water requirements, and even water deficit. It should be noted that this decline of the 1980s is identical to those of the 1880s [18]. This author attributed it to the period of drought from 1875 to 1881. He said: "This prolonged period of drought has weakened cedar that causes the frequent attacks of the bark beetles." The amount of timber harvested from the cedar trees of the Saharan atlas reflects the impact of decline in the region. According to Messaoudene (2013), thousands of cubic meters of cedar wood (34850.86 m3) were felled from cedar forest of Chelia and Belezma (Fig. 10).

Table 1, describes the areas populated by cedar and their fate after the decline. These data permitted us to quantify the intensity of cedar dieback in Belezma after the clean-up of all dead wood in 2008.

TABLE 1
IMPACT OF DIEBACK ON ATLAS CEDAR OF BELEZMA

Stands	Area (ha)	Impact (%)
Tichaou	504	50
Tugguert	675	50
Bordjem	651	30 to 40
Boumerzoug	375	100

8. CONCLUSION

To identify drought, several climatic indices are used. The ISP is currently the most effective weather drought index. Its application in Batna region allowed to identify drought periods using actual climatic data collected from Batna weather station.

Drought generally maintains a moderate character in Batna region, but the occurrence of periods with severe and extreme droughts makes the life of some so-called drought-resistant species in difficulty. The ISP may be used as an indicator to understand the cause of the occurrence of certain phenomenon. It is desirable to multiply meteorological stations in altitude and latitude in order to give more efficiency to the ISP in interpreting the results on a phenomenon related to meteorological drought.

The results confirm that since 1975 the climate has evolved causing dry and wet periods. The comparison with the years of decline coincides with the periods of drought recorded during the 1975-1974 series. This climatic history opened another window to explain the cause of cedar dieback of the atlas. This method also makes it possible in the future to monitor the phenomenon of dieback by comparing it with the dry and wet periods calculated from the ISP.

Finally, cedar is known for its resistance to drought of short duration of less than four months [17], but the presence of dry periods of long period: duration and severity had major repercussions on its health, especially if they are accompanied by a global warming of the study area that was recorded from 1992. The mortality of trees of different age over large areas testifies the decline of the carbon sink associated with decline. Cedar trees in Algeria are under severe human and pastoral pressure, resulting in a gradual degradation of stands. The cedar of atlas is permanently threatened and stands are disappearing in North Africa because of overgrazing and other factors still unknown [25]

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