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Efficiency of some meteorological drought indices in different time scales, case study: wadi Louza basin (NW-Algeria)

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Abstract

Drought is an insidious hazard of nature in many parts of the world. It originates from persistent shortage of precipitation over a specific region for a specific period of time and has a conceptual and operational definition. Drought impact on some activity, group, or environmental sector depends on the extent of water shortage and ground conditions. Algeria and especially the western region has experienced several periods of drought over the last century, since 1975 to the present day. The most recent drought in 1981, 1989, 1990, 1992, 1994 and 1999 was characterized by its intensity and spatial extent. Drought is identified using various drought indices (meteorological, hydrological and agricultural). In this research, we focus on the meteorological drought, to assess the reliability of these indices under changing climatic conditions. Data was recorded for the period of 1980–2009 at wadi Louza catchment (NW-Algeria). For describing and monitoring drought severity periods, we calculated the correlation between both meteorological drought indices: Standardised Precipitation Index (*SPI*) and Effective Drought Index (*EDI*). The results show that the watershed of wadi Louza has experienced a severe meteorological drought. The correlation between meteorological drought indices was good for all time steps and the best was found for 9-month time step. The obtained results may provide some scientific support for fighting against droughts.

Key words: *drought, effective drought index, standardised precipitation index, wadi Louza*

INTRODUCTION

Droughts are one of the most dangerous and damage-causing natural phenomena. Compared with the mean sum of precipitation in the last three decades of the 20th century, the mean sum of precipitation in growing seasons (April–September) of the years 2011–2050 is predicted to decrease by 55 mm [BAK, LABEDZKI 2014]

Many semi-arid areas (e.g. The Mediterranean basin, Western United States, South Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. By 2020, between 75

and 250 million people in Africa are projected to be exposed to increased water stress due to climate change. In some countries, yields from rain-fed agriculture could be reduced by up to 50%. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Drought affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production and health [IPCC 2007].

Over the years, more than 150 different drought indicators have been proposed and developed for drought characterization [ZARGAR *et al.* 2011]. Sever-

al studies used Palmer Drought Severity Index (*PDSI*) [PALMER 1965], Surface Water Supply Index (*SWSI*) [SHAFER, DEZMAN 1982], Standardised Precipitation Index (*SPI*) [MCKEE *et al.* 1993], Effective Drought Index (*EDI*) [BYUN, WILHITE 1999], Reconnaissance Drought Index (*RDI*) [TSAKIRIS *et al.* 2007]. A large number of drought indices are calculated using more hydro-meteorological variables [RAZIEI *et al.* 2009].

In the present research, our interest to assessment and monitoring drought severity in wadi Louza watershed (NW-Algeria). We used both indexes *SPI* and *EDI*.

The most prominent and widely used drought indicator is the Standardised Precipitation Index (*SPI*), which has been recommended to be used to characterize the meteorological droughts around the world by the World Meteorological Organization (WMO) due to its flexibility for various time scales, simplicity in input parameters and calculation, as well as effectiveness in decision making [SHEFFIELD, WOOD 2011; HAYES *et al.* 2011]. The *SPI* is determined by precipitation at different time scales (e.g. 1 month, 3 months, 12 months) [MCKEE *et al.* 1993; 1995].

In a comparative study between *EDI* and *SPI*, the *EDI* was found to be better than *SPI* in detecting long term, extremely long term and short term drought, short term rainfall and also dealing with the problem of overestimation and under estimation [BYUN, KIM 2010]

METHOD AND MATERIAL

STUDY AREA

The wadi Louza catchment is situated within the wadi Hammam basin north west of Algeria, between north latitudes of 34.68°–35.03° and the west longitudes of 0.70°–0.37°, with an area of 746 km². The main watercourse originates at an altitude of 1455 m on the fallout of mountain Mezioud. The main tributaries are Telzaa River, Telagh River, Neksifia River, Teghalimet River, then Louza River with a total length of about 39.51 km and elevations ranging from 580 m to 1460 m (the average elevation is 855 m). Its climate is classified as semi-arid, with a mean precipitation of 286 mm·year⁻¹ (1980–2009) (Fig. 1).

