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Climate variability and its impact on water resources: case study of the Souk Ahras region, northeastern Algeria

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ABSTRACT

Climate variability has been identified as one of the major factors affecting water resources. The purpose of this study is to characterize climate variability in the region of Souk Ahras and to evaluate its impact on surface and groundwater resources. Various statistical methods, including Mann–Kendall test, Pettitt test, drought indices, and Fourier filter were used. Pettitt test revealed the occurrence of breaks over the period (1994–1996), showing significant increase in the annual rainfall and temperature data time series. The analysis of drought indices provided insights into the relationship between meteorological and hydrological droughts in the study area. This mainly revealed that rainfall deficit results in an immediate response to runoff regime and a delayed response to groundwater level. Moreover, it was found that both meteorological and hydrological drought conditions significantly decreased after the climatic shift in terms of frequency, intensity and duration. Such information is of great importance for managing water resources and preparing drought mitigation measures.

Keywords: Climate variability; Mann–Kendall test; Pettitt test; Drought indices; Algeria

1. Introduction

Climate change is a globally recognized reality and its negative impacts on different sectors were reported [1–5]. The average air temperature of the globe has raised by around 0.7°C during the twentieth century, and different hydro-climatic variables have been affected [6]. In particular, global warming has been shown to increase the frequency and intensity of extreme drought and flood events, accentuating thereby climate variability [7,8].

Generally, developing countries are more susceptible to the impacts of climate variability, as they are generally localized in arid, semiarid, and tropical regions [9,10]. The rapid population growth and recent agricultural and industrial developments in these countries further aggravated the situation [11].

Drought, which can be simply defined as a decrease in rainfall compared to the average, ranks at the top of the disastrous effects associated with the recent changes in climate variability. According to Haile et al. [12] since the

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1970s, droughts have caused 572,000 deaths, along with 1.5 million USD in economic damages in East Africa. In such a shocking context, several authors, including [13–15] reported that increased water resource scarcity is expected to be the main cause of future-armed conflicts.

The Mediterranean Basin experienced significant drought events during the 1970s and the 1980s as reported by many studies [16–21]. Several authors related climate variability in the Mediterranean Basin with El Nino Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) [22–26]. According to Salinger et al. [27], ENSO and NAO are amongst the main factors of climate variability increase in the context of global warming. Furthermore, recent simulations of the Intergovernmental Panel on Climate Change (IPCC) [28–30] showed that inter-annual climate variabilities particularly associated with ENSO and NAO are expected to endure and probably increase during the 21st century.

Identifying the impact of climate variability on water resources is one of the major issues that scientists are dealing with nowadays. In this context, statistical methods have been widely applied by researchers dealing with climate variability analysis around the globe [31–34]. These methods were shown to be efficient in predicting future hydrological behavior [35,36], resulting thereby in the implementation of water management and resilience strategies [37–39].

The present study concerns the region of Souk Ahras located in northeastern Algeria at the southern coastline of the Mediterranean Sea. This area suffers repetitively from severe and persistent droughts [40], usually resulting in the disturbance of water supply and the reduction of crop yields [41]. However, to the authors' knowledge, there is no previous study that examined climate and hydrologic variability in the study area and its impact on water resources to implement the required management strategies. In this context, several statistical tools (Mann–Kendall and Pettitt tests and drought indices) were used in this study in order to: (i) investigate the inter-annual variability of rainfall, runoff, and temperature in the study area over the period (1969–2012), (ii) identify different dry and wet cycles and, and (iii) investigate the relationships between rainfall fluctuations, runoff and groundwater resources.

2. Study area and data used

This study area is the region of Souk Ahras (northeastern Algeria), located in the upstream part the Medjerda wadi basin, with latitudes varying between 7° 50 and 7° 87 and longitudes varying between 36° 10 and 36° 26. It is limited to the north by the El-Kebir wadi basin, to the west by the Seybouse wadi basin, to the south by the Mellegue wadi basin, and to the east by the Algerian – Tunisian border (Fig. 1).

