EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(6), 243–263
https://doi.org/10.12912/27197050/152959
ISSN 2719-7050, License CC-BY 4.0

Received: 2022.08.07
Accepted: 2022.08.24
Published: 2022.09.07

Meteorological Drought Assessment in the Ziz Watershed (South East of Morocco)

Safae Dafouf[1*], Abderrahim Lahrach[1], Hassan Tabyaoui[2], Mohammed El Hafyani[3], Lahcen Benaabidate[1]

[1] Laboratory of Functional Ecology and Environment Engineering, Faculty of Sciences and Techniques, University of Sidi Mohammed Ben Abdellah, Fes 30000, Morocco

[2] Laboratory of Natural Resources and Environment, Polydidisciplinary Faculty, University of Sidi Mohammed Ben Abdellah, Taza 35000, Morocco

[3] Department of Geology, Laboratory of Geoengineering and Environment, Faculty of Sciences, Moulay Ismail University, Zitoune, Meknes 11201, Morocco

* Corresponding author's e-mail: safae.dafouf@usmba.ac.ma

ABSTRACT

In the face of climate change, drought monitoring and characterisation is indispensable in arid and semi-arid areas. This paper represents a metrological drought assessment in the Ziz watershed located in south-eastern Morocco, through the application of four meteorological indices: rainfall anomaly index (RAI), percentage of normal index (PNI), standardized precipitation index (SPI), z-score index (ZSI). Based on rainfall data series from four stations over a time scale of 37 years (from 1983), also taking into account the relationship between these indices. The analysis of the rainfall series indicates a variability in its spatio-temporal distribution. However, the calculated drought indices indicate that the Ziz basin has experienced drought periods with their different classifications between 1983–2019, noting that the years 1986 and 2001 were dry to extremely dry in all stations of the basin. Thus, the results highlight a strong correlation between the four indices ($r \geq 0.967$).

Keywords: meteorological drought, drought indices, arid regions, South East Morocco.

INTRODUCTION

It is clear that the water scarcity is a concern in significant regions of the world. Indeed, this problem relies upon two crucial factors: hydro climatology and the socio-economic situation (El Moçayd et al., 2020; Wada et al., 2014). Consequently, water scarcity is reflected in 66% of the world's population suffering from it (Cuenca et al., in press; El Hafyani et al., 2020). Nevertheless, the Mediterranean regions are the most threatened by this environmental problem due to several factors, namely: The severe natural variation between years, furthermore, the seasonal water resources and the declined stream flows in expected contemplated in the forthcoming years. (El Hafyani et al., 2020; Martinez and Poole, 2004).

Nonetheless, these critical conditions of water scarcity are linked by drought. Hence, Stagna defined drought as the period and state of water supply resulting from the negative difference between water inflow and outflow in the hydrological system, thus it can cause imbalances and malfunctions of reversible or irreversible character (Stângă, 2009). In case where the precipitation deficit is the only considered, then is considered as a meteorological drought (Boken et al., 2005; Keyantash and Dracup, 2002). Arid and semi-arid areas are the most likely to be threatened by this type of drought due to their climatic characteristics which are reflected in the rainfall deficit. In addition, climate change increases the risks related to drought, due to a strong increase in temperature that contributes to amplified evaporation, which leads to the consolidation of the intensity and duration of drought. Therefore, the occurrence and adverse effects of drought are likely to accelerate land degradation and desertification in the long term (OMM and GWP, 2014). Not only the environment, but also the impact of droughts could also affect the economic and social sectors (Layelmam, 2008), on account of the importance of water used for the production of goods and services (Stour and Agoumi, 2008).

Morocco by its geographical location is characterized by a high spatial variability of the climate (El Moçayd et al., 2020), which might vary from sub humid to arid on the country (Born et al. 2008), as well as an uneven distribution of precipitation in the space (El Moçayd et al., 2020). The characterization of climatic drought in Morocco throughout the last decades (Stour and Agoumi, 2008) has laid out a sturdy vigor of drought portrayed by a propensity reduction of precipitation, moreover, a notable warming of the climate equivalent to a noticeable jump of the evapotranspiration; all what have been referenced induces to an absolute crucial hydric deficit (Stour and Agoumi, 2008).

Within the similar environmental context, the demand for water among various user sectors is still increasing due to the demographic evolution, hence the rise of environmental problems and the severe impact of drought sequences (Jellali, 1997). In addition, climate change predictions envisaged that Morocco will experience dry weather in the future (El Moçayd et al., 2020; Giorgi and Lionello, 2008) and rainfall scarcity (El Moçayd et al., 2020; Patricola and Cook, 2010), as well as an expected change in their distribution and extreme events (Driouech et al., 2010).

Several previous studies on drought in Morocco have presented regional drought assessments through the application of meteorological indices. Most of the latter studies have utilized the standardized precipitation index (SPI) (McKee et al., 1993). Melhaoui et al. have used the SPI corrected for the assessment of meteorological drought in the Moroccan Eastern Highlands between 1980 and 2015, this study showed that in 2000 most of the rural communes are affected by severe drought (Melhaoui et al., 2018). Thus, El Hafid et al have applied the SPI on the Isly basin watershed and the results showed that there is a significant trend of severe drought in the Isly basin during 1970–2016 (El Hafid et al., 2017). In another region, precisely in the Oum Rbie catchment, the SPI identified sequences of metrological drought between 1985 and 2013 (Daki et al., 2016). Another study carried out on the same basin and by applying SPI and other indices including rainfall deviation, deviation from average index, rainfall normal index and standardized rainfall index, the results showed dry spells in most of the 1980s and the first half of the 1990s, as well as in the early 2000s (Jouilil et al., 2013). In the south-east of Morocco precisely at the level of the Ziz catchment area the SPI showed that this catchment area experienced during the period 1982–2013 a drought severity (Mehdaoui et al., 2018).

To summarize, it is inevitable to implement a risk management policy intended to reduce the potential impacts of drought, yet first it is necessary to reinforce information on the characterization and analysis of drought sequences by the various useful materials excited for a given area over a given time interval. In this context, the present work is interested in characterizing and analyzing the sequences of meteorological drought in the Ziz catchment between 1983 and 2019. We will adopt the standardized precipitation index and other indices, namely: precipitation anomaly index (RAI), percentage of normal index (PNI), z-score index (ZSI), on a scale of 37 years in order to transmit precise information on the evolution of drought.

MATERIAL AND METHODS

Study area

This study was carried out on the Ziz watershed, part of the large Ziz-Rhéris and Guir watershed (Errachdia region), located in the South East of Morocco. It covers an area of 13992 km², and reaches from the Rheris watershed to the West and the Guir watershed to the East (Fig. 1). Its main rivers come from the summits of the High Atlas, where they are supplied by springs emanating from the aquifers of the Jurassic limestone and by pluviometric contributions, including a snowy quantity. Consequently, they affirm in particular the impoundment of a large part of temporary tributaries (Hammada, 2007).

The Ziz watershed is characterised by a semi-desert (Saharan) climate with continental dominance (Riad, 2003) (Table 1). Between 1983 and 2019, the average annual precipitation varies between 3.09 mm and 13.42 mm

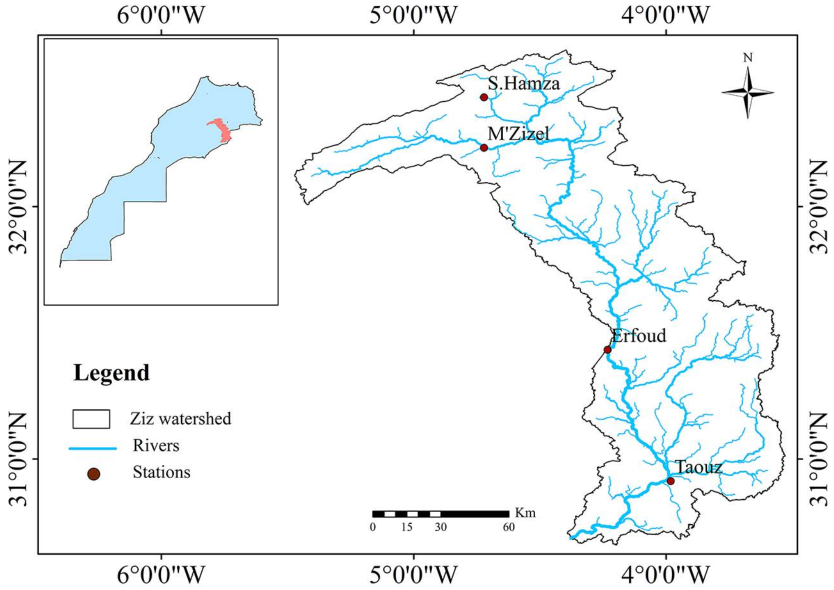

Figure 1. Geographical location of the climatic stations of the Ziz watershed

Table 1. Geographical characteristics of the stations in the Ziz watershed

Station	Latitude (°, N)	Longitude (°, W)	Altitude (m)
Sidi Hamza	32.43	-4.72	1738
M'Zizel	32.23	-4.72	1600
Erfoud	31.43	-4.23	800
Taouz	30.91	-3.98	676

recorded respectively in 1986 and 2008, the minimum and maximum values of the average annual temperature over the whole basin were recorded respectively 19.86 °C and 23.66 °C. Evapotranspiration values vary from 255.40 mm/year to 460 mm/year (Fig. 2).

The adopted methodology

The meteorological indices were used to determine the intensity and duration of the drought, which allows us to define the current climatic characteristics of the study area. The first step required in completing this work was the collection of data from the Hydraulic Basin Agency of Guir Ziz and Rheris. These data are related to the monthly rainfall of the selected study area which is the watershed Ziz, precisely at Sidi Hamza, M'zizel, Erfoud and Taouz stations, during the period 1983–2019 (Fig. 1).

On the basis of these collected data, a series of calculations of meteorological indices (RAI, PNI, SPI, ZSI) was performed by the RDIT tool, which is a software that allows us to calculate eight meteorological drought indices from the precipitation data. Several indices are referred to in order to reinforce the information, and to study the compatibility of these indices through the results obtained.

Subsequently, two non-parametric tests, namely the Mann-Kendall test (Kendall, 1975; Mann, 1945) and the Sen slope (Sen, 1968), were applied to the calculated indices time series in order to determine the trend of the meteorological drought in the Ziz basin during the period 1983–2019. Figure 3 presents flowchart of the implemented methodology.