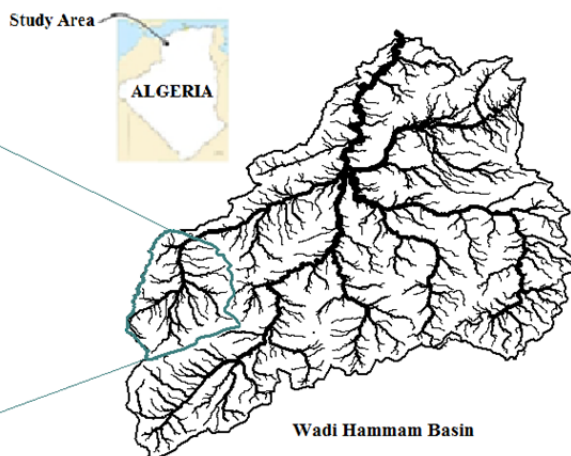
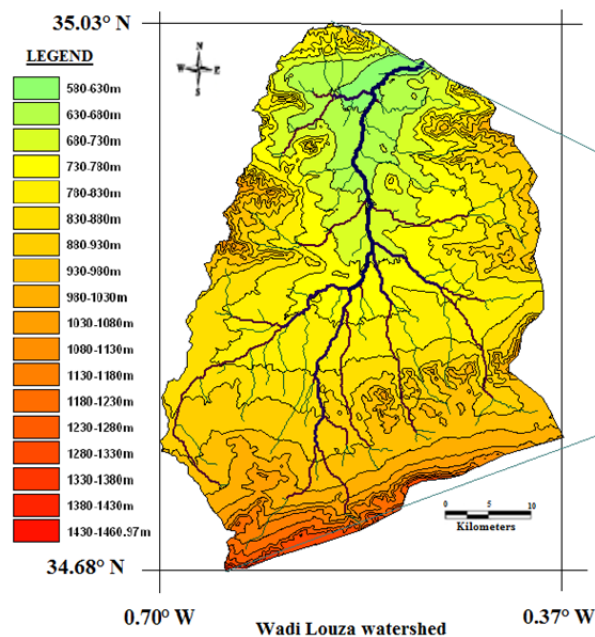


Fig. 1. Situation of wadi Louza watershed; source: own elaboration

DATA USED

In this paper, all chosen precipitation stations (Telagh, Merine, Sid Ahmed) (Fig. 2) show the quality of good data, are managed by the National Agency of Hydric Resources (NAHR) (Tab. 1). Some gaps are observed in the time series of Sid Ahmed station. Data homogeneity was tested using Pettit test and Hubert test [HUBERT, CARBONNEL 1987; HUBERT *et al.* 1989]. Indeed, the average rupture in rainfall series, is detected only by the test of Hubert, characterized by an increase in rainfall. It's occurred in 2007.

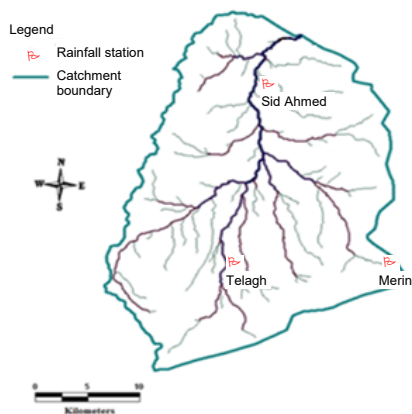


Fig. 2. Location of rainfall stations in wadi Louza basin; source: own elaboration

Table 1. Characteristics of rainfall stations in wadi Louza basin

Station name	Gauge type	Longitude	Latitude	Elevation m	Selected period
Telagh	rain gauge	0°34'28.9726" W	34°47'4.9442" N	889	1980–2009
Merine	rain gauge	0°24'12.1733" W	34°47'34.5859" N	959	1980–2009
Sid Ahmed	rain gauge	0°32'41.3488" W	34°57'54.1487" N	653	1980–2009

Source: own elaboration.

METHODS

Both meteorological drought indices have used for this research: the Standardised Precipitation Index (*SPI*) and the Effective Drought Index (*EDI*); for objective to investigate and confirm the pertinence of these indices and estimate the impact of climate change on the water cycle of wadi Louza basin. These drought indices were calculated for each station based on monthly data, recorded for 1980 to 2009.

Drought indices

Standardised Precipitation Index (*SPI*)

SPI should be used to characterize the meteorological droughts around the world by the World Meteorological Organization (WMO) [HAYES *et al.* 2011]. *SPI* is developed by [MCKEE *et al.* 1993] for the quantifying precipitation deficit for multiple time steps (e.g. 1-month, 3-months, 12-months), identifying dry and wet events and evaluate their intensity [BARTCZAK *et al.* 2014]. A long-term precipitation record is fitted to a probability distribution (e.g. Gamma distribution) and the cumulative probability of an observed precipitation event for each time scale of interest is deduced, The value of *SPI* can be obtained by transformation of the cumulative probability to the standard normal random variable with mean of zero and variance of one [JAIN *et al.* 2015], *SPI* varies between +2.0 and -2.0, with extremes outside this range occurring in 5% of the time [EDWARDS, MCKEE 1997].