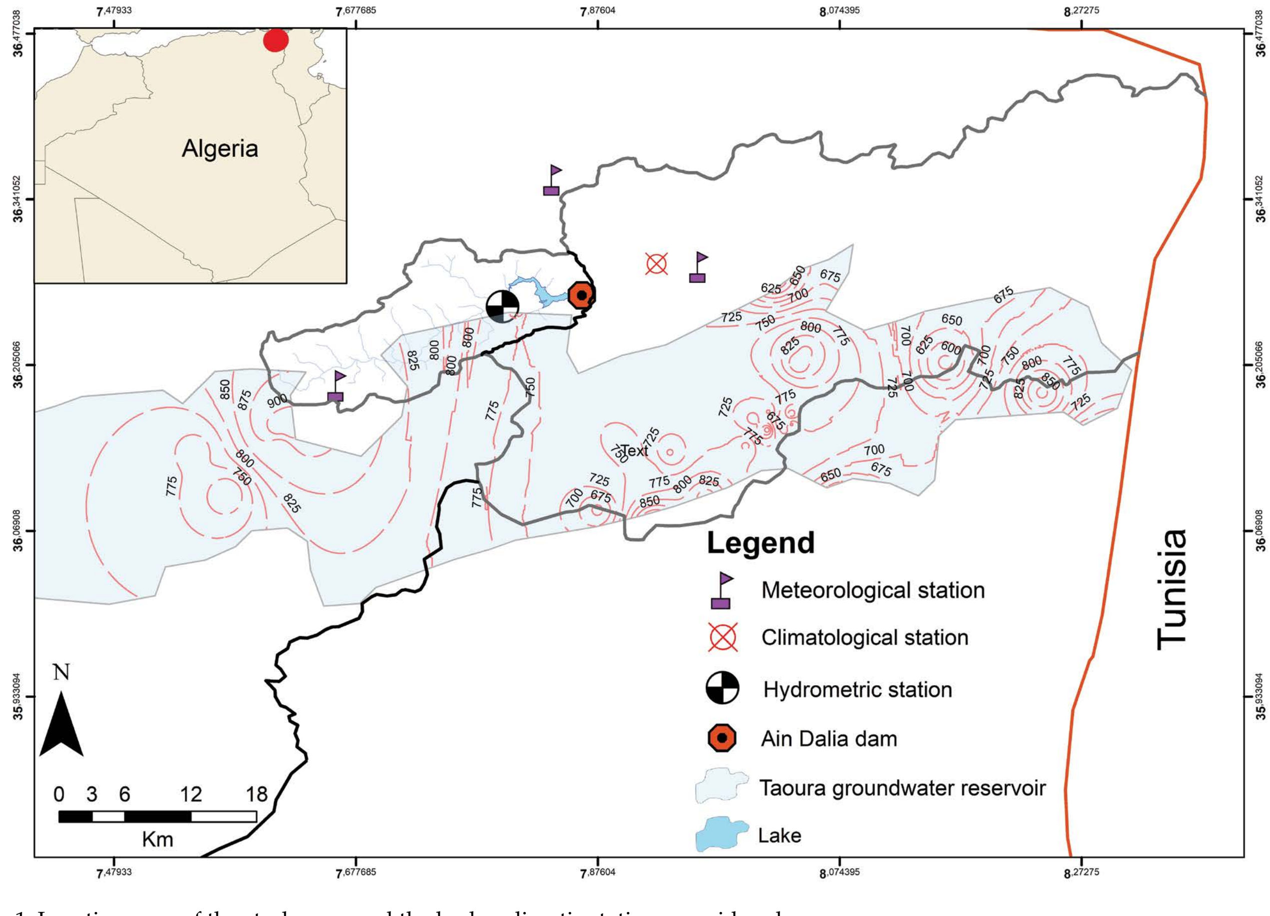

Fig. 1. Location map of the study area and the hydro-climatic stations considered.

The region is characterized by a rugged relief and a dense vegetation cover. Around 254,000 ha of the study area are dedicated to agriculture, with 145,000 ha of arable lands devoted to cereal and 9,500 ha to fodder. Irrigated agriculture covers 7,400 ha dedicated to a variety of fruits and legumes. The main water resources distinguished in the study area include Ain Dalia dam on Medjerda River (75 Hm^3) and Taoura groundwater reservoir. This latter includes two superimposed aquifers [42]: The first is characterized by groundwater levels close to 40 m in the Mio-Plio-Quaternary aquifer, which is rich in marl, conglomerates, sands and gravels. The second aquifer is considered as confined, and it is composed of marls and fractured limestones of low Maastrichtian and the middle Campanian. This groundwater reservoir is mainly recharged by drainage waters from the basins of Medjerda and Mellegue located in the south [42]. According to Emberger aridity index, the study area falls under a sub-humid climate type [10]. Annual mean rainfall in the study area increases from south to north and varies from 494 mm in the Khemissa station to 1,130 mm in the Machrouha station (Table 1). Average annual temperature is around 15.5°C (Table 1).

The data series used, which were collected from the Algerian National Agency for Water Resources (ANRH), consist of three rainfall time series and a runoff sequence recorded over the (1969–2012) period. In addition, temperature data covering the (1969–2012) period were collected from the weather station of Souk Ahras city managed by the National Meteorological Office (ONM). The geographical characteristics of the stations and the main statistical characteristics of their data series are illustrated in Table 1. Statistical analysis of rainfall and runoff data time series shows high variability, with coefficients of variation reaching 43% and 62% for rainfall and runoff time series, respectively. On the other hand, mean annual temperature was shown to follow a regular distribution, with a low coefficient of variation (0.04).

3. Methods

3.1. Homogeneity analysis

3.1.1. Trend analysis

The Mann–Kendall test [43,44] was employed in this study to detect monotonic upward or downward trends in the considered hydro-climatological data time series. It is a non-parametric method, which tolerates missing values and has the ability to detect trends without assuming any special form for the data distribution function [45]. The Mann–Kendall test has been widely used in the literature to assess the significance of trends in various hydro-climatological data time series [34,46,47]. The trend's significance is assessed in this study via the Monte Carlo resampling procedure by computing the corresponding *p*-value at the level of significance of 5%. The magnitude of the trend (β) is estimated by the Sen's slope [48,49], which is defined as the median of all pairwise slopes between all the consecutive data points of the data set, as follows:

$$\beta = \text{Median}\left[\frac{x_j - x_i}{t_i - t_j}\right] \quad (1)$$

where X_i and X_j are the values of the sample data at times t_i and t_j ($i > j$).

3.1.2. Break detection

Pettitt test [50] was used to detect the presence of significant breaks in the considered hydro-climatological data time series. It is a rank-based and distribution-free test for detecting a significant change in the mean of the distribution [51]. Pettitt test has been widely employed to detect breaks in various hydro-climatological data time series [52–55]. A significant breakpoint *t* is detected at a given level of significance by the Pettitt test if the considered time series can be divided into two subseries with different statistical characteristics before and after *t* [56]. As for the trend test, its significance was assessed using the Monte Carlo resampling procedure at a level of significance of 5%. The null hypothesis (Ho) which indicates the absence of a break in the time series is accepted when *p*-value ≥ 0.05. On the other hand, the hypothesis of non-homogenous data series (Ha) cannot be rejected if *p*-value < 0.05.

3.2. Drought investigation

The standardized precipitation index (SPI) developed by McKee et al. [57,58] was used to characterize meteorological drought conditions. The SPI has been extensively used in Algeria [59–64]. The main advantages of SPI are its low data requirements and its flexibility to analyze different time scales [56,65]. Moreover, the SPI is highly recommended by the leading meteorological and climatological organizations, including the World Meteorological Organization

Table 1
Characteristics of the considered hydro-climatological data series

Variable	Station name	Coordinates		Altitude (m)	Min.	Max.	Mean	Std. deviation	Variation coeff.
		Lat.	Long.						
	Machrouha	07°50′E	36°21′N	769	299	2,171	1,131	487	0.43
Rainfall (mm)	Khemissa	07°52′E	36°10′N	900	259	1,186	494	168	0.34
	Souk Ahras	07°57′E	36°15′N	590	177	991	582	175	0.30
Temperature (°C)	Souk Ahras (ONM)	07°55′E	36°17′N	680	14.43	16.58	15.52	0.55	0.04
Runoff (m^3/s)	Ain Dalia	07°87′E	36°26′N	717	0.25	3.38	1.21	0.75	0.62

(WMO) and the United States National Oceanic and Atmospheric Administration (NOAA).