Meteorological indices

Rainfall anomaly index

The rainfall anomaly index was established by (Van Rooy, 1965) to identify positive and negative precipitation anomalies over a historical series, it can be calculated on a monthly or annual time scale. It is considered to be among the most efficient meteorological indices in terms of result, and the simplest in terms of its method of

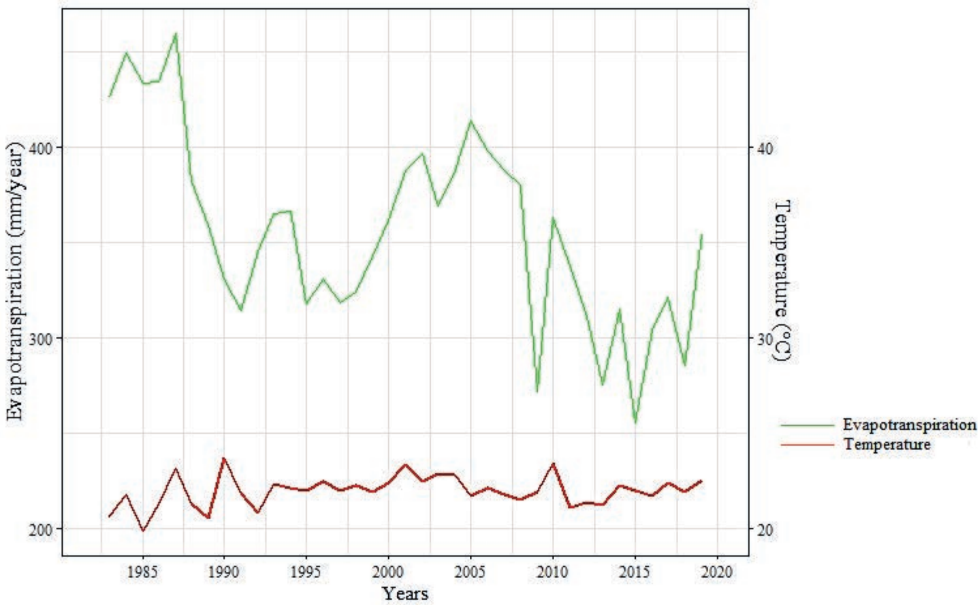

Figure 2. Evolution of the annual average of temperature and evapotranspiration in the Ziz watershed (Period 1983–2019)

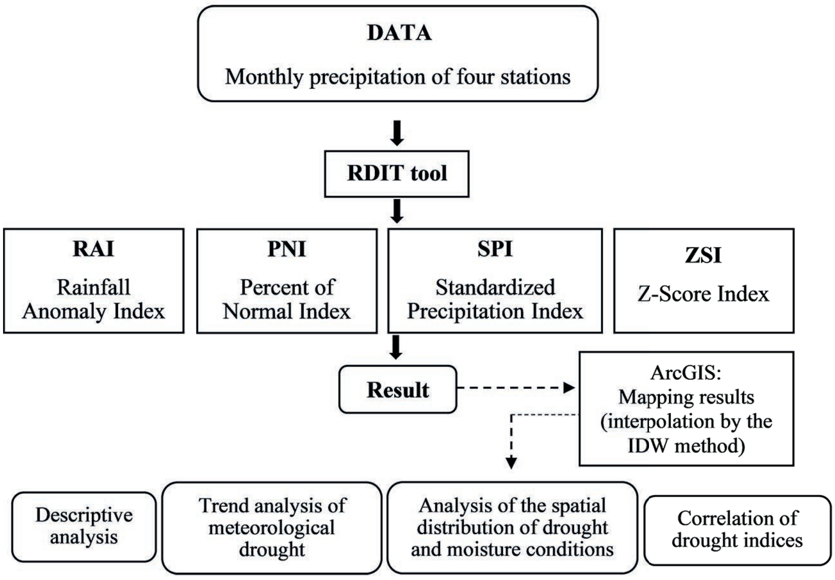

Figure 3. Flowchart of the implemented methodology

calculation (Ndlovu and Demlie, 2020). The RAI is calculated using the following equations:

$$RAI = 3\left[\frac{P-\bar{P}}{\bar{M}-\bar{P}}\right] \; if \; P > \bar{P} \tag{1}$$

$$RAI = -3\left[\frac{P-\bar{P}}{\bar{X}-\bar{P}}\right] \; if \; P < \bar{P} \tag{2}$$

where: P – the actual precipitation (mm); $\bar{P}$ – the average precipitation of the historical series (mm); $\bar{M}$ and $\bar{X}$ – respectively represent the average of the ten highest and lowest precipitation values of the historical series. The drought classification based on the RAI is indicated in Table 2.

Percent of normal index

The percentage of normal index (Willeke et al., 1994) is used to describe the meteorological drought. Based on precipitation data, the PNI is calculated by a simple and rapid method, for various time scales. Indeed, it is the ratio of actual precipitation to normal precipitation multiplied by 100.

Table 2. Classification of drought according to the value of the rainfall anomaly index (Van Rooy, 1965)

RAI	Drought category
≥3.0	Extremely wet
2.0 to 2.99	Very wet
1.0 to 1.99	Moderately wet
0.50 to 0.99	Slightly wet
0.49 to −0.49	Near normal
−0.50 to −0.99	Slightly dry
−1.0 to −1.99	Moderately dry
−2.0 to −2.99	Very dry
≤−3.00	Extremely dry

$$PNI = \frac{P_i}{P} \times 100 \quad (3)$$

where: P_i – the actual precipitation; P – the normal precipitation.

Table 3 shows the different categories of drought according to PNI values.

Standardized precipitation index

The standardized precipitation index (McKee et al., 1993) is one of the most recognized meteorological indices for identifying and monitoring drought periods. Based on a long historical precipitation record, the SPI can be calculated for different time scales (1, 3, 6, 12, 24 and 48 months). The mathematical formula for SPI is as follows:

$$SPI = \frac{(P_i - P_m)}{\sigma} \quad (4)$$

where: P_i – total precipitation of the period (i); P_m – the mean precipitation of the period; σ – standard deviation.

Z-score index

Several researchers have admitted that the ZSI is as efficient as the SPI (Table 4), and that it can be calculated on several time scales (Jain et al., 2015). The ZSI does not require adjusting the precipitation data to the gamma distribution or the Pearson type III distribution. It is expressed by the following equation:

$$ZSI = \frac{P_i - P}{S} \quad (5)$$

where: P_i – the precipitation of year or month (i) in (mm); P – the mean precipitation (mm); S – the standard deviation (mm).

Trend analysis

Mann-Kendall (MK) trend test

The non-parametric Mann-Kendall test (Kendall, 1975; Mann, 1945) is used to detect the trend of a time series, particularly the series of meteorological and hydrological variables (Yagbasan et al., 2017). The Mann-Kendall S-test statistic is calculated using the following equation (Yagbasan et al., 2020):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (6)$$

$$sgn(x_j - x_i) = \begin{cases} +1 & x_j > x_i \\ 0 & x_j = x_i \\ -1 & x_j < x_i \end{cases}$$

where: n is the number of data points, x_i and x_j represent the data in the timeseries i and j respectively.

The variance of the S-statistic is calculated as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i\,(t_i - 1)(2t_i + 5)}{18} \quad (7)$$

where: P – the number of tied groups (a tied group refers a set of sample data and has the same value); t_i – the number of ties of extent i.

If the sample size greater than 10, the Mann–Kendall Z value may be obtained by:

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

According to the values of Z obtained, it can be deduced that there is a statistically significant trend if $|Z| \geq |Z_{1-\alpha/2}|$ in which case the null hypothesis is rejected and the alternative hypothesis is therefore accepted.

Table 3. The classification of drought categories according to PNI (Javan et al., 2017)

PNI	Drought category
> 80%	Normal
70–80%	Soft drought
55–70%	Moderate drought
40–55%	Severe drought
< 40%	Extreme drought

Sen's slope estimator

The non-parametric method of Sen slope (1968) used to determine the magnitude of the trend in a time series (Sharma and Goyal, 2020). The slope of Sen is calculated using the following formula:

$$S_i = \frac{x_j - x_k}{j - k} (i = 1, \ldots, N) \quad (9)$$

where: N – the number of data; x_j and x_k – the data at time j and k respectively.

An upward trend is indicated by a positive value of Sen's slope estimator and a downward trend is indicated by a negative value of the time series (Sharma and Goyal, 2020).

RESULTS

In general, during the period 1983–2019 the rainfall regime in the Ziz watershed is characterised by a variability in its spatiotemporal distribution, considering the coefficient of variation as well as the coefficient of immoderation which express this variability in the four stations (Table 5). In addition, the average annual rainfall takes a maximum value of 20.8 mm in the M'Zizel station and a minimum value of 0.38 mm in the Taouz station. Furthermore, the Fisher asymmetry coefficient is positive in the four stations, this indirectly reflects an interannual irregularity of precipitation in the Ziz watershed (Table 5).

From the series of rainfall data, we can determine the rupture period, which means the point of change of the average of the data (Ozer et al., 2014). For this, several methods have been implemented to detect this rupture, we mention the pettitt test (1979), the Bayesian method of Lee and Heghinian (1977), the statistic of Buishand (1982, 1984) and the segmentation of Hubert et al. (1989). These four methods are applied to the rainfall series (1983–2019) from the station S. Hamza, M'Zizel, Erfoud and Taouz.

The results of pettitt test and Hubert segmentation indicate that the three stations S. Hamza, M'Zizel and Taouz show no rupture during the 37 years. On the other side, these two methods reveal a rupture in 2005 in the Erfoud station, thus the results of the Bayesian method of Lee and Heghinian also reveal a rupture in 1988, 1984, 2005 and 2004 respectively in the rainfall series of the S. Hamza station, M'Zizel, Erfoud and Taouz station.

Indeed, the annual rainfall regime varies from North to South of the watershed, where the S. Hamza station records the highest values of precipitation, while the Taouz station records the lowest values (Fig. 4), which leads to the altitude factor where precipitation increases as a function of altitude (Fig. 5) $R^2 = 0.93$.

Table 4. Drought classification according to SPI, ZSI values (Jain et al., 2015)

SPI, ZSI	Drought category
≤−2.00	Extremely dry
-1.99 to -1.50	Very dry
-1.49 to -1.00	Moderately dry
-0.99 to 0.99	Normal
1.0 to 1.49	Moderately wet
1.5 to 1.99	Very wet
≥2.0	Extremely wet

Table 5. The statistical parameters characterizing the precipitation distributions (mm) in the four stations of the Ziz watershed

Parameter	S. Hamza	M'Zizel	R. Erfoud	Taouz
Average	10.96	7.67	3.49	2.72
Median	10.70	6.83	2.87	2.91
Min	4.27	3.34	0.81	0.38
Max	20.82	20.85	9.21	6.67
Standard deviation	3.64	3.57	2.09	1.54
Variance	13.23	12.73	4.36	2.36
Coefficient of variation	0.33	0.47	0.60	0.56
Coefficient of immoderation	4.88	6.24	11.39	17.78
Coefficient of asymmetry (Fisher)	0.58	1.54	1.10	0.80

Note: coefficient of variation – standard deviation/average; coefficient of immoderation – maximum value/minimum value; coefficient of asymmetry (Fisher) – the centered moment of order three/ cube of the standard deviation.