SPI may be used for monitoring both dry and wet conditions. The greater value of *SPI* close to 1 or above indicates the wet event. The *SPI* value shows: The near normal precipitation events ($-0.99 \leq SPI \leq 0.99$), moderately dry ($-1.49 \leq SPI \leq -1.0$), severely dry ($-1.99 \leq SPI \leq -1.5$) and extremely dry ($SPI \leq -2.0$) (Tab. 2). A drought event of the time scale is defined here as a period in which the *SPI* is continuously negative and the *SPI* reaches a value of -1.0 or less and ends when *SPI* becomes positive again [MCKEE *et al.* 1993]. The *SPI* at different time scales may vary in its usefulness in drought monitoring. In the case of shorter time scales (e.g. 1-month and 3-months), the *SPI* values have the tendency to fluctuate frequently above and below the zero line, while for longer time scales (e.g. 12-months and 24-months) there are well-defined dry and wet cycles [IONITA *et al.* 2016].

Table 2. Classification of Standardised Precipitation Index (*SPI*) values

<i>SPI</i> value	Drought condition
≥ 2.0	extremely wet
(1.5; 1.99)	very wet
(1.0; 1.49)	moderately wet
(-0.99; 0.99)	near normal
(-1.0; -1.49)	moderately dry
(-1.5; -1.99)	severely dry
≤ -2.0	extremely dry

Source: MCKEE *et al.* [1993], modified.

The calculation for *SPI* is given with under equation (1) [NOROUZI *et al.* 2012];

$$SPI = \frac{x_{i,j} - \bar{x}}{\sigma} \tag{1}$$

Where, x = the seasonal precipitation at the i^{th} rain gauge and j^{th} observation, \bar{x} = the long-term seasonal mean and σ = standard deviation, *SPI* = Standardised Precipitation Index.

Effective drought index (*EDI*)

BYUN and WILHITE [1999] proposed Effective Drought Index (*EDI*), is a reply and have the potential to deal with all of the limitations of *SPI*. *EDI* provides more information's: duration and severity of rainfall deficit, start and end of the drought period. Effective precipitation (*EP*) that represents resources daily depletion of water is the base of concept *EDI* [MORID *et al.* 2006]. The original form of *EDI* is computed with a daily time step using daily rainfall data. SMAKHTIN and HUGHES [2007] modified his algorithm to be tested with monthly data.

An innovative discovery in the field of drought research has provided by BYUN and WILHITE [1999], confirmed by BYUN and LEE [2002], YAMAGUCHI and SHINODA [2002], HAN and BYUN [2006] and CHOI and BYUN [2007].

BYUN and WILHITE [1999] suggested the following equation for *EP*:

$$EP_i = \sum_{n=1}^i \left[\left(\sum_{m=1}^n P_m \right) / n \right] \tag{2}$$

where: EP_i = valid effective precipitation, P_m = daily precipitation, m = number of days before a specific day, i = the number of days of the time window, n = running from 1 till i [CHHAJER *et al.* 2015].

$$DEP = EP - MEP \tag{3}$$

where: *EP* = effective precipitation for 365 days counting from a specific day, *MEP* = the mean of effective precipitation *DEP* = deviation of *EP* from *MEP*.

EDI is calculated as,

$$EDI = DEP / SD(EP) \tag{4}$$

$SD(EP)$ = the standard deviation of each day's *EP*.

Ranks of *EDI* reflect drought conditions [BYUN, WILHITE 1999] indicate: extreme drought ($EDI \leq -2.0$), severe drought ($-1.99 \leq EDI \leq -1.5$), moderate drought ($-1.49 \leq EDI \leq -1.0$) and near normal conditions ($-0.99 \leq EDI \leq 0.99$).

RESULTS AND DISCUSSIONS

CORRELATION ANALYSIS BETWEEN METEOROLOGICAL INDICES

Pearson correlation coefficient and the linear regressions between the monthly values of the *SPI* versus the *EDI* were calculated for three chosen stations. Figure 3 was prepared to spot trends and correlations between the *SPIs* and *EDIs* indices, the scatter diagram of *SPI1* and *EDI1* is very scattered and more tightly for *SPI9* and *EDI9*. The results showed, the maximum value of (*r*) between *SPIs* and *EDIs* was obtained for 9-months time scale, showed a good relationship in terms of this time scale and the minimum

value of 1-month time scale in all areas (Tab. 3). On a time scale 3, 6 and 12-months in all stations, correlation coefficient (*r*) is greater than 0.73.

ASSESSMENT OF DROUGHT CHARACTERISTICS

The assessment, the prediction and mitigation are needed in order to quantify drought. The severity and duration characterized drought. During the period 1980–2009, *SPI* and *EDI* are used to these objectives in wadi Louza basin.