Two indices were used in this study to characterize hydrological drought: (i) The standardized runoff index (SRI) [66], which evaluates the actual river discharge in comparison to a pre-determined reference period and (ii) the standardized water table level index (SWI), which is calculated based on water level [67]. A hydrological drought is usually preceded by a meteorological drought and followed by an agricultural drought. This would imply that SRI and SWI may generally be used to explain water availability [68]. Previously, Charifi Bellabas et al. [69] demonstrated the effectiveness of SRI in assessing hydrological drought in northern Algeria. However, no previous study dealt with the use of SWI in near regions, according to our state of knowledge.

SPI, SRI and SWI indices are defined, at an annual time scale, by the following equation:

$$Z_i = \frac{X_i - \mu}{\delta} \tag{2}$$

where Z is the considered drought index (SPI, SWI, SRI) in year *i*, X_i is the actual value of the variable (rainfall/runoff/water table level), μ is the long-term mean of the annual data time series and δ is the standard deviation.

According to McKee et al. [57,58], a drought event starts when Z first falls below zero and ends with the positive value of SPI following a value of −1.0 or less. The severity of drought can be classified through SPI, SRI and SWI values as moderately dry (–1.00 to –1.49), severely dry (–1.50 to –1.99), and extremely dry (<=2.0) [68].

For a better visualization and investigation of the inter-annual variability of the considered drought indices, their obtained series were smoothed using the Fourier model. The concept of the Fourier smoothing is to transform a time series into its Fourier coordinates, then the higher frequencies are removed and the coordinates of the remaining frequencies are converted back to a signal [70]. This new signal is a smoothed series.

4. Results and discussions

4.1. Homogeneity analyses of the hydro-climatic data series

Results of homogeneity analysis carried out using Mann–Kendall and Pettitt tests, at the level of significance of 5%, are illustrated in Table 2. According to the Mann–Kendall test, the study area witnessed a significant warming trend (p-value < 0.05) during the 1969–2012 period of about 0.2°C/decade, suggesting an increase in temperature as a result of climate change in the study area (Fig. 3). Concerning the inter-annual variability of rainfall, the hypothesis of homogeneity Ho is rejected for two of the three studied stations (Khemissa and Machrouha), as they showed significant increasing trends at the significance level of 5%. However, the null hypothesis Ho cannot be rejected for the Souk Ahras station (p-value ≥ 0.05), implying a statistically non-significant trend. Overall, the three considered stations showed increasing rainfall trends, with an excess of about 18%. This is consistent with the findings of previous studies, including [40,59,71] which revealed perceptible increase in rainfall in northeastern Algeria since the 1990s.

According to the Pettitt test, the hypothesis of homogeneity Ho is rejected for the mean annual temperature data series as a significant break at the significance level of 5% is observed in 1994 (Fig. 3). Concerning the inter-annual variability of annual rainfall, the hypothesis of homogeneity Ho is accepted for the Souk Ahras station (p-value ≥ 0.05) (Fig. 4). On the other hand, significant breaks at the significant level of 5% occurring in 1994 for the Khemissa station and in 1996 for the Machrouha station were obtained (Fig. 5). These findings are consistent with those of several studies

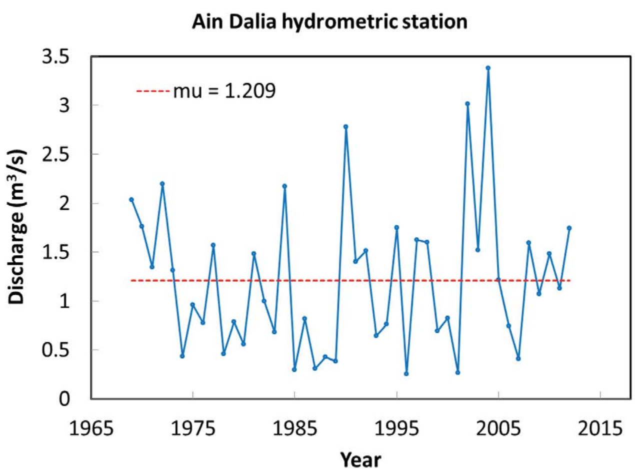

Fig. 2. Inter-annual variability of annual runoff in the Ain Dalia station.

Table 2
Summary of Mann–Kendall and Pettitt tests' results

Variable	Station name	Mann–Kendall test		Pettitt test	
		p-value	Sen's slope	p-value	Break year
	Khemissa	0.0219	**3.521**	0.0057	**1994**
Rainfall	Machrouha	0.0003	**22.951**	0.0002	**1996**
	Souk Ahras	0.5711	1.419	0.2841	2001
Temperature	Souk Ahras (ONM)	0.0039	**0.02**	0.0007	**1994**
Discharge	Ain Dalia	0.880	0.002	0.62	2001

Bold values indicate significant trends/change points at the level of significance of 5%.

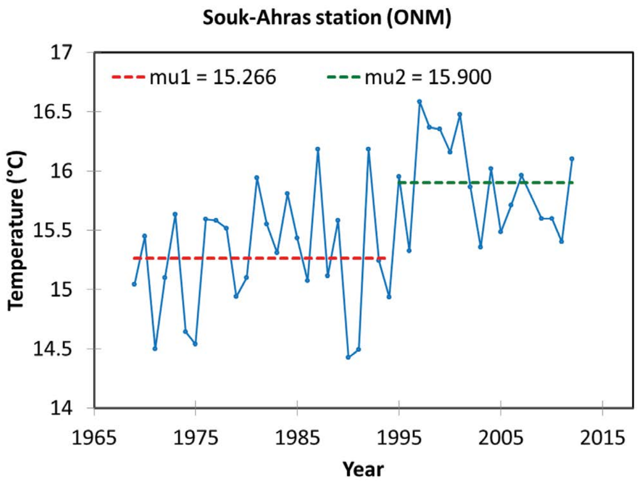

Fig. 3. Shift in mean annual temperature data series according to Pettitt test.

