



Trend analysis of precipitation records using an innovative trend methodology in a semi-arid Mediterranean environment: Cheliff Watershed Case (Northern Algeria)

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Abstract

The description and analysis of rainfall trends is necessary for effective planning, management, and exploitation of water resources. This study investigates the possible trend of precipitation of 28 stations in a semi-arid Mediterranean environment (Northern Algeria) for the period from 1959 to 2019 (60 years), using a recently proposed innovative partial trend methodology. The main advantage of this new method is that it provides qualitative interpretations of trends in the high, medium, and low precipitation ranges in terms of the structure of the time series' internal trend. An accurate database has been established thanks to the homogeneity of the data quality leading to rather satisfactory results with a precision of the spatial and temporal tendencies, thus establishing maps of regional trends: "high precipitation," "average precipitation," and "low precipitation" for the whole study area.

1 Introduction

Water is a survival element which is directly or indirectly linked to any economic or social development in a semi-arid country like Algeria. Unluckily, water resources face serious difficulties linked to the need and shortage of precipitation as well as its geographical inconstancy. According to experts, by 2020, Algeria will experience a reduction of about 5 to 13% in rainfall and an increase of 0.6 to 1.1 °C in temperature (Khelil and Nichane 2014).

In addition, Algeria will suffer recurrent droughts and floods, and water requirements will double in volume under the pressure of population growth and urbanization. Thus, so many problems will emerge to make the management of water resources even more difficult, like the worsening of desertification phenomena, salinization of the soil, pollution of surface water (of urban and industrial origin), the rapid degradation of the hydraulic infrastructure, and, consequently, the progressive degradation of water resources. It is critical to notice that, in 2008, among an average of

100 billion m³ received as rainfall every year, in the northern piece of Algeria, just 4.8 billion m³ are kept in operational dams in Algeria (Kettab et al. 2008). In 2012, as indicated by the National Agency for Dams and Transfers (ANBT), a filling rate of 65% of operational dams was observed as a stored quantity of 5.5 billion m³ as indicated in a study by Harkat et al. (2014).

This quantity is definitely reduced if diverse kinds of losses are incorporated, in addition to the increase in demand for domestic, industrial, and agricultural purposes. As indicated by recent studies (Haddad and Rahla 2004), water demand reaches 5 billion m³ every year, with an offer of 170 (m³/capita/day), rather than a base standard of 250 (m³/head/day) which is considered, from now on, as a shortage of drinking water in m³/inhabitant/year, which, in the future, will slightly exceed the threshold of 400 m³/ha as indicated by the study of Harkat et al. (2014). This deficit becomes increasingly problematic year after year. An urgent and compelling arrangement is, therefore, important to guarantee a consistent water supply for all users.

The new Algerian policy centers on the integrated water resources management (Mate 2001). Accordingly, two kinds of actions must be considered. The first one is identified with the economics of these resources, whereas the second is related to their ideal management. Water resource management is based mainly on prediction models and successful analyses of tendencies in water variability. In this context, the investigation of rainfall time series has a high priority in the studies of water resources planning, management, and exploitation as well as in the design of hydrodynamic projects. Moreover,

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trend analysis of hydroclimatic variables can deepen the study of the effects of climate change because of their non-stationary character and the presence of noise and other stochastic elements. Trend analysis is also a useful tool for policy and decision makers in the water resources sector as well as for other operators and partners in the economic, industrial, and environmental fields.