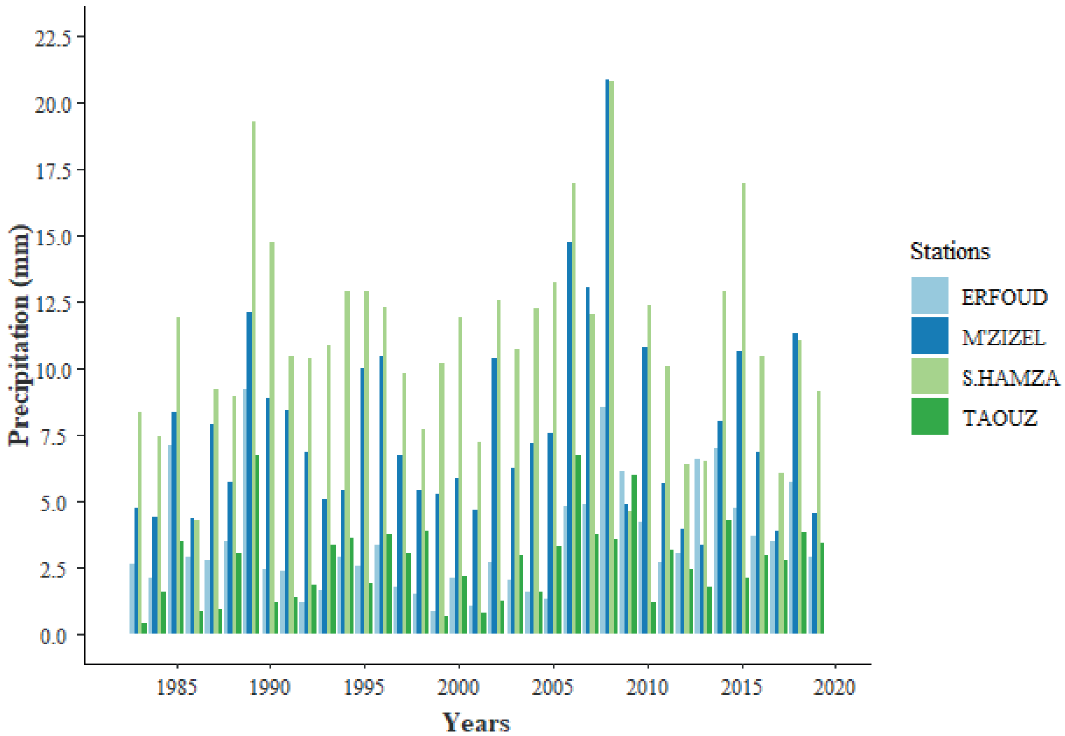

Figure 4. Evolution of annual average precipitation in S. Hamza, M'Zizel, Erfoud, Taouz stations (Period 1983–2019)

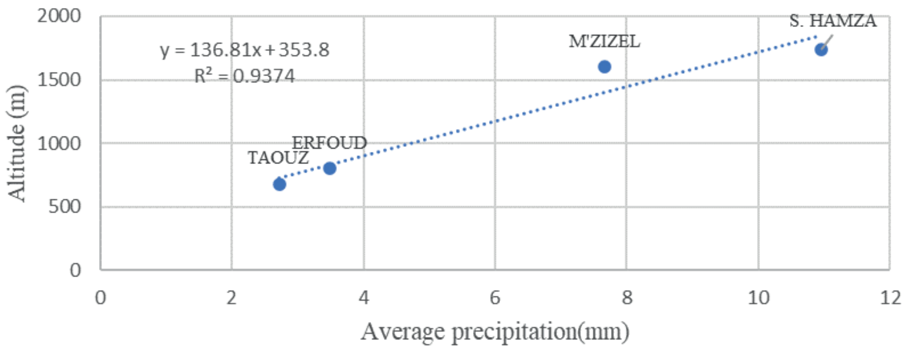

Figure 5. Evolution of average annual precipitation as a function of station altitude (Period 1983–2019)

Identification of meteorological drought in the Ziz watershed

In this section, we will analyze the results of calculation of meteorological drought indices (RAI, PNI, SPI, ZSI) for each station separately, in order to identify the intensity and duration of droughts over 37 years.

Sidi Hamza station

The analysis of meteorological drought indices RAI, PNI in Sidi Hamza station reveals very dry years during the period 1983–1988 except for the year 1985 which was slightly wet. In contrast, during the same period the SPI, ZSI indices indicate only one dry year which was 1986. From the results of all calculated indices, the period 1989–2008 was marked by the dominance of normal years and also very wet years. Furthermore, the period 2009–2019 saw years of extremely dry compared to normal and wet years (Fig. 6).

M'zizel station

About the M'Zizel station, the results of meteorological drought indices RAI, PNI show a succession of dry periods and wet periods. Moreover, the period 1987–2011 is generally characterized by the dominance of normal years expressed by the results of SPI, ZSI (Fig. 7).

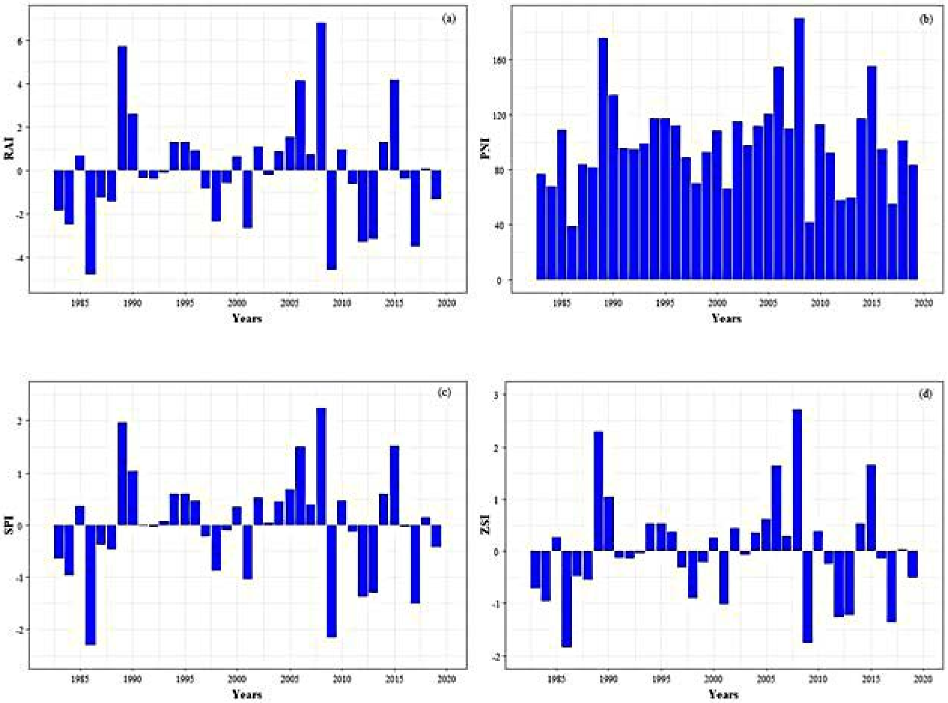

Figure 6. Evolution of meteorological drought indices (a – RAI, b – PNI, c – SPI, d – ZSI) in the Sidi Hamza station, over time (1983–2019)

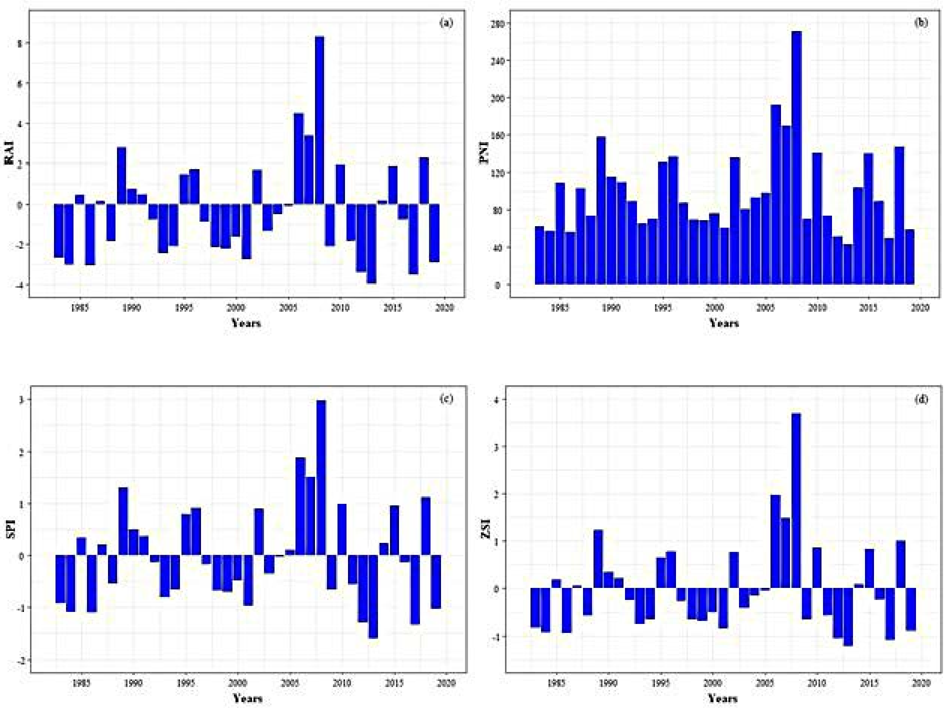

Figure 7. Evolution of meteorological drought indices (a – RAI, b – PNI, c – SPI, d – ZSI) in the M'Zizel station, over time (1983–2019)

Erfoud station

From the results of the meteorological drought indices, precisely the RAI, we can deduce that the period 1983–2005 has known a succession of dry to extremely dry years, with the exception of the years 1985 and 1989 which are considered as extremely wet years. While, the results of SPI and ZSI reveal moderately dry years between 1992 and 2005.

Thus, from 2006 the results of all meteorological indices indicate a succession of wet years which are more dominant than normal years (Fig. 8).

Taouz station

The analysis of meteorological drought indices at the Taouz station indicates a dominance of dry years during the period 1983–1992. Nevertheless, during the same period, the year 1989 is considered extremely wet. We also notice a remarkable drought in the years 1999, 2001 and 2010 expressed by the different calculated indices (Fig. 9).

Trend analysis of meteorological drought

To identify the meteorological drought trend in the Ziz watershed, two non-parametric tests were used; the Mann-Kendall test (Kendall, 1975; Mann, 1945) and the Sen slope (1968).

These two tests were applied to the time series of the four indices for the four stations. The results showed non-significant positive trends of meteorological dryness at the 5% level of significance for the series of the four indices in all stations of the Ziz catchment. Indeed, this trend is evidenced by the two p-values of Kendall's tau and Sen's slope (Table 6). However, these results reflect the succession of dry and wet years in the whole catchment during the period 1983–2019

Frequency and spatial distribution of drought and moisture conditions from the SPI during the period (1983–2019)

The SPI results of four stations were interpolated by the IDW method using ArcGIS software in order to analyse the spatiotemporal distribution of this index. Indeed, the SPI index varies from year to year throughout the watershed Ziz (Fig. 10), where we notice some years drier and others wetter, however the years 1986 and 2001 were marked by a drought that covered almost all of the watershed. Thus, the year 1999 was very dry for the southern part of the watershed, notably the stations Erfoud and Taouz. While, in 2012, 2013 and 2017 the drought was recorded just at the northern of the watershed (Sidi Hamza and M'Zizel). We also note that the wettest conditions prevailed in 1989, 2006 and 2008.