For short-term drought

In Sid Ahmed region, the *EDI* is the major in the maximum duration of the drought and in number of drought months. In Merine region, the longest drought among all events measured using *SPI1* and *SPI3* is 51 months and 63 months respectively (Tab. 4). The number of drought months grew with the increase of time step for *SPI*, but, for *EDI* decrease and the maximum duration of drought varies for each station.

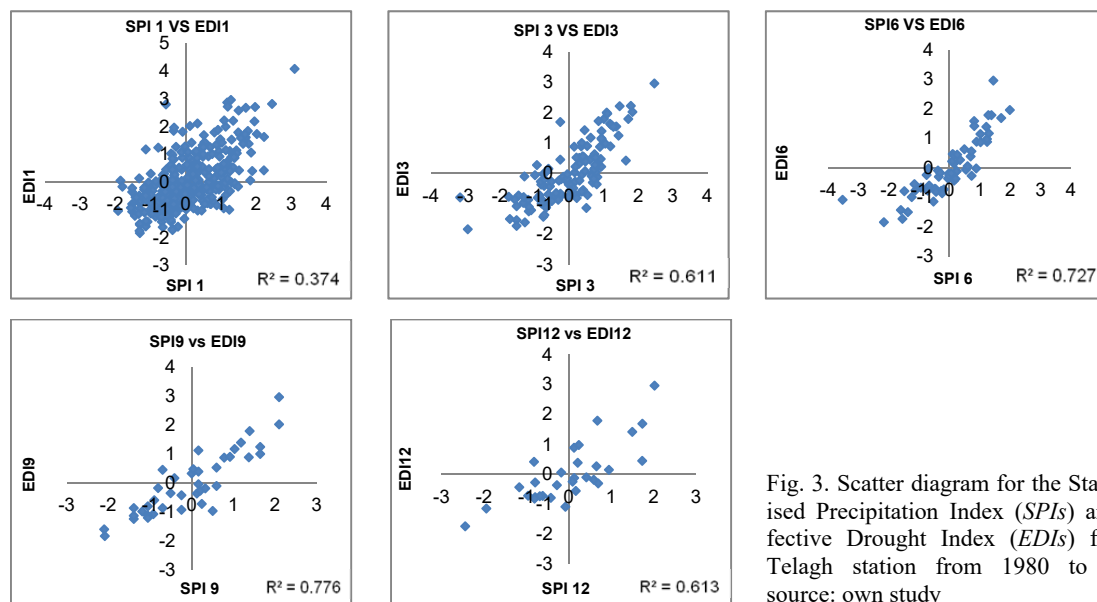


Fig. 3. Scatter diagram for the Standardised Precipitation Index (*SPIs*) and Effective Drought Index (*EDIs*) for the Telagh station from 1980 to 2009; source: own study

Table 3. Correlation coefficient (*r*) between Standardised Precipitation Index (*SPIs*) and Effective Drought Index (*EDIs*) in different time scales (1, 3, 9 and 12 months)

Scale time	Region	<i>r</i>
<i>SPI1</i> vs <i>EDI1</i>	Telagh	0.61
	Sid Ahmed	0.64
	Merine	0.61
<i>SPI3</i> vs <i>EDI3</i>	Telagh	0.78
	Sid Ahmed	0.85
	Merine	0.81
<i>SPI6</i> vs <i>EDI6</i>	Telagh	0.85
	Sid Ahmed	0.85
	Merine	0.84
<i>SPI9</i> vs <i>EDI9</i>	Telagh	0.88
	Sid Ahmed	0.84
	Merine	0.84
<i>SPI12</i> vs <i>EDI12</i>	Telagh	0.78
	Sid Ahmed	0.73
	Merine	0.74

Source: own study.

As showed in Figure 4, the maximum duration of droughts detected by *EDI1s*, which occurred from April 1988 to February 1989, observed in Sid Ahmed area. That was the initial stage of a moderate drought event, followed by a severe shortage of rainfall in winter, spring and summer, began in December 1999, of 9 months duration. *SPI1s* which is the most similar to the *EDI1s*, was able to detect in this short-term drought the most severe droughts months (November 1981 and March 1997) in all regions during the period of study. For 1-month time scale, it can be seen 10–14% the total number of months with $SPI < -1$ and 11–17% with $EDI < -1$ belong to moderate, severe or extreme drought classes. Succession of dry months varies from 1-month minimum to 11 months maximum. Less accurate forecasts are the result of sensitivity the *SPI1* to variation in precipitation from month to month.

