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Drought monitoring till 2100 using future projected climate in Wadi M'Zi sub-basin

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Abstract— Drought can be defined as a slow process with a long absence of precipitation. This phenomenon touches Algeria from four decades. several drought indices were developed among them the Standardized Precipitation Index “S.P.I” and Reconnaissance Drought Index “R.D.I” which are used worldwide and they proved their performance. Our study took place in Wadi M'Zi sub-basin in order to monitor the real and predicted meteorological drought till 2100 using Coupled Model Intercomparison Project “C.M.I.P”. Drought monitoring between 1980 and 2017 showed two periods with a moderate to extreme severity, while the predicted drought shows a durations and severities diminution compared to the real ones except for the eighteen and ten last years for SPI-RDI 9 & 12 respectively.

Key-Words— Wadi M'Zi sub-basin, drought, “S.P.I.”, “R.D.I.”, “C.M.I.P.”, Duration and severity.

I. INTRODUCTION

Algeria is concerned by drought since 1975 [1]. This phenomenon may have negative impacts on water resources. Drought prediction has been deemed by many studies. Therefore, appropriate methodological approaches are necessary for the accurate assessment of historical and future drought events. Effective drought prediction methods are essential for the mitigation of adverse effects of severe drought events [2].

The real and predicted drought monitoring becomes possible with the initiation of the meteorological drought indices. About 150 drought indices have been developed characterizing drought anomalies. The Standardaized Precipitation Index and the Reconnaissance Drought index have been used in this study for monitoring the actual drought (1980-2017) with different “P.E.T.” methods (Hargreaves-Samani, Thornthwaite and Blaney-Criddle methods) and the predicted drought (2018-2100) using the Thornthwait method for the determination of the PET. basing on the projected precipitations and temperatures extracted from the Global Climate Models and among them the Coupled Model Intercomparison Project “C.M.I.P.”. The main goal of this research is to investigate the future projection of droughts in the Wadi M'Zi sub-basin using projected meteorological data extracted from a Global Climate Model which is the Coupled Model Intercomparison Project “C.M.I.P.2.”.

II. STUDY AREA

Wadi M'Zi is one of the most important wadies in the Central Saharian Atlas. This wadi begun in Aflou in Djebel Amour massif to meet Wadi Messaad in the South-East of Laghouat to create a new Wadi which is called Wadi Djedi (fig.1).

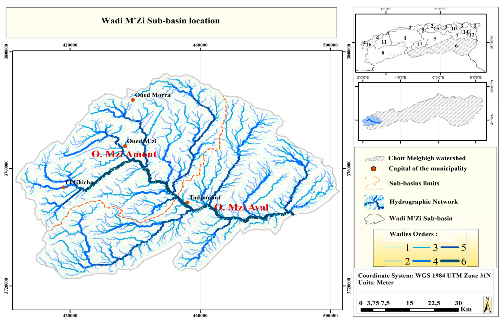

Fig. 1. Wadi Djelfa-Hadjia sub-basin location.

Table I. Laghouat meteorological station characteristics.

Station	Longitude	Latitude	Z(m)	Selected period
Laghouat	E 2° 55' 48"	N 33° 45' 36"	765	1980-2017

III. METHODS

This work methodology is based on the measured and predicted precipitations and temperatures to assess and monitor the drought. The drought prediction till 2100 is determined on the base of the Global Climate Models "G.C.M." among them the Coupled Models Intercomparison Project "C.M.I.P.". The "S.P.I." and "R.D.I." indices are used with different "E.T.P." methods: Hargreaves-Samai, Thornthwaite and Blaney-Criddle.

A. Standardized Precipitation Index

Designed by McKee et al [3] to quantify the precipitation deficit, The "S.P.I." can be calculated in any place on the base of the precipitation over a long period.

The "S.P.I." can be calculated for a variety of time scales (1, 3, 6, 12, 24 et 48 months). This versatility allows "S.P.I." to monitor short-term water supplies, such as soil moisture, which is important for agricultural production, and long-term water resources, such as groundwater supplies, stream flow, lake and reservoir levels [4]. It is expressed mathematically as follows:

$$SPI = \frac{\left(X_{ij} - \overline{X}\right)}{\sigma} \quad (1)$$

In which, X is the seasonal precipitation at the i^{th} rain gauge and j^{th} observation, $\overline{X}$: the long-term seasonal mean and σ : standard deviation.

B. Reconnaissance Drought Index

Reconnaissance Drought Index "R.D.I." was created by G. Tsakiris and H. Vangelis (2005) [5]. It is a meteorological index for the drought assessment, based on the measured cumulative precipitation and calculated potential evapotranspiration [6]. The "R.D.I." is expressed in three forms as follows:

- The Initial α_k:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, i = 1(1)N \text{ and } j = 1(1)k \quad (2)$$

Where, P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of month *j* of hydrological year *i*.