Such models are various and different in hydrology. The literature offers an extensive variety of works and obtained results using parametric and non-parametric statistical tests. Regarding the precipitation variable, one can notice that many studies have been conducted for precipitation analysis around the world. For example, seasonal and annual precipitations of 32 stations in Italy, occurring during the period from 1833 to 1996, were examined by Buffoni et al. (1999). Fundamental attributes of the temporal and spatial variability of the summer rainfalls measured in 40 stations in Emilia-Romagna were investigated for the 1922–1995 period by Tomozeiu et al. (2000). Longobardi and Villani (2009) determined the potential trends in the 211 measured rainfall series, mainly in the Campania region of southern Italy for the period from 1918 to 1999, and Türkeş (1996) examined monthly precipitation from 91 stations during the period from 1930 to 1993. Additionally, Partal and Kahya (2006) identified trends in the long-term monthly average and annual average rainfall series between 1929 and 1993. Jiang et al. (2007) examined spatial and temporal trends of daily precipitations from 147 weather stations for the period of 1961–2000, while Türkeş et al. (2009) examined the long-term trends of annual, seasonal, and monthly total precipitations utilizing 97 stations for the period from 1930 to 2002. Moreover, Yavuz and Erdogan (2012) examined the annual and monthly precipitation trends for 120 stations during 2009. Şen (2014) suggested applying the method to a test of statistical significance for the identification of trends in an innovative way for three time series from various regions of the world, including annual precipitation records. Kisi and Ay (2014), have shown that the innovative Sen method can be successfully used for identifying trends in high and low monthly total precipitations. Kisi (2015) trend analysis of monthly pan evaporations was performed by using the recently developed innovative trend analysis (ITA) method. The ITA was applied to the monthly pan evaporation data of six different locations, i.e., Adiyaman, Batman, Diyarbakir, Gaziantep, Kilis, and Siirt, in Turkey. Monthly trends of pan evaporation were also investigated by the commonly used non-parametric Mann–Kendall (MK) method. According to the MK method, a significantly decreasing trend was found for the Adiyaman Station while the Diyarbakir and Kilis stations showed a significantly increasing trend at the confidence level of 10% (Demir and Kisi 2016). In Japan, Yue and Hashino (2003) examined the precipitation variable using MK trend test for the 100-year data period. Gemmer et al. (2004) examined trends of monthly precipitations recorded at 160 weather stations in China using the MK for the period from

1951 to 2002. Raziei et al. (2005) used MK for verifying climatic variability and trend of annual precipitations (1965–2000). Cannarozzo et al. (2006) examined the rainfall trend in Sicily utilizing monthly data, obtained from 247 stations for the period from 1921 to 2000, Iran. Kampata et al. (2008) studied trends in rainfall data measured at 5 stations situated in the upstream Zambezi Basin regions of Zambia. Spatial and temporal trends of rainfalls in the Yellow River Basin, in China, from 1960 to 2006 were studied by Liu et al. (2008), while trends of summer, winter, and annual rainfalls of 160 stations, in China also, from 1951 to 2005 were investigated by Zhang et al. (2008). Trends of monthly, seizures, and most recent rainfalls over Kerala, during the period from 1871 to 2005 were examined by Yangtze Krishnakumar et al. (2009). Modarres and Silva (2007) examined the annual rainfall time series by MK using data from 20 stations, Tabari and Hosseinzadeh Talaee (2011) assessed the annual trends and seasonal precipitations. They studied the precipitation trend in 41 stations in Iran using the Sen Slope test, MK, and linear regression methods for the period from 1966 to 2005; Dinpashoh et al. (2013) examined precipitation trends using MK and found the annual, seasonal, and monthly trends for the period from 1955 to 2004. They used precipitation data recorded at 16 stations in Iran.

In Algeria, bibliographic research has shown an increasing interest in the trend analysis in recent years. Among others, one can cite Lazri et al. (2014a), (2014b) who studied the temporal trends of precipitation in northern Algeria from a weather radar. Their results indicated that the rainfall was well defined by a Markov chain order with three states (without rain, stratiform precipitation, and convective precipitation) related to two zones: one situated in the sea and the two others situated on the ground.

The stationary probabilities, which are computed through the Markovian model, and the real probabilities are nearly identical. Elouissi et al. (2016) studied monthly rainfall series of Macta watershed in Algeria with 25 stations, and they found that there was a downward trend in the northern region near the Mediterranean coastal zone in the Macta Basin, while in the southern part, trends were more and more numerous. Analysis indicated that the low and medium precipitations tend to be trending, while high precipitations had downward trends in Macta watershed. Ghenim and Megnounif (2016) studied trends in the annual maximum daily rainfall series and their contribution in the annual precipitation of 35 weather stations covering northern Algeria for 43 years data recorded after the 1970s by utilizing Burn's seasonality procedure, MK, and linear regression. It was found that among 35 stations, only 6 had a significant trend. Another study, dealing with precipitation modeling for the purpose of prediction in Algeria, was done by Harkat et al. (2016), where Kalman filter technique has been applied to annual and monthly precipitations, the result was a satisfactory dynamical prediction model for both monthly and annual data with a minimum prediction error, as indicated by the studies of Harkat et al. (2016), (Harkat 2019) and Harkat et al. (2020).