Table 4. Drought monitoring with *SPIs* and *EDIs* indices for short-term (1 and 3 months) in wadi Louza watershed

Station	Number of											
	drought months acc. to		drought events acc. to		maximum duration of drought (months) acc. to		drought months acc. to		drought events acc. to		maximum duration of drought (months) acc. to	
	<i>SPI1</i>	<i>EDI1</i>	<i>SPI1</i>	<i>EDI1</i>	<i>SPI1</i>	<i>EDI1</i>	<i>SPI3</i>	<i>EDI3</i>	<i>SPI3</i>	<i>EDI3</i>	<i>SPI3</i>	<i>EDI3</i>
Telagh	35	41	26	12	3	9	51	42	13	8	12	12
Sid Ahmed	38	59	31	15	3	11	60	57	16	10	9	12
Merine	51	44	35	18	4	8	63	48	17	11	9	9

Explanations: *SPI1*, *SPI3* = Standardised Precipitation Index in 1-month time scale and 3-months time scale, respectively; *EDI1*, *EDI3* = Effective Drought Index in 1-month time scale and 3-months time scale, respectively.
Source: own study.

Figure 5 shows a comparison of the *EDI3s* with the *SPI3s* over the same period. Both indices indicated severe and moderate event was relieved between May 1983 to November 1983 in Merine and Sid Ahmed areas. As the drought period lengthened, was 12 months continuous, occurred from December 1982 to November 1983 at Sid Ahmed region.

SPI3s and *EDI3s* showed extreme drought period (September 1981 to November 1981) in all areas. *SPI3s* indicated the extreme drought event with *SPI* value -2.82 at Sid Ahmed, -3.16 at Telagh and -2.35 at Merine, but *EDI3* showed the extreme drought just

in Sid Ahmed with *EDI3* value -2.15 . At all stations, *SPI3s* and *EDI3s* upheld the period between December 1995 to December 1996 is the wetly duration. September 2008 to February 2009 is identified as the wet months by *SPI3s* but *EDI3s* extended this phase to May 2009, confirm the average rupture in rainfall series detected by Hubert test, characterized by an increase in rainfall.

The difference between *SPI* and *EDI* for time scale 1-month and 3-month. *EDI* can be detected succession period (dry or wet) but the *SPI* overestimates intensity of the (dry or wet) event.

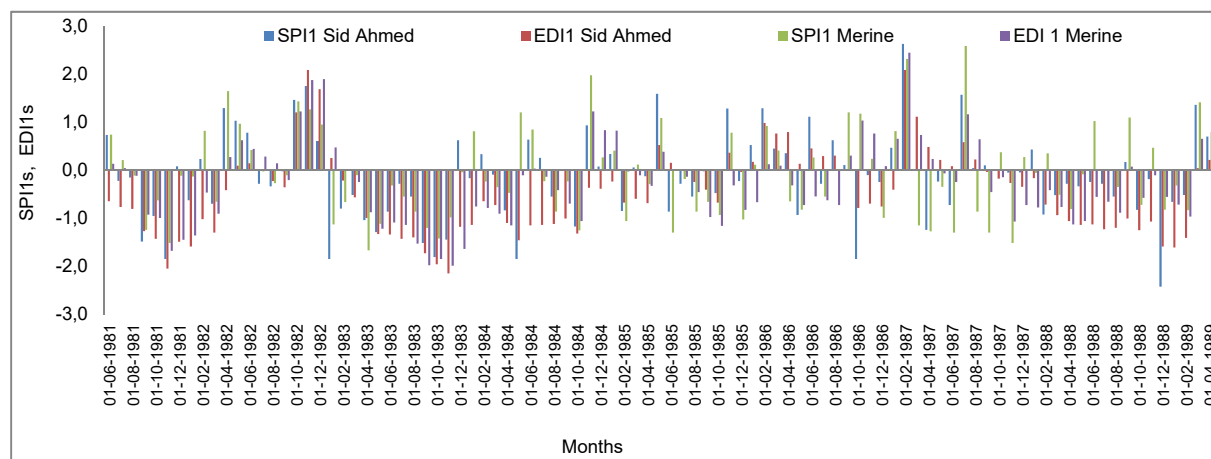


Fig. 4. Comparison of the Standardised Precipitation Index (*SPI1s*) and Effective Drought Index (*EDI1s*) for Merine and Sid Ahmed stations with a one month time step during period 1981 to 1989; source: own study