- The Normalized RDI (RDI_n):

$$RDI_n^{(i)} = \frac{\alpha_k^{(i)}}{\overline{\alpha_k}} - 1 \quad (3)$$

Where:

$\overline{\alpha_k}$ is the arithmetic mean of α_k values.

- The Standardized RDI (RDI_{st}):

$$RDI_{st}^{(i)} = \frac{y_k^{(i)} - \overline{y_k}}{\hat{\sigma}_{yk}} \quad (5)$$

Where, $y_k^{(i)}$ is the $\ln(\alpha_k^{(i)})$, is the arithmetic mean and $\hat{\sigma}_{yk}$ is the standard deviation.

Table II. Classification of Drought according to "S.P.I." and "R.D.I." values.

Description	Criterion
2 or more	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

C. Potential evapotranspiration

The methods of the potential evapotranspiration "P.E.T." estimation are divided into two categories, the temperature based equations which contains the three methods which will be used in this work (The Hargreaves-Samani, the Thornthwaite, the Blaney-Criddle methods), and the Reduced-set "P.M." methods containing the Priestley-Taylor, The Makkink, The Turc, The Jensen and Haise methods [7].

The calculation of "R.D.I." with four "P.E.T." methods (Hargreaves, Thornthwaite, Blaney-Criddle and "F.A.O." Penmane-Monteith (only T)) in a coastal semi-arid (Mediterranean) climatic conditions has shown that there is no significant influence on the results [6].

C. 1. The Hargreaves-Samani method

The Hargreaves-Samani is a temperature based empirical method, it was developed from 1975 until 1985, and the equation is written as [8].

$$PET = 0.0023R_a(T+17.8)(T_{\max} - T_{\min})^{0.5} \quad (6)$$

In which R_a is the extraterrestial radiation in mm/day, *T isthe mean Temperature in* ℃, T_{max} is the mean daily maximum temperature and T_{min} is the mean daily minimum temperature.

C. 2. The Thornthwaite method

Widely used all over the world, it was developed by Thornthawaite in 1948 to estimate ET_0 for short vegetation with an adequate water supply in certain parts of the USA [7]. The calculation of this method is based on the following equation:

$$I = \sum_{i=1}^{12} \left(\frac{T_{mean}}{5} \right)^{1.5} \quad (7)$$

Where:

T_{mean} is the mean monthly temperature (°C).

C. 3. The Blaney-Criddle method

Created by Blaney and Criddle (1950) [9] and modified by Doorenbos and Pruitt (1977) [10], The equation of Blaney-Criddle method is written as: $PET = \alpha + \beta[P(0.46T + 8.13)]$ (8)

Where:

α and β are calibration parameters, T is the average monthly temperature, P is the mean annual percentage of daytime hours, RH_{min} is the average of minimum relative humidity, n is the monthly average of actual sunshine hours, N is the monthly average of possible sunshine hours and U_{day} the wind speed at 2 m height.

D. Drought prediction

Aquifers are recharged mainly by precipitation or through interaction with surface-water bodies [11]. In order to predict the drought in the study area, future projections of climate must be realized.

D. 1. Future Projections of climate

These projectios are essentially based on Global Climate models "G.C.M." A model is a climate mathematical modelisation in a gegraphical location. These models come in different forms, ranging from simple energy-balance models to Earth-system models of intermediate complexity to comprehensive three-dimensional general circulation models of the atmosphere and oceans or global climate models "G.C.Ms.". "G.C.Ms." are the most sophisticated tools available for simulation of the current global climate and future climate scenario projections. Over the last few decades, physical processes incorporated into these models have increased from simple rain and "CO2" emissions to complex biogeochemical (includingwater vapor) feedbacks [12].

The "I.P.C.C." (Intergovernmental Panel on Climate Change) (2007b) [13] considered six scenarios for projected climate change in the twenty-first century. These included a subset of three IPCC Special Report on Emission Scenarios [14] non-mitigation emission scenarios representing 'low' "B.1.", 'medium' "A.1.B." and 'high' "B1." scenarios.

The Coupled Model Intercomparison Project "C.M.I.P." is a project of the World Climate Research Project "W.C.R.P.". This project aims to perform climate simulations in coordinated ways between the different research groups, allowing a better estimation and understanding of the differences between the climate models. It also makes it possible to estimate the uncertainty due to the imperfection of models in the estimation of climate change related to humans. The research results based on these simulations are taken into account in the assessment of the state of climate knowledge by the Intergovernmental Panel on Climate Change "I.P.C.C.". In our case we will use the "C.M.I.P.2." for temperatures and precipitations projection.

IV. RESULTS AND DISCUSSIONS

A. Assessment of the meteorological drought

- *Long term drought*

In this study we used the "S.P.I." and "R.D.I." indices which proved their performance and in order to determine the drought duration and severity in the Wadi M'Zi sub-basin.