Spatial distribution of drought and moisture conditions from RAI, PNI, SPI and ZSI indices

The four meteorological drought indices indicate drought in the majority of the watershed

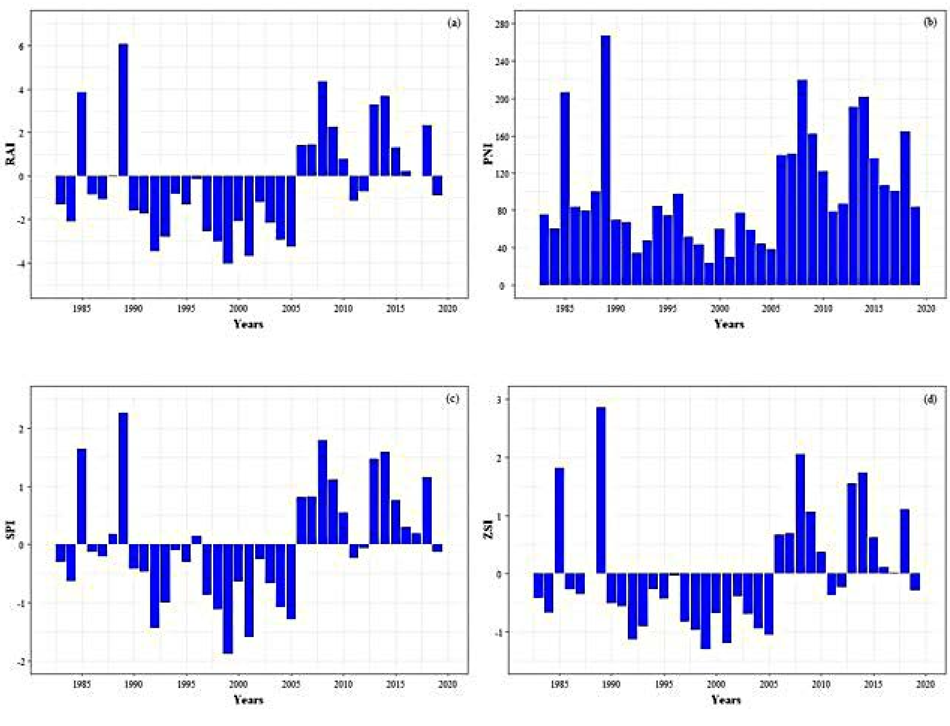

Figure 8. Evolution of meteorological drought indices (a – RAI, b – PNI, c – SPI, d – ZSI) in the Erfoud station, over time (1983–2019)

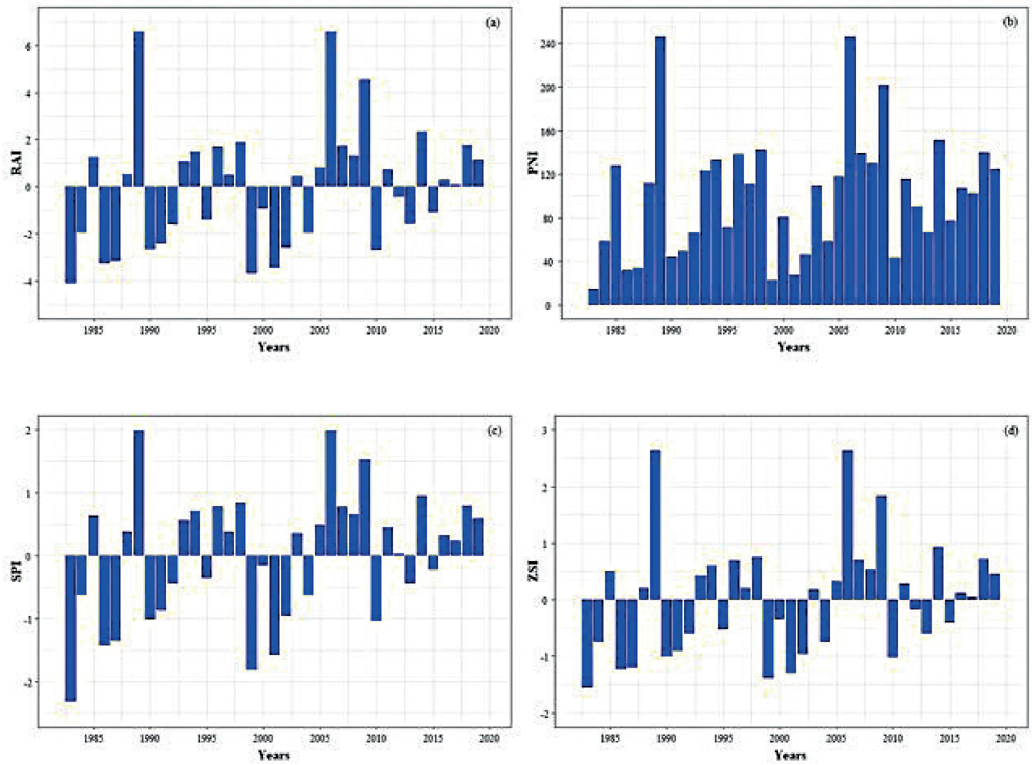

Figure 9. Evolution of meteorological drought indices (a – RAI, b – PNI, c – SPI, d – ZSI) in the Taouz station, over time (1983–2019)

Table 6. Mann-Kendall and Sen's Slope tests of drought indices

Station	Kendall's Tau	*p* value	Sen's Slope				Trend
			RAI	PNI	SPI	ZSI	
Sidi Hamza	0.044	0.714	0.014	0.181	0.006	0.006	NS
M'Zizel	0.048	0.685	0.020	0.304	0.009	0.007	NS
Erfoud	0.189	0.102	0.068	1.372	0.029	0.023	NS
Taouz	0.226	0.051	0.074	1.558	0.032	0.028	NS

Note: NS – not significant 5% level of significance.