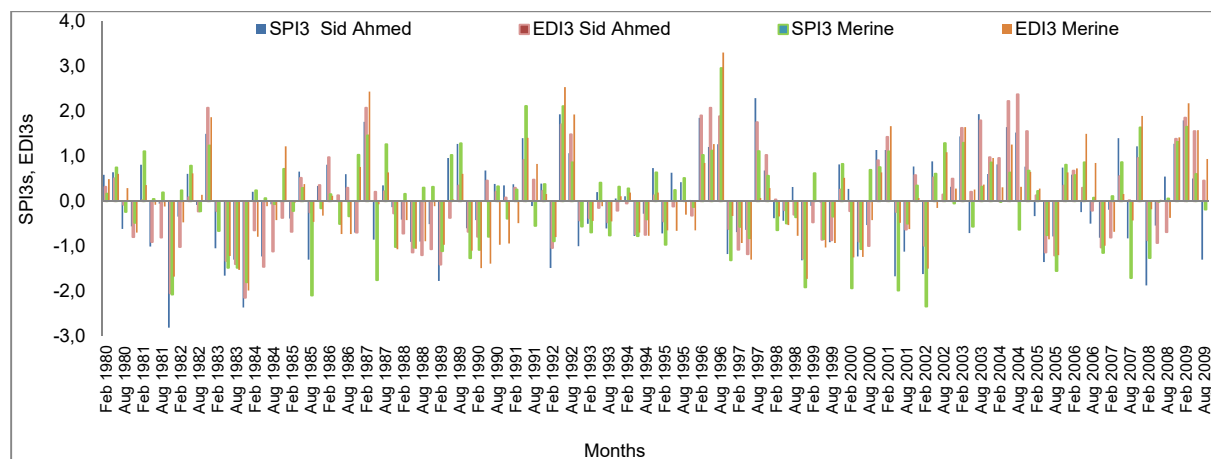


Fig. 5. Comparison of the Standardised Precipitation Index (*SPI3s*) and Effective Drought Index (*EDI3s*) for Merine and Sid Ahmed station with a 3-months time scale; source: own study

For average- and long-term drought

The *SPI9s* show similar behaviour to the *EDI9s* as can be identified visually, reveal the same severity of dry and wet cases (Fig. 6a, b, c).

For each index, there were 18 months is the maximum duration of the drought, started in March 1983, ended in August 1984 with the monthly *EDI* and *SPI* were < -1 (Tab. 5).