In the present paper, the innovative partial trend methodology, recently suggested by Öztopal and Şen (2017); Şen (2017), is used for the analysis of precipitation variations in Cheliff watershed in Algeria. This new method is the most modern, the simplest, and the easiest to interpret, as well as the most effective way for trend detection and trend type identification by only a visual inspection of the concerned time series (Şen 2009). This strategy relies on the analysis of sub-series variation that are obtained from a given time series on a Cartesian coordinate system. In such a plot, trends in subsections can appear along the 45° straight line. Increasing and decreasing trends, respectively, occur in the upper and lower triangular areas of the square zone indicated by the variation range of the variable studied (Şen 2012). The evaluation of this method was made by employing a set of Monte Carlo simulations considering the independent and dependent procedures. In this new method, all the previously mentioned concepts used in the MK tests and SR are abstained, and, in addition, it is conceivable to compute the trend magnitude of square-surface plots. The main advantage of this method is the supply of qualitative interpretations of trends in the precipitation ranges (low, medium, high) in terms of the time series internal structure trend. Recently, Öztopal and Şen (2017) proposed innovative partial trend methodology (IPTM) by applying precipitation records of Turkey. To the knowledge of the authors, there is not any other work related to the application of this methodology in the literature.

Our main objective is to apply the IPTM for identifying possible trends of precipitation from 28 rainfall stations in the watershed of Cheliff in the north of Algeria for a spreading period from 1959 to 2019 and to establish regional trend charts of “high,” “average,” and “low” precipitation—increasing/decreasing—for the entire study area.

2 Materials and methods

2.1 Study area

Algeria is located on the southern shore of the Mediterranean and is bordered to the south by Niger and Mali, to the east by Tunisia and Libya, to the west by Morocco, and to the southwest by Mauritania and Western Sahara. The study area is located in the central-western part of Algeria between two main mountain ranges: the Saharan Atlas to the south and the Tellien Atlas to the north; it corresponds to the upper valley of the Cheliff watershed, covering an area of 56,227 km² (extends over 10 wilayas). The geographical coordinates of the study region include the longitude between 0° 08' West and 3° 50' East, and the latitude between 33° South and 36° North (Fig. 1).

It covers four sub-regions, the Cheliff upstream of Boughzoul, upper and middle Cheliff, and lower Cheliff. It is drained by the largest and most important river in Algeria,