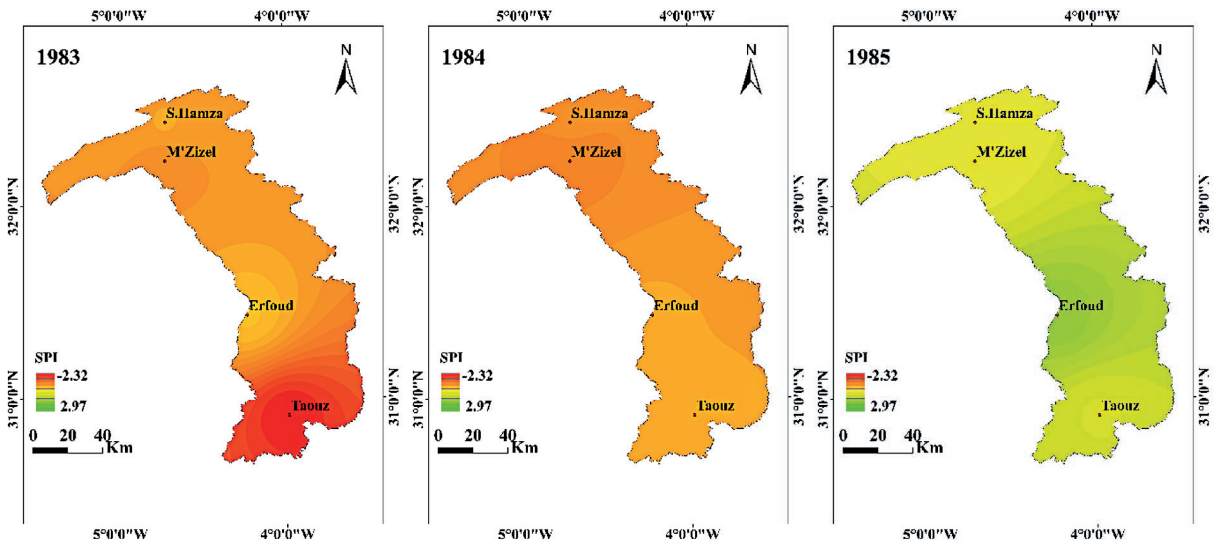

Figure 10. Spatiotemporal distribution of the SPI in the ZIZ Watershed

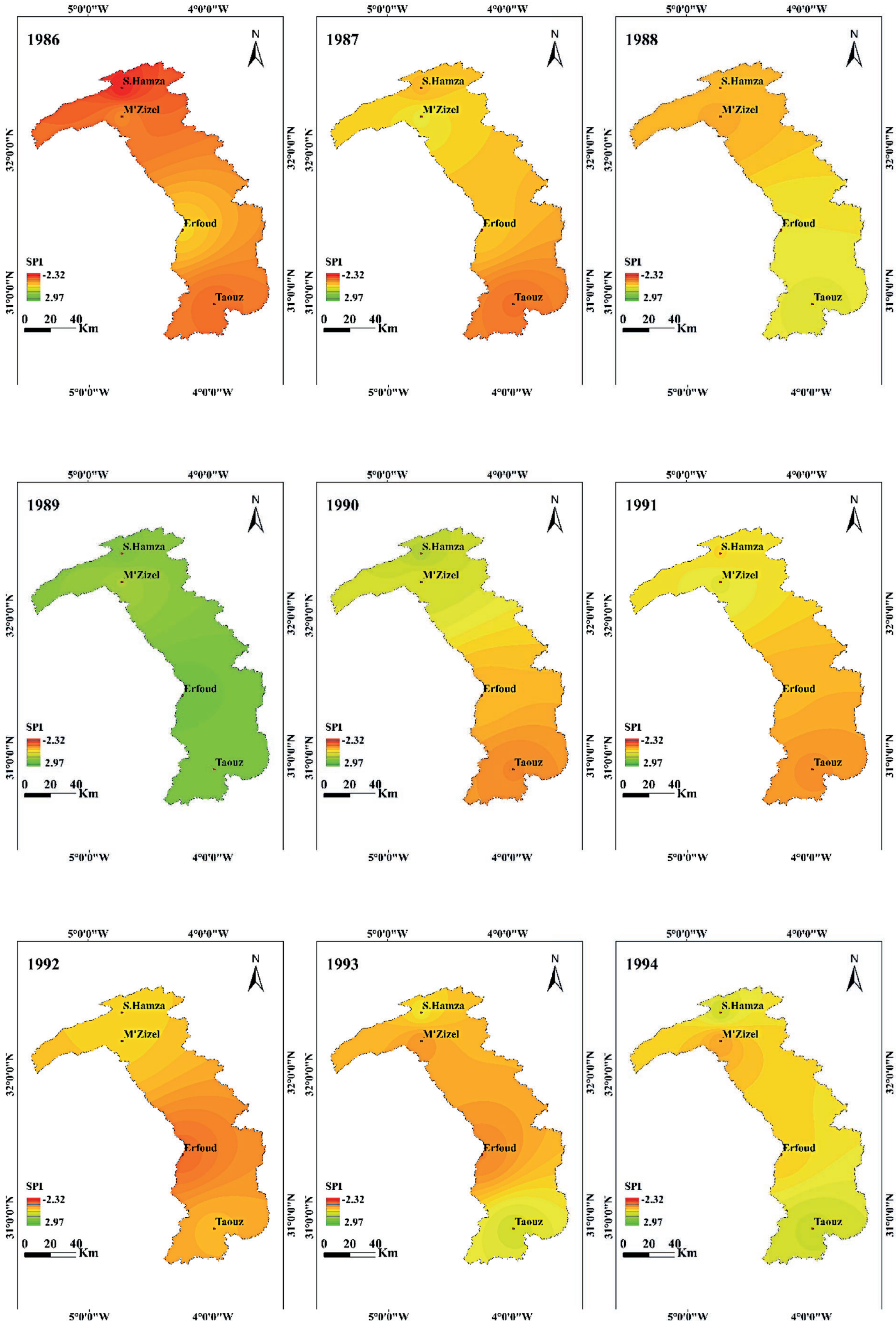

Figure 10. Cont. Spatiotemporal distribution of the SPI in the ZIZ Watershed

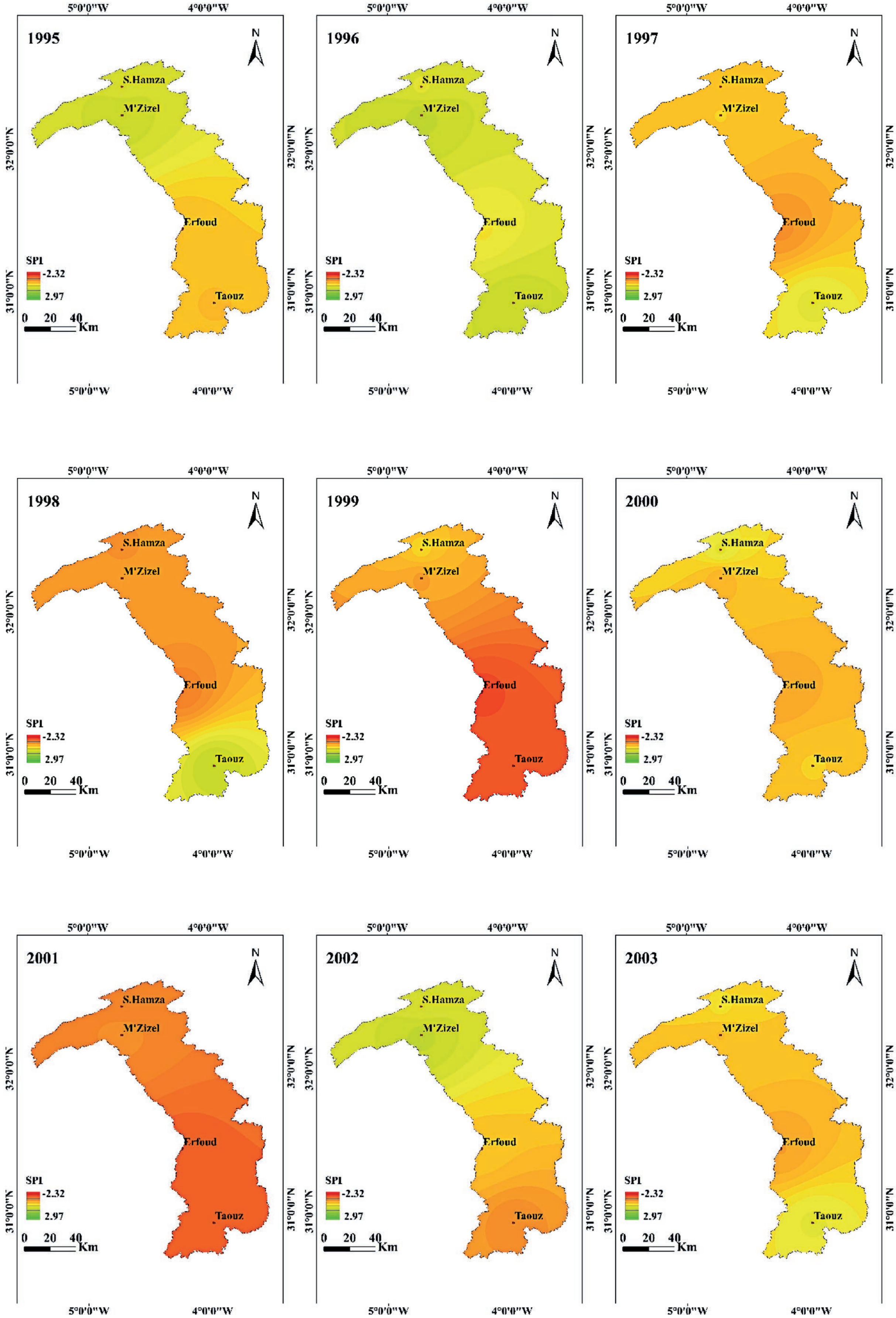

Figure 10. Cont. Spatiotemporal distribution of the SPI in the ZIZ Watershed

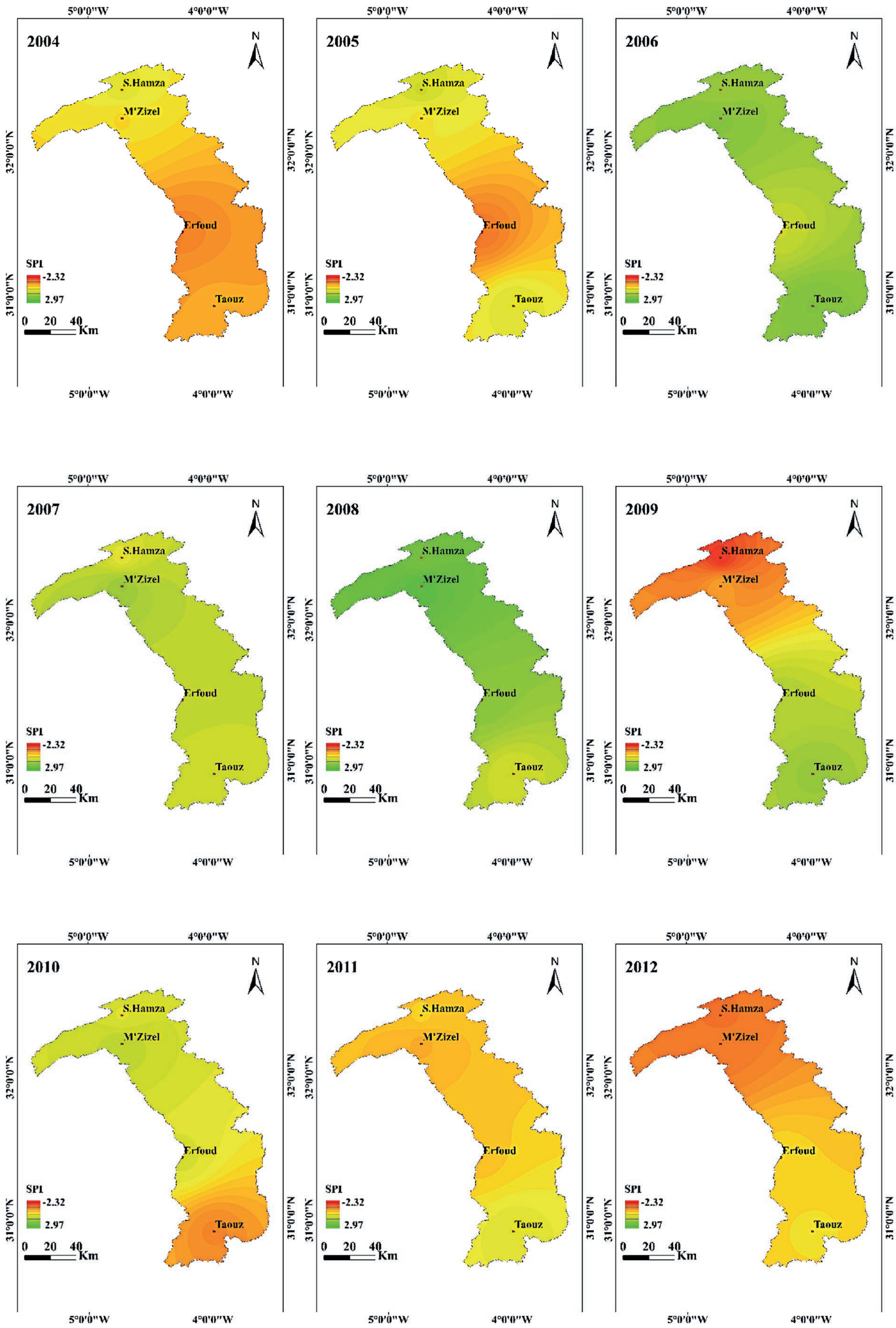

Figure 10. Cont. Spatiotemporal distribution of the SPI in the ZIZ Watershed

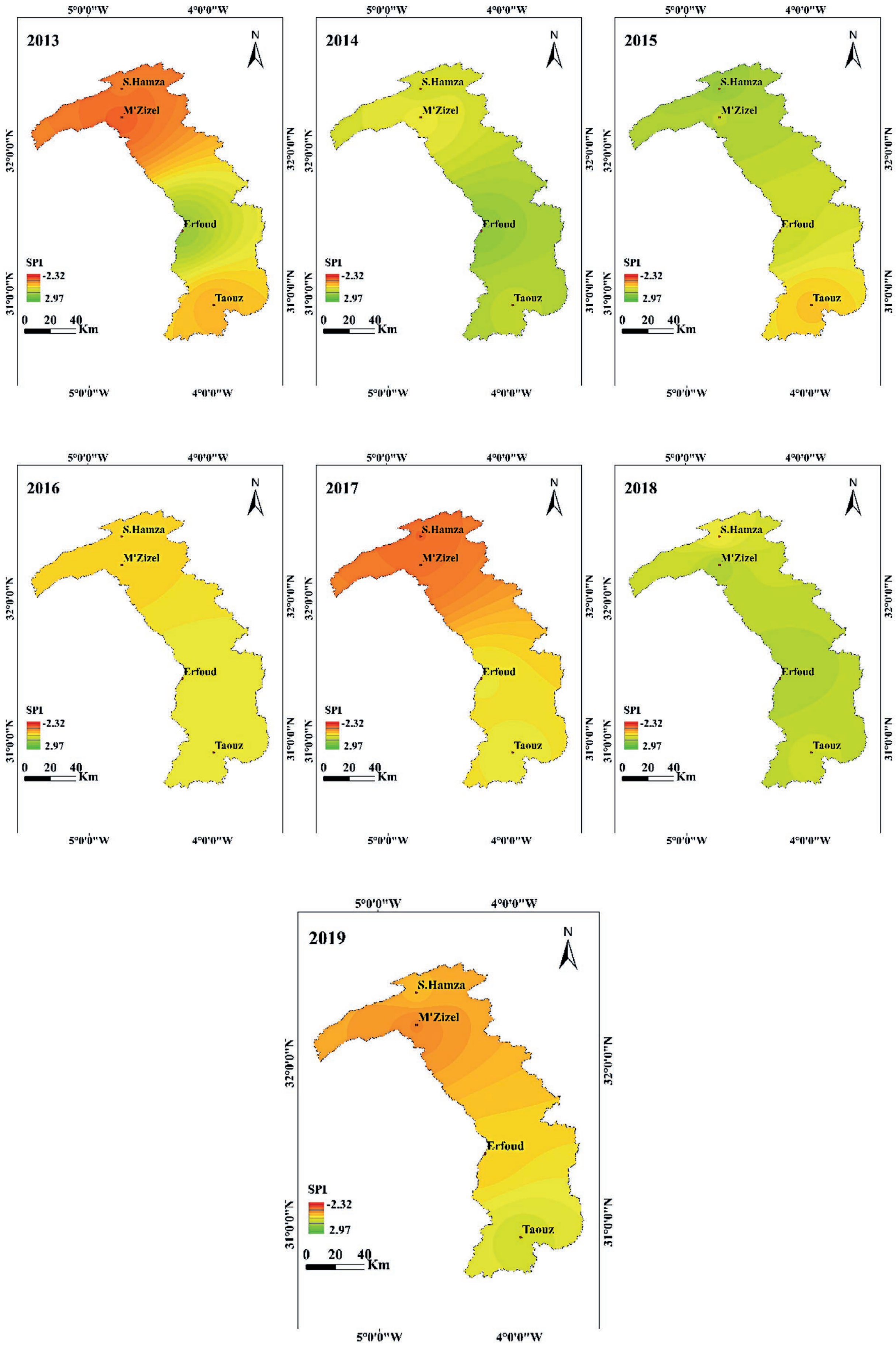

Figure 10. Cont. Spatiotemporal distribution of the SPI in the ZIZ Watershed

during the years 1986 and 2001 (Fig. 11). In 1986, the drought covered the whole basin except for the Erfoud station which was characterised by normal conditions. However, in 2001 the RAI, PNI and SPI show a more intense drought in the southern stations compared to the northern stations. On the other hand, the ZSI in its distribution indicates only one category of drought (moderate drought) in the whole basin except for the M'Zizel station which was marked by a normal climate also expressed by the SPI.

In contrast, the wettest conditions prevailed in 1989, 2006 and 2008. All four indices indicate very wet to extremely wet conditions at all four stations in 1989 (Fig. 12). The stations Erfoud and Taouz showed respectively in 2006 and 2008 the least intense conditions compared to the other stations (Fig. 12).

Correlation of drought indices