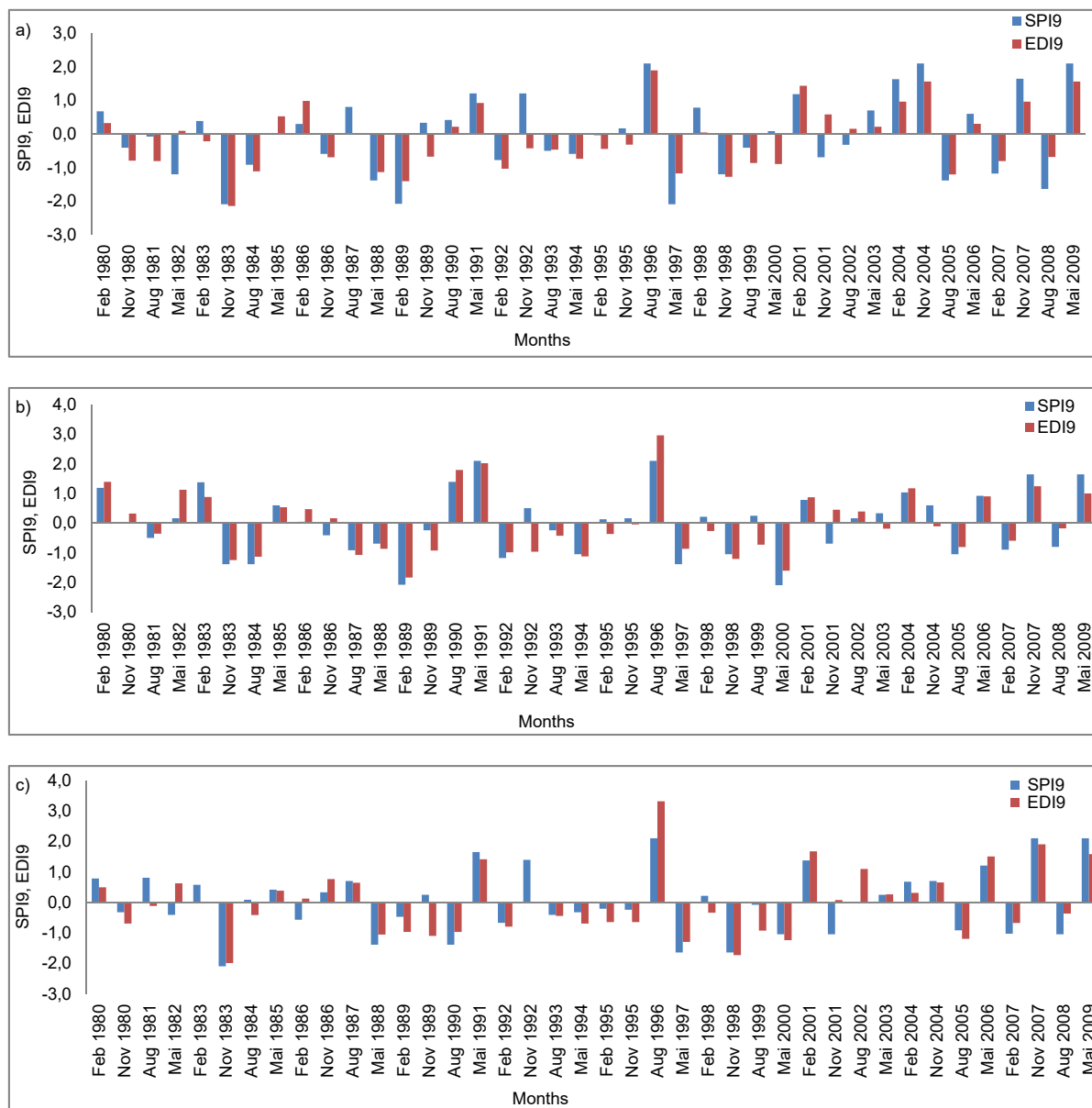


Fig. 6. Comparison of the Standardised Precipitation Index (*SPI9*) and Effective Drought Index (*EDI9*) values with a 9-months time scale for: a) Sid Ahmed station b) Telagh, c) Merine; source: own study

Table 5. Drought monitoring with *SPIs* and *EDIs* indices for average and long-term (9 and 12 months) in wadi Louza watershed

Station	Number of											
	drought months acc. to		drought events acc. to		maximum duration of drought (months) acc. to		drought months acc. to		drought events acc. to		maximum duration of drought (months) acc. to	
	<i>SPI9</i>	<i>EDI9</i>	<i>SPI9</i>	<i>EDI9</i>	<i>SPI9</i>	<i>EDI9</i>	<i>SPI12</i>	<i>EDI12</i>	<i>SPI12</i>	<i>EDI12</i>	<i>SPI12</i>	<i>EDI12</i>
Telagh	81	63	9	7	18	18	36	36	3	3	12	12
Sid Ahmed	81	72	9	8	18	18	60	60	5	5	12	18
Merine	81	63	9	7	9	9	60	24	5	2	12	12

Explanations: *SPI9*, *SPI12* = standardised precipitation index in 9-month time scale and 12-months time scale, respectively; *EDI9*, *EDI12* = effective drought index in 9-month time scale and 12-months time scale, respectively.
Source: own study.

Best correlation was obtained between *SPI* and *EDI* by Pearson correlation coefficient confirm the result, for 9-months time scale, it can be seen 20–23% of the total number of months with *SPI* < -1 and 16–20% with *EDI* < -1. In study basin, extreme drought events are identified for various stations. At Sid Ahmed, Telagh and Merine *SPI* value is -2.10 but *EDI* value is -2.15 at Sid Ahmed. 9-months time scale is the most suitable time step to provide reasonable estimates of drought severity and capture the soil moisture anomalies [CHAMPAGNE *et al.* 2015; PAULO *et al.* 2012; JAIN *et al.* 2015].

In 12-months time step moderate droughts have been determined, by *SPI*: 4, 1, and 3 times, by *EDI*: 5,

2 and 1 times in Sid Ahmed, Telagh and Merine districts respectively. Severe drought has been identified 1 time for each station by *SPI*, but by *EDI* just in Telagh and Merine. During the period between 1982–2005 all stations indicate moderate to severe drought, except Sid Ahmed. In Telagh region extreme drought has been identified by peak value -2.44 (2000) (Fig. 7).

The drought intensity increase spatially in the study area, from Sid Ahmed Region (North) to Telagh Region (South) confirms the findings of GHENIM and MEGNOUNIF [2013]. For time scale 9-months and 12-months, *SPI* and *EDI* show almost identical characteristics: frequency and intensity (drought or wet).