We mention that the results obtained by “S.P.I.s.” and “R.D.I.s.” 9 & 12 time scales (Fig. 2 & 3) represents the long term drought. The maximum drought durations are observed between October-1998 (“S.P.I.”-“R.D.I.” 9 & 12), May-2005 (“S.P.I.”-“R.D.I.” 12), July-2005 (“S.P.I.” 9) and August-2005 (“R.D.I.” 9) also between November-1984 and January-1986 for the “S.P.I.”-“R.D.I.” 12 with a moderate to extreme severity.

The maximum drought months are in the order of 82 and 80 months for “S.P.I.” 9 & 12, 83 and 80 months for “R.D.I.” 9 & 12 respectively.

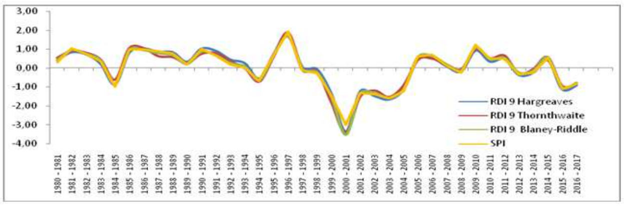

Fig. 2. “S.P.I.s.” and “R.D.I.s.” comparison with a nine months time scale calculated using different PET methods.

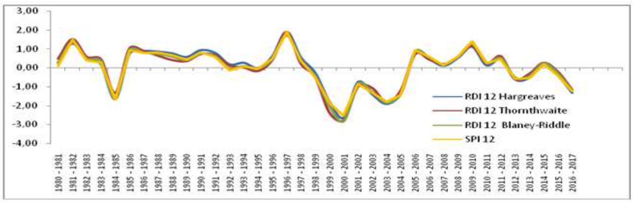

Fig. 3. “S.P.I.s.” and “R.D.I.s.” comparison with a nine months time scale calculated using different PET methods.

B. Drought prediction

- *Long term drought*

The figures 4 and 5 representing the “S.P.I.”-“R.D.I.” 9 & 12, the figure 4 show three maximum drought durations. The “S.P.I.s.” from October-2029 to February-2034, from October-2055 to March-2060 and from April-2082 to January-2100. The “R.D.I.s.” between: November-2027 & January-2034, October-2055 & September-2060 and March-2082 & January-2100. The figure 5 show four maximum drought durations, The “S.P.I.s.”: October-2027 to August-2030, September-2053 to October-2057, October-2085 to October-2088 and February-2091 to September-2100. For the “R.D.I.s.”, the maximum drought durations are ranged between: February-2027 & April-2030, October-2053 & October-2057, March-2085 & September-2089 and October-2090 & September-2100. We mention that all this durations are with a moderate to extreme severity.

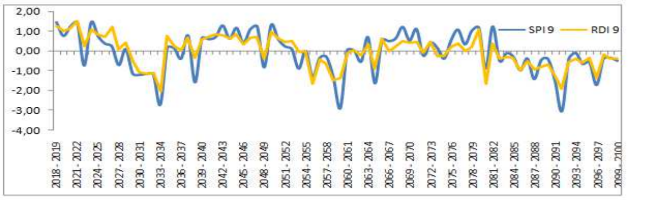

Fig. 4. SPI & RDI comparison with a nine months time scale for the projected climate.

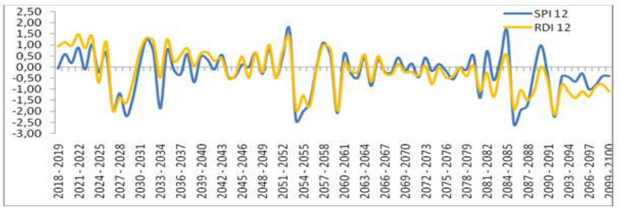

Fig. 5. SPI & RDI comparison with a twelve months time scale for the projected climate.

From the comparison between the real and projected drought we can conclude that there is a diminution in drought durations and severities for the projected climate compared with the actual situation (1980-2017) in contradiction with the projected precipitations and temperatures which decrease also. The only durations which increase are observed in the last eighteen and ten years by the SPIs & RDIs 9 and 12 respectively. The RDI is the index that shows the greater number of drought months compared with the SPI [15].

V. CONCLUSION

The drought monitoring for the real (1980-2017) and the projected climate basing on the Global Climate Models among them the Coupled Model Intercomparison Project (CMIP2) (2018-2100) in order to have an idea about the drought severities and durations using meteorological drought indices (SPI and RDI) allow to concluse that the

Wadi M'Zi sub-basin knew and will know several drought durations with moderate and extrem severities and this laters will decrease in the future in a contraduction with the projected precipitations and severities.

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