The Pearson correlation (Pearson, 1896) is used to determine the strength and direction of the linear relation between two variables following the normal distribution. Otherwise, the relation between the two variables can be estimated by the Kendall (1938) or Spearman (1904 a, b) test. In this study we used the Pearson correlation since the values of the calculated indices follow a normal distribution.

The Pearson correlation matrix (Table 7) shows a positive and strong correlation between

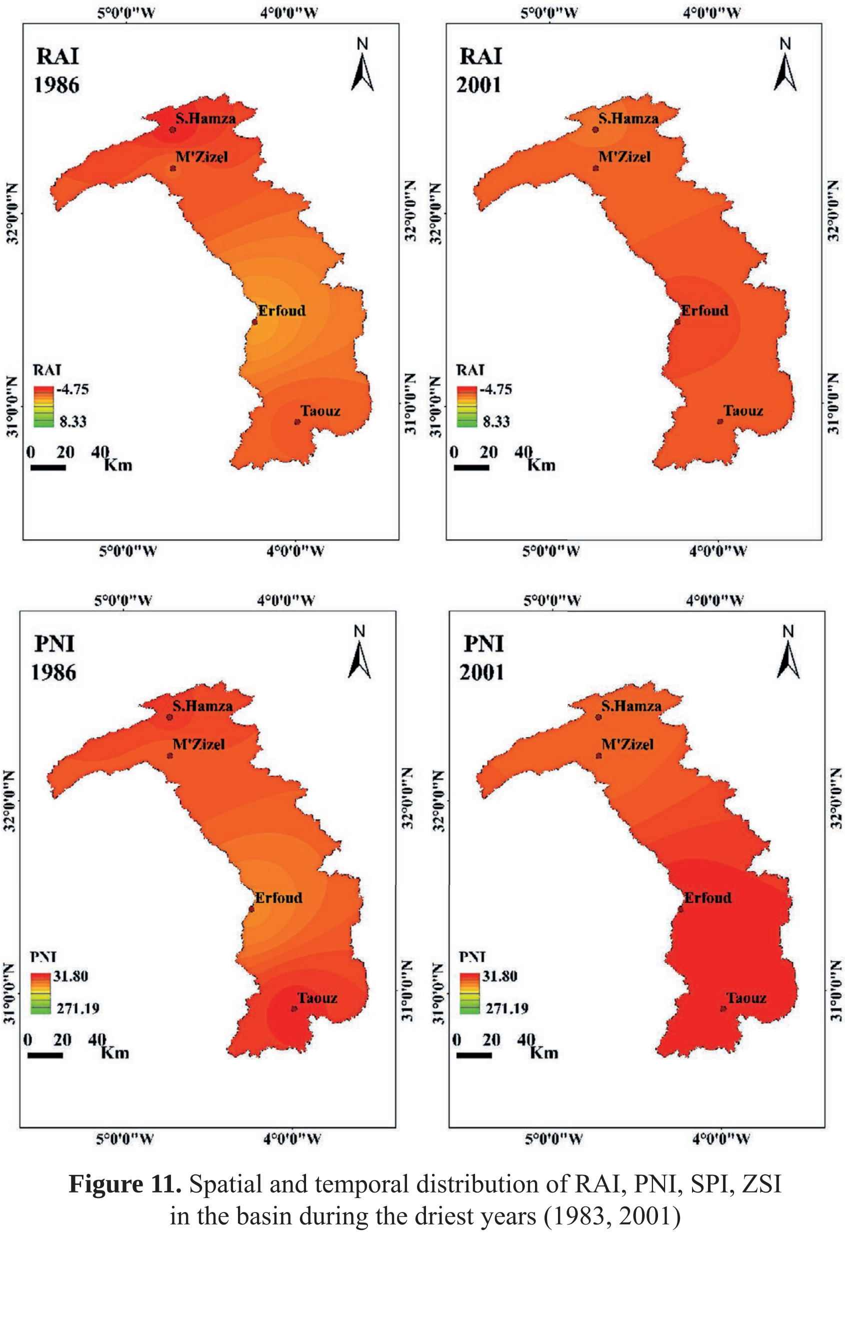

Figure 11. Spatial and temporal distribution of RAI, PNI, SPI, ZSI in the basin during the driest years (1983, 2001)

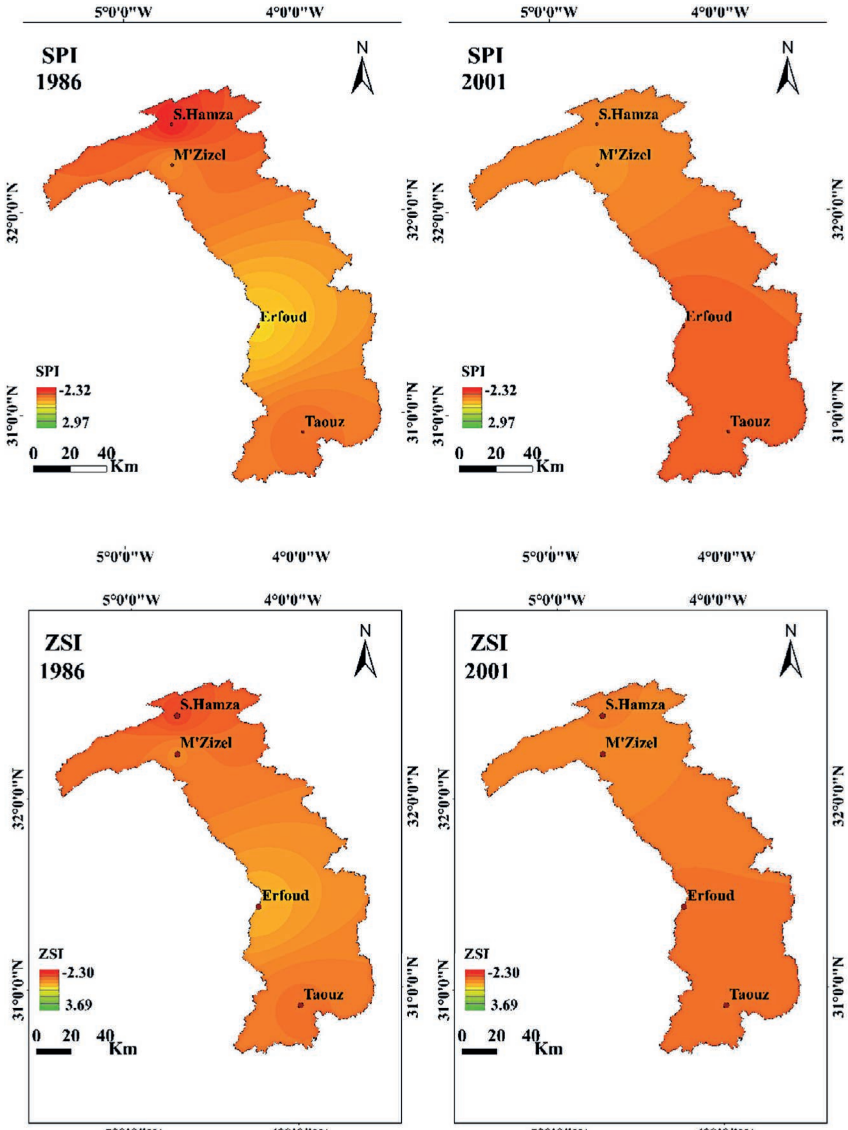

Figure 11. Cont. Spatial and temporal distribution of RAI, PNI, SPI, ZSI in the basin during the driest years (1983, 2001)

all the indices calculated in the four stations (r ≥ 0.967), thus the correlation coefficient between the two indices ZSI and PNI is still equal to 0.999, which ensures a strong relation between them.

DISCUSSION

Precipitation, as a major factor in the identification of meteorological drought, requires analysis on a spatial and temporal scale to monitor its variability. On an overview of the whole of Morocco, the spatio-temporal distribution of TRMM precipitation varies according to season, proximity to the sea and altitude (Ezzine et al., 2014), However, this study has highlighted a spatio-temporal variability of precipitation at the level of the Ziz watershed, the spatial variability translated by the altitude factor, precipitation belonging to the eastern part of the central high Atlas increases from south to north. It can be noted that in the arid and semi-arid regions the areas characterized by low altitude are more vulnerable to drought because of their rainfall character.