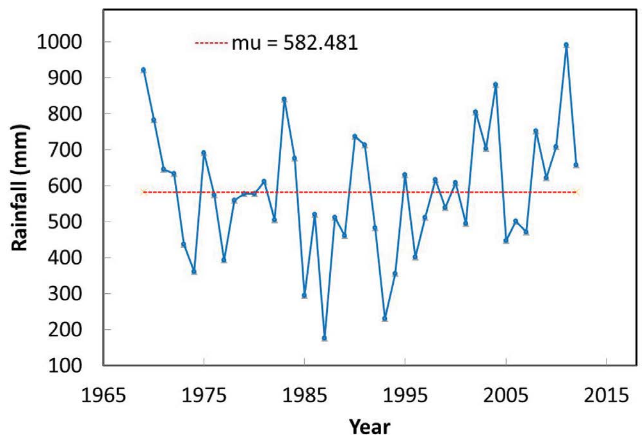

Fig. 4. Inter-annual variability of annual rainfall in the Souk Ahras station.

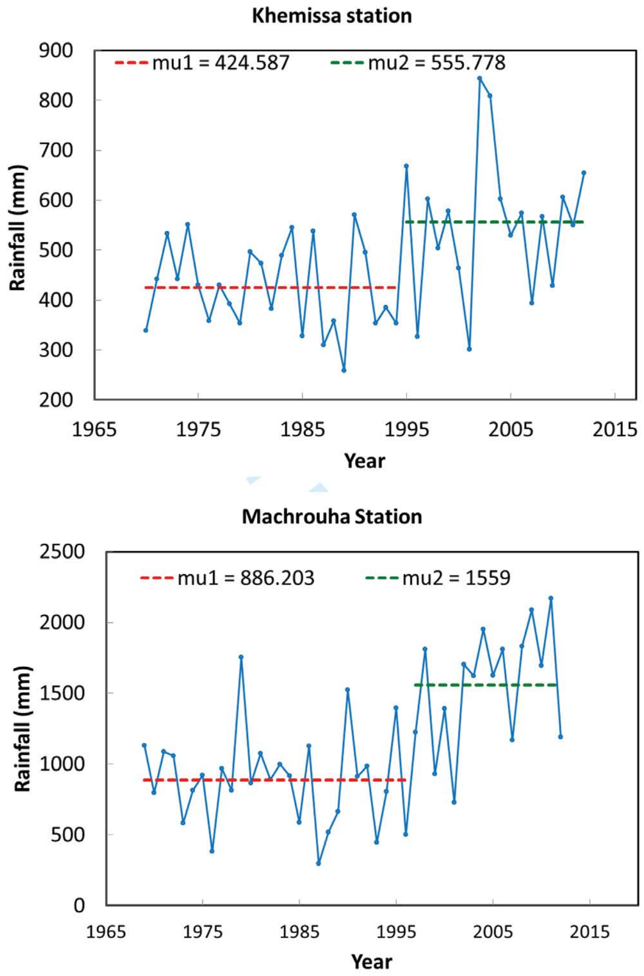

Fig. 5. Shifts in annual rainfall data series (Khemissa and Machrouha) according to Pettitt test.

conducted in nearby regions. For instance, Khezazna et al. [59] detected significant breaks in annual rainfall time series, which occurred in the 1990s and the 2000s at the majority of the rainfall gauges of the Seybouse basin. Likewise, Bendjema et al. [72] detected breaks between 1994 and 2001 in rainfall annual series over the Mellah basin. According to Fniguire et al. [32], the breaks in rainfall time series are generally related to climate change and/or climatic variability. In this study, these abrupt changes in rainfall coincided with the break in mean annual temperature series identified in 1994. Abrupt changes in the climate at a regional scale modify the hydrological regime, and the hydrological variables in this area follow this new regime until another break occurs [73].

4.2. Temporal variability of drought and relationship between meteorological and hydrological droughts

The inter-annual variability of the smoothed SPI, SRI and SWI time series is depicted in Fig. 6. The relationship between precipitation variability and the hydrological conditions in the study area was first investigated by determining the correlation coefficients between SPI and SRI on one hand, and SPI and SWI on the other. The corresponding correlation coefficient values were 0.72 and 0.51, respectively, implying good to moderate relationships between meteorological and hydrological conditions according to Bachmair et al. [74]. Previously, Wang et al. [75] and Huang et al. [76] argued that hydrological drought (SRI and SWI) is more sensitive to climate variability and change than meteorological drought (SPI) due to the nonlinear response of runoff and infiltration to rainfall and temperature changes. Indeed, besides their influence by rainfall variability, runoff and infiltration processes are influenced by several local factors, such as soil type, land slope, land use/cover changes [77–79].

The inter-annual variation of SPI, SRI and SWI were analyzed in terms of occurrence, severity and duration of droughts (Fig. 7). This resulted in the following: (i) Meteorological and hydrological drought conditions significantly decreased after the climatic shift in terms of frequency intensity and duration. (ii) Several runoff dry years (SRI) occurred without a meteorological drought (SPI) in 1986 and 2006. (iii) Two groundwater droughts (SWI)