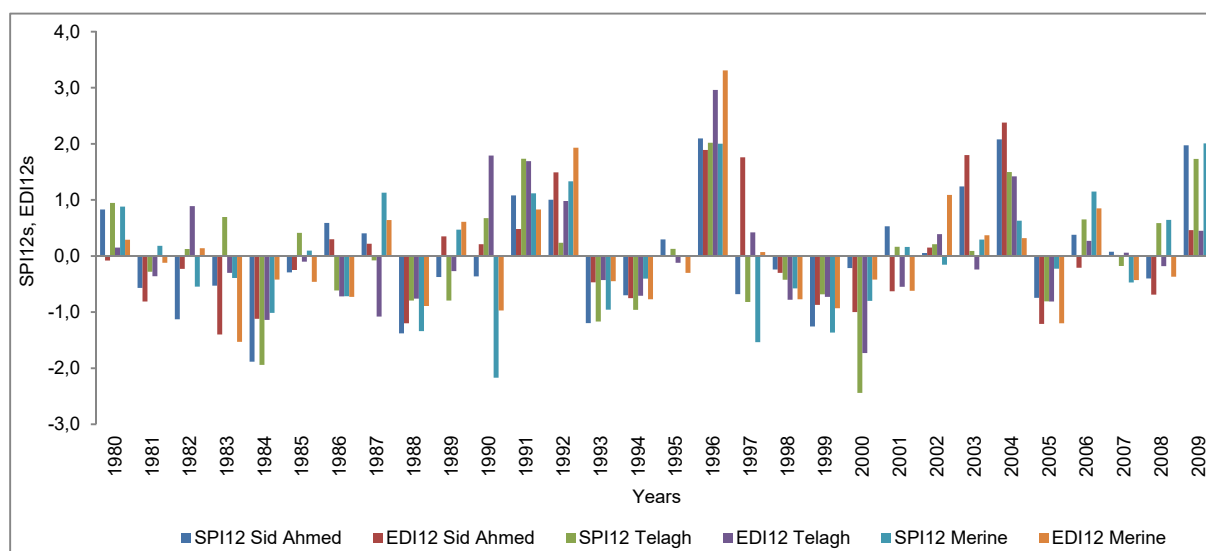


Fig. 7. Standardised Precipitation Index (*SPI*_{12s}) and Effective Drought Index (*EDI*_{12s}) values for selected stations with a 12-months time scale; source: own study

CONCLUSIONS

1. Identification of efficacious indices is referred to the capacity of *SPI* and *EDI* to be performed to forecast and assess drought severities of an appropriate time step, for short-term and long-term [MASHARI ESHGHABAD *et al.* 2014].

2. Sensitivities of *SPI* to variation in precipitation decrease with the increase of time step.

3. The short-term *SPIs* (1-month and 3-months) overestimates intensity of the drought, may lead to an erroneous assessment.

4. In 9-months time step, *SPIs* had a high R^2 value, greater than 0.73, was the closest to the *EDIs*.

5. It could be concluded, at this long-term, *SPI* and *EDI* had almost the same drought severity and the maximum efficiency. This time scale is a better choice to detect the drought severity for study basin.

6. Two severe periods of drought have been detected: one, between March 1983 and August 1984 and the other between March 1988 and November 1989.

7. *SPI* has been recommended to be used to characterize the meteorological droughts around the

world. For better understanding the drought attributes of the study area, it is recommended to integrate *EDI* into an emerging drought monitoring system and can serve as predictors of drought.

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Efektywność niektórych wskaźników suszy meteorologicznej w różnej skali czasu na przykładzie zlewni uedu Louza w północno-zachodniej Algierii

STRESZCZENIE

Susza jest naturalnym zagrożeniem w wielu częściach świata. Powstaje wskutek trwałego ograniczenia ilości opadów w danym regionie i okresie czasu. Jest zdefiniowana w sensie konceptualnym i operacyjnym. Wpływ suszy na różne rodzaje działalności człowieka i na środowisko zależy od rozmiaru deficytu wody i od warunków glebowych. Algieria, szczególnie jej zachodnia część doświadczyła okresów intensywnej suszy już w ubiegłym wieku, począwszy od roku 1975 r., i doświadcza ich po dzień dzisiejszy. Ostatnia susza charakteryzowała się dużą intensywnością i przestrzennym zasięgiem. Suszę identyfikuje się, używając różnych wskaźników meteorologicznych, hydrologicznych lub rolniczych. W badaniach prezentowanych w niniejszej pracy skupiono się na suszy meteorologicznej, aby ocenić wiarygodność tych wskaźników w zmieniających się warunkach klimatycznych. Dane notowano w okresie 1980–2009 w zlewni uedu Louza w północno-zachodniej Algierii. Na potrzeby charakterystyki i monitoringu okresów suszy obliczono korelację między dwoma wskaźnikami – wskaźnikiem standaryzowanego opadu (*SPI*) i efektywnym wskaźnikiem suszy (*EDI*). Wyniki dowodzą, że w zlewni uedu Louza wystąpiła głęboka susza meteorologiczna. Korelacja między wskaźnikami suszy meteorologicznej była dobra w odniesieniu do wszystkich kroków czasowych, ale najlepsza w odniesieniu do okresów 9-miesięcznych. Uzyskane wyniki mogą stanowić naukowe wsparcie w walce z suszą.

Słowa kluczowe: efektywny wskaźnik suszy, susza, ued Louza, wskaźnik standaryzowanego opadu