Although the drought indices are based on precipitation, it is evident that the spatio-temporal variability is not limited to precipitation but is also reflected in the results of the drought indices obtained over the whole basin. The results of the four indices vary from year to year and from station to station. However, the years 1986 and 2001 were the driest years in the

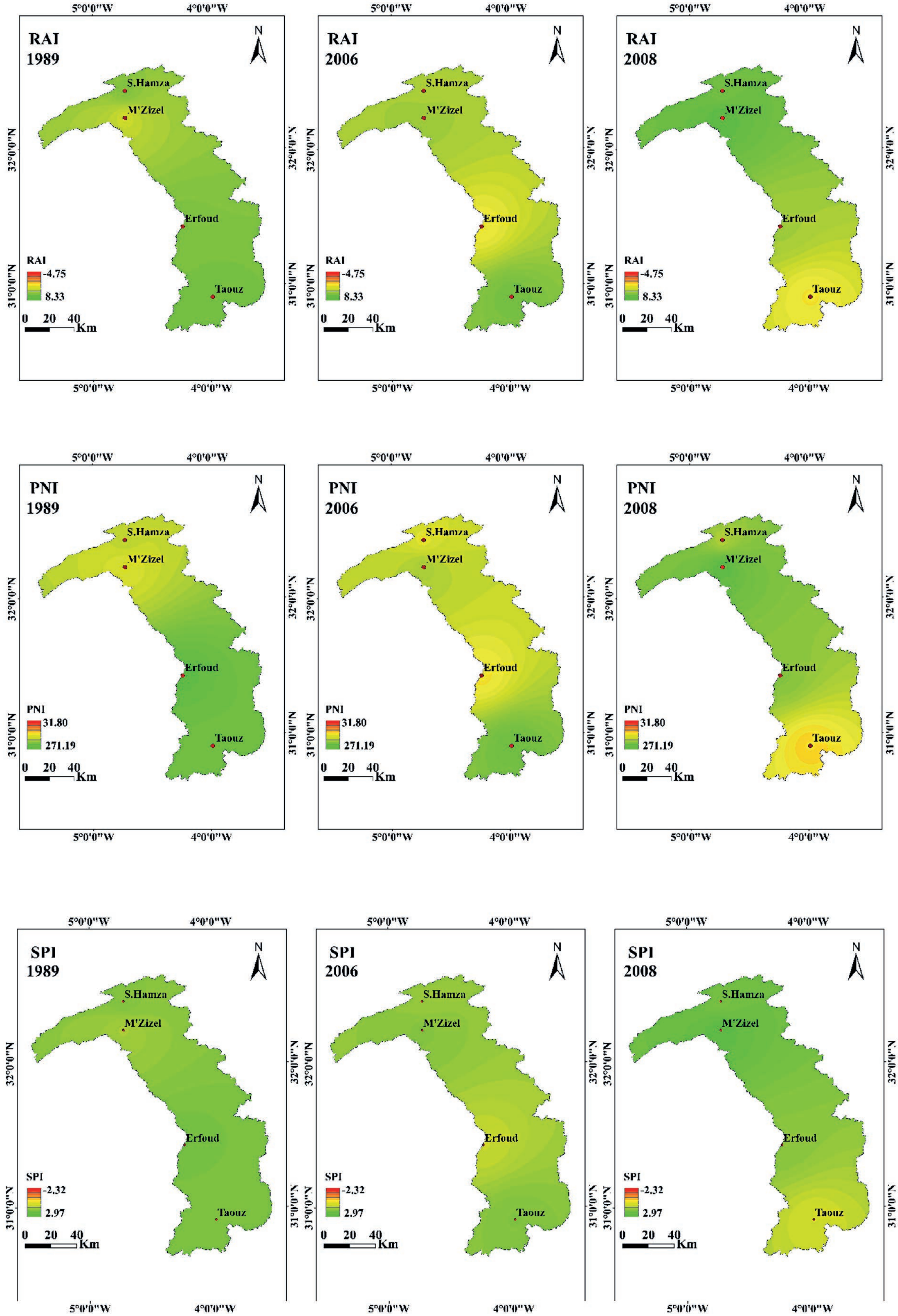

Figure 12. Spatial and temporal distribution of RAI, PNI, SPI, ZSI in the basin during the wettest years (1989, 2006, 2008).

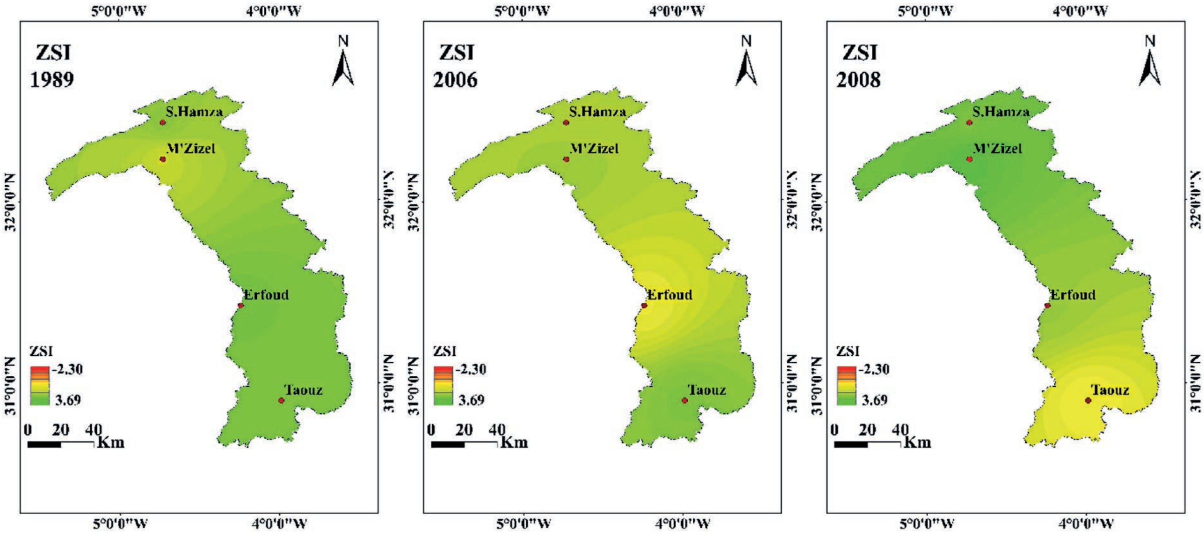

Figure 12. Cont. Spatial and temporal distribution of RAI, PNI, SPI, ZSI in the basin during the wettest years (1989, 2006, 2008).

Table 7. Pearson correlation matrix between drought indices for the four stations

	Index	RAI	PNI	SPI	ZSI
Sidi Hamza	RAI	1			
	PNI	0.999	1		
	SPI	0.988	0.986	1	
	ZSI	0.999	0.999	0.986	1
M'zizel	Index	RAI	PNI	SPI	ZSI
	RAI	1			
	PNI	0.995	1		
	SPI	0.996	0.984	1	
	ZSI	0.995	0.999	0.984	1
Erfoud	Index	RAI	PNI	SPI	ZSI
	RAI	1			
	PNI	0.995	1		
	SPI	0.993	0.978	1	
	ZSI	0.995	0.999	0.978	1
Taouz	Index	RAI	PNI	SPI	ZSI
	RAI	1			
	PNI	0.999	1		
	SPI	0.971	0.967	1	
	ZSI	0.999	0.999	0.967	1

basin, characterized by low rainfall. The results of (Mehdaoui et al., 2018) also showed that the period 2000-01 was among the driest periods at all stations in the Ziz basin. The wettest conditions were recorded in 1989, 2006 and 2008, the M'Zizel station had the highest values of the four indices in 2008; this result agrees with that of (Diani et al., 2019) who found that 2008 was the wettest year in the M'Zizel station.

In addition, research on other watersheds in Morocco, such as the Oum Rbie watershed, carried out by (Jouilil et al., 2013) and (Daki et al., 2016) have shown that the Oum Rbie watershed has experienced sequences of droughts over the past decades and is very vulnerable to drought (El Hafid et al., 2017). Thus, at the level of the d'Isly catchment area, the study carried out by (El Hafid et al., 2017) indicated an important rainfall deficit accompanied by droughts after the year 1980. At the national scale, (Ezzine et al., 2014) revealed that at the end of the nineties through 2001, Morocco experienced moderate droughts, while the years 2008–2011 were characterized by wet and extremely wet conditions, meaning that the driest and wettest conditions experienced by the Ziz basin were generally in Morocco.

On the other hand, a similar study by (Diani et al., 2019) found that the annual precipitation in the high Ziz basin had no significant trend. In the same context the results of present work also indicate an insignificant trend of meteorological drought over the whole study area, indicated by the four indices. The correlation between these indices is strong precisely between ZSI and PNI (r= 0.999). Indeed, this result corroborates with other studies, (Katipoğlu et al., 2020) and (Dikici and Aksel, 2021) showing high correlation for metrological drought indices of the same time periods. Thus (Ekwezuo and Madu, 2020; Salehnia et al., 2017; Keyantash and Dracup, 2002), who conducted studies based on meteorological drought indices showed a high correlation between them.

CONCLUSION

Within the context of drought monitoring in arid and semi-arid areas, the present work was conducted to determine the drought characteristics in the Ziz watershed located in south-eastern Morocco using four meteorological drought indices.

The results showed a biennial irregularity of precipitation that varies according to the altitude factor, which is reflected by a rainfall trend increasing from the South to the North of the watershed. The drought indices applied in this study showed a strong correlation between them ($r \geq 0.967$). Therefore, the assessment of drought by these metrological indices indicated that the Ziz River basin experienced alternating dry and wet periods. Thus, in most years the distribution of drought was not homogeneous in the basin. According to this result, adaptive water management strategies to climate change should be further strengthened, in order to reduce the impact of drought periods and ensure the sustainability of water resources throughout Morocco, especially in the arid and semi-arid environments, the most sensitive to climate change and the adverse effects of drought.