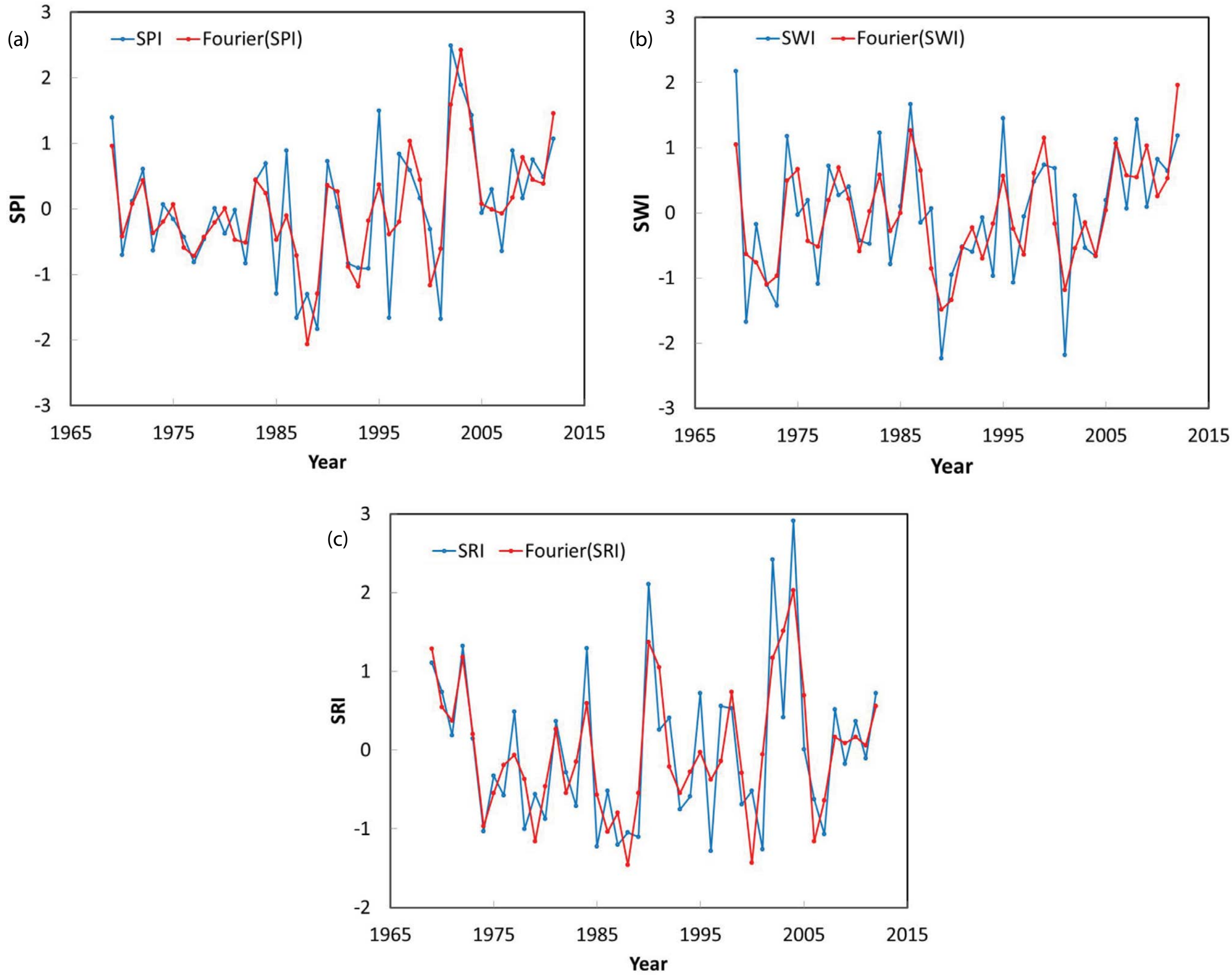

Fig. 6. Inter-annual variability of SPI, SRI and SWI.

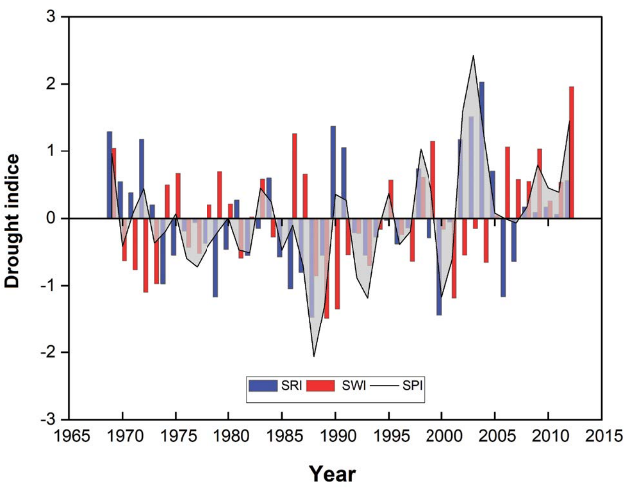

Fig. 7. Inter-annual variation of the smoothed SPI, SRI and SWI series using the Fourier filter.

occurred without meteorological droughts: 1970–1973 and 1977. This can be explained by excessive extraction of groundwater from the Taoura reservoir. (iv) All the meteorological droughts caused concurrent runoff droughts (SRI). (v) Meteorological droughts triggered groundwater droughts with a delay of one or two years. This can be related to the hydrogeological characteristics of the aquifers prevailing in the study area. (vi) Meteorological droughts under severely dry class of two years or longer propagate into long groundwater droughts, with extremely dry conditions: 1989–1994 and 2001–2004.

5. Conclusion

This paper investigated the impacts of change in climate variability on water resources in the region of Souk Ahras. To this end, various hydro-climatological data time series recorded during the (1969–2012) period were analyzed using nonparametric tests and drought indices.

Results of the nonparametric tests showed that the study area has experienced significant increasing trends of rainfall (+18%) and temperature (+0.2°C/decade). These increasing trends were accompanied by abrupt breaks, which occurred around 1994. These breaks indicate the modification of the hydrological regime in the study area, which leads to fewer, less severe and shorter meteorological and hydrological droughts. This study also encompassed an investigation of the relationship between meteorological and hydrological droughts. This revealed that meteorological droughts cause immediate runoff droughts and delayed groundwater droughts, depending on the geological nature of the aquifers prevailing in the study area.

Generally, the findings of this study enhanced the current understanding of climate variability and trend in the region of Souk Ahras along with the potential consequences on surface and groundwater resources. For future research, it would be of great importance to investigate the response of agricultural drought to meteorological and hydrological droughts. This will provide a better comprehension of drought evolution mechanisms in the study area and help forecasting agricultural droughts and suitable adaptation strategies.

References

[1] S.V. Smith, R.W. Buddemeier, Global change and coral reef ecosystems, Annu. Rev. Ecol. Syst., 23 (1992) 89–118.
[2] R. Mendelsohn, The impact of climate change on agriculture in developing countries, J. Nat. Resour. Policy Res., 1 (2008) 5–19.
[3] K.C. Abbaspour, M. Faramarzi, S.S. Ghasemi, H. Yang, Assessing the impact of climate change on water resources in Iran, Water Resour. Res., 45 (2009), doi: 10.1029/2008WR007615.
[4] S. Nunez, E. Arets, R. Alkemade, C. Verwer, R. Leemans, Assessing the impacts of climate change on biodiversity: is below 2°C enough?, Clim. Change, 154.(2019) 351–365.
[5] S.J. Bandara, Y.Y. Cai, The impact of climate change on food crop productivity, food prices and food security in South Asia, Econ. Anal. Policy, 44 (2014) 451–465.
[6] M. Kazemzadeh, A. Malekian, Changeability evaluation of hydro-climate variables in Western Caspian Sea region, Iran, Environ. Earth Sci., 77 (2018), doi: 10.1007/s12665-018-7305-x.
[7] R.L. Heathcote, The Arid Lands: Their Use and Abuse, Longman, New York, 1986.
[8] S.I. Seneviratne, N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, X. Zhang, M. Rusticucci, V. Semenov, L.V. Alexander, S. Allen, G. Benito, T. Cavazos, J. Clague, D. Conway, P.M. Della-Marta, M. Gerber, S. Gong, B.N. Goswami, M. Hemer, C. Huggel, B. van den Hurk, V.V. Kharin, A. Kitoh, A.M.G. Klein Tank, G. Li, S. Mason, W. McGuire, G. Jan van Oldenborgh, B. Orlowsky, S. Smith, W. Thiaw, A. Velegrakis, P. Yiou, T. Zhang, T. Zhou, F.W. Zwiers, Chapter 3 – Changes in Climate Extremes and Their Impacts on the Natural Physical Environment, C.B. Field, V. Barros, T.F. Stocker, D. Qin, Eds., Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2012, pp. 109–230.
[9] A. AghaKouchak, S. Sorooshian, K. Hsu, X. Gao, The potential of precipitation remote sensing for water resources vulnerability assessment in arid southwestern United States, (2013) 141–149, doi: 10.1016/B978-0-12-384703-4.00512-8.
[10] O. Derdous, S.E. Tachi, H. Bouguerra, Spatial distribution and evaluation of aridity indices in Northern Algeria, Arid Land Res. Manage., 35 (2021) 1–14.
[11] J. Cheeseman, Chapter 7 – Food Security in the Face of Salinity, Drought, Climate Change, and Population Growth, M.A. Khan, M. Ozturk, B. Gul, M.Z. Ahmed, Eds., Halophytes for Food Security in Dry Lands, Academic Press, 2016, pp. 111–123.
[12] G.G. Haile, Q. Tang, S. Sun, Z. Huang, X. Zhang, X. Liu, Droughts in East Africa: causes, impacts and resilience, Earth Sci. Rev., 193 (2019) 146–161.
[13] P. Beaumont, Water and Armed Conflict in the Middle East — Fantasy or Reality?, N.P. Gleditsch, Ed., Conflict and the Environment, NATO ASI Series, Vol. 33, Springer, Dordrecht, 1997, pp. 355–374.
[14] A. Swain, Water Wars, J.D. Wright, Ed., International Encyclopedia of the Social & Behavioral Sciences, 2nd ed., Vol. 25, Elsevier, Oxford, 2015, pp. 443–447.
[15] J. Schillinger, G. Özerol, Ş. Güven-Griemert, M. Heldeweg, Water in war: understanding the impacts of armed conflict on water resources and their management, Wiley Interdiscip. Rev.: Water, 7 (2020) e1480, doi: 10.1002/wat2.1480.
[16] Y. Djellouli, P. Daget, Consequences of the drought of the past two decades on Algerian natural ecosystems, Publ. Assoc. Int. Climatologique, 6 (1993) 105–14.
[17] Z. Nouaceur, B. Laignel, I. Turki, Changements climatiques au Maghreb: vers des conditions plus humides et plus chaudes sur le littoral algérien?, Géogr. Phys. Environ., 7 (2013a) 307–323.
[18] S. Taibi, D. Souag, Regionalization of Drought in Northern Algeria Using a Standardized Precipitation Index (1936–2010), From Prediction to Prevention of Hydrological Risk in Mediterranean Countries, 4th International Workshop on Hydrological Extremes, University of Calabria, Cosenza, Italy, 2011, pp. 169–182.
[19] H. Jemai, M. Ellouze, H. Abida, B. Laignel, Spatial and temporal variability of rainfall: case of Bizerte-Ichkeul Basin (Northern Tunisia), Arabian J. Geosci., 11 (2018) 177, doi: 10.1007/s12517-018-3482-x.
[20] Z. Nouaceur, Vers un retour des pluies sur la rive sud du bassin méditerranéen occidental: analyse et évaluation de la tendance pluviométrique sur plus d'un demi-siècle en Algérie, Ann. Valahia Univ. Târgovişte. Geogr. Ser., 11 (2011) 32–36.
[21] O. Ghadbane, M. EL Ghachi and M. Chakir, Étude de la variabilité climatique et de ses impacts sur le régime hydrologique de l'Oued Srou, affluent de rive gauche de l'Oued Oum Er Rbia, Afr. Sci., 18 (2021) 69–80.
[22] E. Xoplaki, J.F. González-Rouco, J. Luterbacher, H. Wanner, Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends, Clim. Dyn., 23 (2004) 63–78.
[23] A. Dünkeloh, J. Jacobeit, Circulation dynamics of Mediterranean precipitation variability 1948–98, Int. J. Climatol., 23 (2003) 1843–1866.
[24] L. Brandimarte, G. Di Baldassarre, G. Bruni, P. D'Odorico, A. Montanari, Relation between the North-Atlantic oscillation and hydroclimatic conditions in Mediterranean areas, Water Resour. Manage., 25 (2011) 1269–1279.
[25] M.G. Donat, T.C. Peterson, M. Brunet, A.D. King, M. Almazroui, R.K. Kolli, D. Boucherf, A.Y. Al-Mulla, A.Y. Nour, A.A. Aly, T.A.A. Nada, M.M. Semawi, H.A. Al Dashti, T.G. Salhab, K.I. El Fadli, M.K. Muftah, S.D. Eida, W. Badi, F. Driouech, K. El Rhaz, M.J.Y. Abubaker, A.S. Ghulam, A.S. Erayah, M.B. Mansour, W.O. Alabdouli, J.S. Al Dhanhani, M.N. Al Shekaili, Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to ENSO and NAO, Int. J. Climatol., 34 (2014) 581–592.
[26] S. Taibi, M. Meddi, G. Mahé, A. Assani, Relationships between atmospheric circulation indices and rainfall in Northern Algeria and comparison of observed and RCM-generated rainfall, Theor. Appl. Climatol., 127 (2017) 241–257.
[27] J. Salinger, M.V.K. Sivakumar, R.P. Motha, Eds., Increasing Climate Variability and Change: Reducing the Vulnerability of Agriculture and Forestry, Springer, Dordrecht, 2005.
[28] J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. Vander Linden, X. Dai, K. Maskell, C.A. Johnson, Eds., Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 881 p.