REFERENCES

1. Boken, V.K., Cracknell, A.P., Heathcote, R.L. 2005. Monitoring and Predicting Agricultural Drought: A Global Study. Oxford University Press, Oxford; New York.
2. Born, K., Christoph, M., Fink, A.H., Knippertz, P., Paeth, H., Speth, P. 2008. Moroccan Climate in the Present and Future: Combined View from Observational Data and Regional Climate Scenarios. In: Zereini, F., Hötzl, H. (Eds.) Climatic Changes and Water Resources in the Middle East and North Africa. Springer Berlin Heidelberg, Berlin, Heidelberg.
3. Buishand, T.A. 1982. Some methods for testing the homogeneity of rainfall records. Journal of Hydrology, 58(1–2), 11–27. DOI: 10.1016/0022-1694(82)90066-X
4. Buishand, T.A. 1984. Tests for detecting a shift in the mean of hydrological time series. Journal of Hydrology, 73(1–2), 51–69. DOI: 10.1016/0022-1694(84)90032-5
5. Cuenca, J.C., de Murcia, R., del Campo García, A., España, D.R.M. In press. Euro-Mediterranean Information System on Know How in the Water Sector. Available from https://www.riob.org/fr/node/3071
6. Daki, Y., Zahour, G., Lachgar, R., El Hadi, H. 2016. Caractérisation de la sécheresse climatique du bassin versant d'Oum Er Rbia (Maroc) par le biais l'indice de précipitation standardisé (SPI). European Scientific Journal, 12(14), 198–209. DOI: 10.19044/esj.2016.v12n14p198
7. Diani, K., Kacimi, I., Zemzami, M., Tabyaoui, H., Haghighi, A.T. 2019. Evaluation of meteorological drought using the Standardized Precipitation Index (SPI) in the High Ziz River basin, Morocco. Sciendo, 19(3), 125–135. DOI: 10.2478/limre-2019-0011
8. Dikici, M., Aksel, M. 2021. Comparison of Drought Indices in the Case of the Ceyhan Basin. International Journal of Environment and Geoinformatics, 8(2), 113–125. DOI: 10.30897/ijegeo.792379
9. Driouech, F., Déqué, M., Sánchez-Gómez, E. 2010. Weather regimes—Moroccan precipitation link in a regional climate change simulation. Global and Planetary Change, 72(1–2), 1–10. DOI: 10.1016/j.gloplacha.2010.03.004
10. Ekwezuo, C.S., Madu, J.C. 2020. Evaluation of Different Rainfall-based Drought Indices Detection of Meteorological Drought Events in Imo State, Nigeria. jasem, 24(4), 713–717. DOI: 10.4314/jasem.v24i4.25
11. El Hafid, D.E., Zerrouqi, Z., Akdim, B. 2017. Etude des séquences de sécheresse dans le bassin d'ISLY (Maroc Oriental), Larhyss Journal, (31), 83–94.
12. El Hafyani, M., Essahlaoui, A., Van Rompaey, A., Mohajane, M., El Hmaidi, A., El Ouali, A., Moudden, F., Serrhini, N.-E. 2020. Assessing Regional

Scale Water Balances through Remote Sensing Techniques: A Case Study of Boufakrane River Watershed, Meknes Region, Morocco. Water, 12(2), 320. DOI: 10.3390/w12020320

13. El Moçayd, N., Kang, S., Eltahir, E.A.B. 2020. Climate change impacts on the Water Highway project in Morocco. Hydrol. Earth Syst. Sci, 24(3), 1467–1483. DOI: 10.5194/hess-24-1467-2020
14. Ezzine, H., Bouziane, A., Ouazar, D. 2014. Seasonal comparisons of meteorological and agricultural drought indices in Morocco using open short time-series data. International Journal of Applied Earth Observation and Geoinformation, 26, 36–48. DOI: 10.1016/j.jag.2013.05.005
15. Giorgi, F., Lionello, P. 2008. Climate change projections for the Mediterranean region. Global and Planetary Change, 63(2–3), 90–104. DOI: 10.1016/j.gloplacha.2007.09.005
16. Hammada, S. 2007. Etudes sur la Végétation des Zones Humides du Maroc, Catalogue et Analyse de la Biodiversité Floristique et Identification des principaux Groupements Végétaux. Ph.D. Thesis, Université Mohammed V Agdal, Faculté des sciences, Rabat.
17. Hubert, P., Carbonnel, J., Chaouche, A. 1989. Segmentation des séries hydrométriques. Application à des séries de précipitations et de débits de l'Afrique de l'ouest. Journal of Hydrology, 110, 349–367.
18. Jain, V.K., Pandey, R.P., Jain, M.K., Byun, H.R. 2015. Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. Weather and Climate Extremes, 8, 1–11. DOI: 10.1016/j.wace.2015.05.002
19. Javan, K., Azizzadeh, M.R., Yousefi, S. 2017. An Investigation and assessment of meteorological drought in Lake Urmia Basin using drought indices and probabilistic methods. Natural Environment Change, 2(2), 153–164.
20. Jellali, M.M. 1997. Développement des ressources en eau au Maroc. Aspects Économiques de la Gestion de l'Eau dans le Bassin Méditerranéen, CIHEAM. Bari, Italy, 51–68.
21. Jouilil, I., Bitar, K., Salama, H., Amraoui, A., Mokssit, A., Tahiri, M. 2013. Sécheresse météorologique au bassin hydraulique OUM ER RBIA durant les dernières décennies. Larhyss Journal, (12), 109–127.
22. Katipoğlu, O.M., Acar, R., Şengül, S. 2020. Comparison of meteorological indices for drought monitoring and evaluating: a case study from Euphrates basin, Turkey. Journal of Water and Climate Change, 11(S1), 29–43. DOI: 10.2166/wcc.2020.171
23. Kendall, M.G. 1938. A new measure of rank correlation. Biometrika, 30(1–2), 81–93. DOI: 10.1093/biomet/30.1-2.81
24. Kendall, M.G. 1975. Rank correlation methods.: Charles Griffin, London.
25. Keyantash, J., Dracup, J.A. 2002. The Quantification of Drought: An Evaluation of Drought Indices. Bull. Amer. Meteor. Soc, 83(8), 1167–1180. DOI: 10.1175/1520-0477-83.8.1167
26. Layelmam, M. 2008. Calcul des indicateurs de sécheresse à partir des images NOAA/AVHRR. Projet de Mise en place d'un Système d'Alerte précoce à la Sécheresse dans trois pays de la rive Sud de la Méditerranée : Algérie, Maroc, et Tunisie / LIFE05 TCY/TN/000150.
27. Lee, A.F.S., Heghinian, S.M. 1977. A Shift Of The Mean Level In A Sequence Of Independent Normal Random Variables—A Bayesian Approach—. Technometrics, 19(4), 503–506. DOI: 10.1080/00401706.1977.10489592.
28. Mann, H.B. 1945. Nonparametric tests against trend. Econometrica, 13, 245–259.
29. Martinez, M.G., Poole, N. 2004. The development of private fresh produce safety standards: implications for developing Mediterranean exporting countries. Food Policy, 29(3), 229–255. DOI: 10.1016/j.foodpol.2004.04.002
30. McKee, T.B., Doesken, N.J., Kleist, J. 1993. The relationship of drought frequency and duration to time scales.
31. Mehdaoui, R., Mili, E.-M., Seghir, A. 2018. Caractérisation à l'aide du SPI de la Sécheresse climatique dans le bassin versant de Ziz (Sud-Est, Maroc). European Scientific Journal, 14(21), 177–194. DOI: 10.19044/esj.2018.v14n21p177
32. Melhaoui, M., Mezrhab, A., Mimouni, J. 2018. Evaluation et cartographie de la sécheresse météorologique dans les hauts plateaux de l'oriental du Maroc (zone du projet PDPEO). Rev. Microbiol. Ind. San et Environn, 12, 71–92.
33. Ndlovu, M.S., Demlie, M. 2020. Assessment of Meteorological Drought and Wet Conditions Using Two Drought Indices Across KwaZulu-Natal Province, South Africa. Atmosphere, 11(6), 623. DOI: 10.3390/atmos11060623
34. OMM, O. météorologique mondiale, GWP, P. mondial pour l'eau. 2014. Lignes directrices pour une politique nationale de gestion de la sécheresse : un modèle d'action.
35. Ozer, P., Hountondji, Y.C., Gassani, J., Djaby, B., De Longueville, F. 2014. Évolution récente des extrêmes pluviométriques en Mauritanie (1933-2010), Dijon (France), 394-400.
36. Patricola, C.M., Cook, K.H. 2010. Northern African climate at the end of the twenty-first century: an integrated application of regional and global climate models. Clim Dyn, 35(1), 193–212. DOI: 10.1007/s00382-009-0623-7
37. Pearson, K. 1896. Mathematical contributions to

the theory of evolution.—III. Regression, heredity, and panmixia. Phil. Trans. R. Soc. Lond. A, 187, 253–318. DOI: 10.1098/rsta.1896.0007

38. Pettitt, A.N. 1979. A Non-Parametric Approach to the Change-Point Problem. Applied Statistics, 28(2), 126–135. DOI: 10.2307/2346729
39. Riad, S. 2003. Typologie et analyse hydrologique des eaux superficielles à partir de quelques bassins versants représentatifs du Maroc. Ph.D. Thesis, Université des sciences et technologies de Lille & Université Ibnou Zohr d'Agadir.
40. Salehnia, N., Alizadeh, A., Sanaeinejad, H., Bannayan, M., Zarrin, A., Hoogenboom, G. 2017. Estimation of meteorological drought indices based on AgMERRA precipitation data and station-observed precipitation data. J. Arid Land, 9(6), 797–809. DOI: 10.1007/s40333-017-0070-y
41. Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's Tau. Journal of the American Statistical Association, 63, 1379–1389.
42. Sharma, A., Goyal, M.K. 2020. Assessment of drought trend and variability in India using wavelet transform. Hydrological Sciences Journal, 65(9), 1539–1554. DOI: 10.1080/02626667.2020.1754422
43. Spearman, C. 1904a. The proof and measurement of association between two things. America Journal of Psychology, 72–101.
44. Spearman, C. 1904b. 'General Intelligence,' Objectively Determined and Measured. The American Journal of Psychology, 15(2), 201–293. DOI: 10.2307/1412107
45. Stângă, I.C. 2009. Quantifier la sécheresse, durée, intensité, fréquence. Analele Stiintifice ale Universităţii Al I. Cuza" Iaşi, Tom LV s. II – c, Geografie 2009, 31–46.
46. Stour, L., Agoumi, A. 2008. Sécheresse climatique au Maroc durant les dernières décennies. Hydroécol. Appl, 16, 215–232. DOI: 10.1051/hydro/2009003
47. Van Rooy, M.P. 1965. A rainfall anomaly index independent of time and space. Notos, 14, 43–48.
48. Wada, Y., Gleeson, T., Esnault, L. 2014. Wedge approach to water stress. Nature Geosci, 7(9), 615–617. DOI: 10.1038/ngeo2241.
49. Willeke, G., Hosking, J., Wallis, J., Guttman, N. 1994. The National Drought Atlas. Institute for Water Resources Report 94-NDS-4, U.S. Army Corps of Engineers.
50. Yagbasan, O., Demir, V., Yazicigil, H. 2020. Trend Analyses of Meteorological Variables and Lake Levels for Two Shallow Lakes in Central Turkey. Water, 12(2), 414. DOI: 10.3390/w12020414
51. Yagbasan, O., Yazicigil, H., Demir, V. 2017. Impacts of climatic variables on water-level variations in two shallow Eastern Mediterranean lakes. Environ Earth Sci, 76(16), 575. DOI: 10.1007/s12665-017-6917-x