[29] W.A. Müller, E. Roeckner, ENSO impact on midlatitude circulation patterns in future climate change projections. Geophys. Res. Lett., 33 (2006), doi: 10.1029/2005GL025032.
[30] P. Ortega, M. Montoya, F. González-Rouco, J. Mignot, S. Legutke, Variability of the Atlantic meridional overturning circulation in the last millennium and two IPCC scenarios, Clim. Dyn., 38 (2012) 1925–1947.
[31] H.M. Kang, F. Yusof, Homogeneity tests on daily rainfall series in Peninsular Malaysia, Int. J. Contemp. Math. Sci., 7 (2012) 9–22.
[32] F. Fniguire, N.-E. Laftouhi, M.E. Saidi, Z. Zamrane, H. El Himer, N. Khalil, Spatial and temporal analysis of the drought vulnerability and risks over eight decades in a semi-arid region (Tensift basin: Morocco), Theor. Appl. Climatol., 130 (2017) 321–330.
[33] A.A. Akinsanola, K.O. Ogunjobi, Recent homogeneity analysis and long-term spatio-temporal rainfall trends in Nigeria, Theor. Appl. Climatol., 128 (2017) 275–289.
[34] O. Derdous, H. Bouguerra, S.E. Tachi, A. Bouamrane, A monitoring of the spatial and temporal evolutions of aridity in northern Algeria, Theor. Appl. Climatol., 142 (2020) 1191–1198.
[35] S. Bouabdelli, M. Meddi, A. Zeroual, R. Alkama, Hydrological drought risk recurrence under climate change in the karst area of Northwestern Algeria, J. Water Clim. Change, 11 (2020) 164–188.
[36] R. Charlton, R. Fealy, S. Moore, J. Sweeney, C. Murphy, Assessing the impact of climate change on water supply and flood hazard in Ireland using statistical downscaling and hydrological modelling techniques, Clim. Change, 74 (2006) 475–491.
[37] M. Meliho, A. Khattabi, G. Jobbins, F. Sghir, Impact of meteorological drought on agriculture in the Tensift watershed of Morocco, J. Water Clim. Change, 11 (2020) 1323–1338.
[38] A. Gazol, J.J. Camarero, W.R.L. Anderegg, S.M. Vicente-Serrano, Impacts of droughts on the growth resilience of Northern Hemisphere forests, Global Ecol. Biogeogr., 26 (2017) 166–176.
[39] S. Mellak, D. Souag-Gamane, Spatio-temporal analysis of maximum drought severity using Copulas in Northern Algeria, J. Water Clim. Change, 11 (2020) 68–84.
[40] D. Mrad, S. Dairi, S. Boukhari, Y. Djebbar, Applied multivariate analysis on annual rainfall in the northeast of Algeria, J. Water Clim. Change, 11 (2020) 1165–1176.
[41] N. Merniz, A. Tahar, A.M. Benmehaia, Statistical assessment of rainfall variability and trends in northeastern Algeria, J. Water Land Dev., 40 (2019) 87–96.
[42] L. Djabri, S. Bouhsina, A. Hani, H. Chaffai, F. Trabelsi, F. Rouaibia, A. Bouderbala, Origin and Quality of Groundwater of the Taoura Syncline Aquifer in Northeastern of Algeria, Water Resources in Algeria - Part I: Assessment of Surface and Groundwater Resources, 2020, pp. 29–52.
[43] H.B. Mann, Nonparametric tests against trend, Econometrica, J. Econometric Soc., 13 (1945) 245–259.
[44] M.G. Kendall, Rank Correlation Methods, 4th ed., Charles Griffin, London, 1975.
[45] R.M. da Silva, C.A.G. Santos, M. Moreira, J. Corte-Real, V.C.L. Silva, I.C. Medeiros, Rainfall and river flow trends using Mann–Kendall and Sen's slope estimator statistical tests in the Cobres River basin, Nat. Hazards, 77 (2015) 1205–1221.
[46] K.H. Hamed, Trend detection in hydrologic data: the Mann–Kendall trend test under the scaling hypothesis, J. Hydrol., 349 (2008) 350–363.
[47] A. Mondal, S. Kundu, A. Mukhopadhyay, Rainfall trend analysis by Mann–Kendall test: a case study of northeastern part of Cuttack district, Orissa, Int. J. Geol. Earth Environ. Sci., 2 (2012) 70–78.
[48] H. Theil, A Rank-Invariant Method of Linear and Polynomial Regression Analysis, B. Raj, J. Koerts, Eds., Henri Theil's Contributions to Economics and Econometrics, Advanced Studies in Theoretical and Applied Econometrics, Vol. 23, Springer, Dordrecht, 1992. Available at: https://doi.org/10.1007/978-94-011-2546-8_20
[49] P.K. Sen, Estimates of the regression coefficient based on Kendall's Tau, J. Am. Stat. Assoc., 63 (1968) 1379–1389.
[50] A.N. Pettitt, A non-parametric approach to the change-point problem, J. R. Stat. Soc. C, 28 (1979) 126–135.
[51] M. Salarijazi, A.M. Akhond-Ali, A. Adib, A. Daneshkhah, Trend and change-point detection for the annual stream-flow series of the Karun River at the Ahvaz hydrometric station, Afr. J. Agric. Res., 7 (2012) 4540–4552.
[52] Z. Ma, S. Kang, L. Zhang, L. Tong, X. Su, Analysis of impacts of climate variability and human activity on streamflow for a river basin in arid region of northwest China, J. Hydrol., 352 (2008) 239–249.
[53] A. Piticar, D. Ristoiu, Analysis of air temperature evolution in northeastern Romania and evidence of warming trend, Carpathian J. Food Sci. Technol., 7 (2012) 97–106.
[54] H.M. Kang, F. Yusof, Homogeneity tests on daily rainfall series in Peninsular Malaysia, Int. J. Contemp. Math. Sci., 7 (2012) 9–22.
[55] N. Milad, M. Bannayan, Spatiotemporal changes in aridity index and reference evapotranspiration over semi-arid and humid regions of Iran: trend, cause, and sensitivity analyses, Theor. Appl. Climatol., 136 (2019) 1073–1084.
[56] O. Derdous, A. Bouamrane, D. Mrad, Spatiotemporal analysis of meteorological drought in a Mediterranean dry land: case of the Cheliff basin–Algeria, Model. Earth Syst. Environ., 7 (2021) 135–143.
[57] T.B. McKee, N.J. Doesken, J. Kleist, The Relationship of Drought Frequency and Duration to Time Scales, Eighth Conference on Applied Climatology, Anaheim, California, 1993, pp. 179–183.
[58] T.B. McKee, N.J. Doesken, J. Kleist, Drought Monitoring with Multiple Time Scales, Proceedings of 9th Conference on Applied Climatology, Boston, 1995.
[59] A. Khezazna, H. Amarchi, O. Derdous, F. Bousakhria, Drought monitoring in the Seybouse basin (Algeria) over the last decades, J. Water Land Dev., 33 (2017) 79–88.
[60] S. Djerbouai, D. Souag-Gamane, Drought forecasting using neural networks, wavelet neural networks, and stochastic models: case of the Algerois Basin in North Algeria, Water Resour. Manage., 30 (2016) 2445–2464.
[61] W. Khoualdia, Y. Djebbar, Y. Hammar, Caractérisation de la variabilité climatique: cas du bassin versant de La Medjerda (Nord-Est algérien), Rév. Sci. Tech., 29 (2014) 6–23.
[62] A. Elouissi, B. Benzater, I. Dabanli, M. Habi, A. Harizia, A. Hamimed, Drought investigation and trend assessment in Macta watershed (Algeria) by SPI and ITA methodology, Arabian J. Geosci., 14 (2021) 1329, doi: 10.1007/s12517-021-07670-7.
[63] B. Zerouali, M. Chettih, Z. Abda, M. Mesbah, C.A.G. Santos, R.M. Brasil Neto, R.M. da Silva, Spatiotemporal meteorological drought assessment in a humid Mediterranean region: case study of the Oued Sebaou basin (northern central Algeria), Nat. Hazards, 108 (2021) 689–709.
[64] M. Achite, O. Bazrafshan, Z. Azhdari, A. Wałęga, N. Krakauer, T. Caloiero, Forecasting of SPI and SRI using multiplicative ARIMA under climate variability in a Mediterranean Region: Wadi Ouahrane Basin, Algeria, Climate, 10 (2022) 36, doi: 10.3390/cli10030036.
[65] M.J. Hayes, M.D. Svoboda, D.A. Wiihite, O.V. Vanyarkho, Monitoring the 1996 drought using the standardized precipitation index, Bull. Am. Meteorol. Soc., 80 (1999) 429–438.
[66] S. Shukla, A.W. Wood, Use of a standardized runoff index for characterizing hydrologic drought, Geophys. Res. Lett., 35 (2008), doi: 10.1029/2007GL032487.
[67] R.N. Sahoo, D. Dutta, M. Khanna, N. Kumar, S.K. Bandyopadhyay, Drought assessment in the Dhar and Mewat Districts of India using meteorological, hydrological and remote-sensing derived indices, Nat. Hazards, 77 (2015) 733–751.
[68] K. Kubiak-Wójcicka, B. Bąk, Monitoring of meteorological and hydrological droughts in the Vistula basin (Poland), Environ. Monit. Assess., 190 (2018) 691, doi: 10.1007/s10661-018-7058-8.
[69] S. Charifi Bellabas, S. Benmamar, A. Dehni, Study and analysis of the streamflow decline in North Algeria, J. Appl. Water Eng. Res., 9 (2021) 20–44.
[70] J.G. Liu, G.L.K. Morgan, FFT selective and adaptive filtering for removal of systematic noise in ETM+ Imageodesy images, IEEE Trans. Geosci. Remote Sens., 44 (2006) 3716–3724.

[71] W. Khoualdia, H. Yahia, Contribution à l'étude de la sècheresse et concepts des modèles probabilistes « cas de la région de Souk Ahras, Algerie », Rev. Courier du Savoir., 2017.
[72] L. Bendjema, K. Baba-Hamed, A. Bouanani, Characterization of the climatic drought indices application to the Mellah catchment, North-East of Algeria, J. Water Land Dev., 43 (2019) 28–40.
[73] A. Kalra, S. Sagarika, P. Pathak, S. Ahmad, Hydro-climatological changes in the Colorado River Basin over a century, Hydrol. Sci. J., 62 (2017) 2280–2296.
[74] S. Bachmair, I. Kohn, K. Stahl, Exploring the link between drought indicators and impacts, Nat. Hazards Earth Syst. Sci., 15 (2015) 1381–1397.
[75] D. Wang, M. Hejazi, X. Cai, A.J. Valocchi, Climate change impact on meteorological, agricultural, and hydrological drought in central Illinois, Water Resour. Res., 47 (2011), doi: 10.1029/2010WR009845.
[76] S. Huang, Q. Huang, J. Chang, G. Leng, L. Xing, The response of agricultural drought to meteorological drought and the influencing factors: a case study in the Wei River Basin, China, Agric. Water Manage., 159 (2015) 45–54.
[77] A.F. Van Loon, G. Laaha, Hydrological drought severity explained by climate and catchment characteristics, J. Hydrol., 526 (2015) 3–14.
[78] A. Bouamrane, O. Derdous, N. Dahri, S.-E. Tachi, K. Boutebba, M.T. Bouziane, A comparison of the analytical hierarchy process and the fuzzy logic approach for flood susceptibility mapping in a semi-arid ungauged basin (Biskra basin: Algeria), Int. J. River Basin Manage., 20 (2022) 203–213.
[79] A. Malekian, B. Choubin, J. Liu, F. Sajedi-Hosseini, Development of a new integrated framework for improved rainfall-runoff modeling under climate variability and human activities, Water Resour. Manage., 3 (2019) 2501–2515.