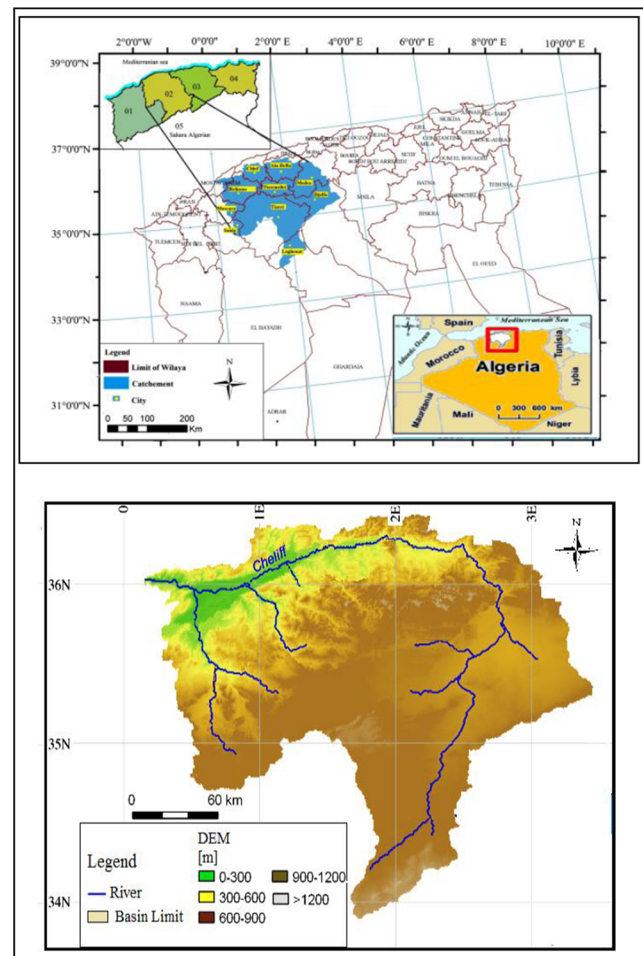


Fig. 1 Catchment, wilayas, and hydrography of the study area (Geographic Coordinates System WGS 84)

the Cheliff River which flows from the Tellien Atlas Mountains to the Mediterranean Sea.

2.2 Weather

Like the other basins of Algeria, the Cheliff Basin is subject to the combined influence of the sea, the relief, and the altitude. It is characterized by a long period of summer drought varying from 3 to 4 months on the coast and from 5 to 6 months in the High Plains. The climate is Mediterranean on the entire northern fringe, which includes the coast and the Tell Atlas, semi-arid type on the highlands in the center of the study area and desert when crossing the Saharan Atlas chain.

The irregularity of the rains is the essential character of the rainfall in the Cheliff Basin, irregularity from one region to another, but above all an inter-annual irregularity. Precipitation shows a great monthly variability. The absence of rain is to be noted in August, July, September, and October (Boucefiane 2006; Meddi and Boucefiane 2008).

The annual rainfall decreases as one advances towards the south and falls to less than 100 mm in the Saharan

Atlas. This irregularity is due to the existence of a longitudinal gradient. Rainfall increases from West to East (300 mm/year in the West and more than 500 mm/year in the East) and by a latitudinal gradient (the average annual rains vary by 100 mm in the Highlands region and more than 900 mm to the North) (Harkat et al 2014; Khelfi et al. 2017).

In this region, many factors contribute to the non-uniform temporal and spatial distribution of precipitation. These factors are the effects of the ridges, the high relief (average altitude 800 m), forests and maquis (4.1 million hectares), and the forestation rate of 16.4%, among others.

The wind speed, for which the roughness of the location is available, was extrapolated from the height of 10 m to an altitude

Table 1 The precipitation stations and the choice of stations after the update

Station N°	Station ID	Record period (year)	Data available (up-to-date)	State of the stations after 2010
1	010502	1966-2009	/	NF
2	010701	1960-2009	/	NF
3	010703	1959-2009	/	NF
4	010704	1959-2009	/	NF
5	010706	1959-2009	1960-2017	F
6	010904	1959-2009	/	NF
7	010905	1959-2009	/	NF
8	011004	1959-2010	1959-2018	F
9	011006	1959-2009	1959-2018	F
10	011104	1959-2009	1959-2019	F
11	011206	1959-2009	1959-2017	F
12	011207	1959-2009	1959-2017	F
13	011208	1959-2009	1959-2016	F
14	011301	1959-2009	1959-2017	F
15	011302	1959-2009	1959-2018	F
16	011404	1959-2010	1959-2016	F
17	011405	1959-2010	1959-2017	F
18	011605	1959-2009	1959-2018	F
19	011606	1959-2009	1959-2018	F
20	011607	1959-2009	1959-2018	F
21	011703	1959-2010	1959-2018	F
22	011803	1959-2010	1959-2018	F
23	011904	1972-2010	1972-2019	F
24	012108	1959-2009	1959-2019	F
25	012205	1959-2009	1959-2019	F
26	012304	1959-2009	1959-2019	F
27	012306	1959-2009	1959-2016	F
28	012309	1959-2010	/	NF
29	012503	1959-2009	1959-2018	F
30	012605	1959-2009	1959-2018	F
31	012706	1959-2009	/	NF
32	012908	1959-2009	1959-2017	F
33	012915	1959-2009	/	NF
34	013004	1959-2009	1959-2017	F
35	013202	1959-2009	/	NF
36	013503	1959-2009	1959-2016/	F
37	013504	1959-2009	/	NF
38	013506	1966-2009	/	NF
39	013507	1960-2009	1960-2016	F

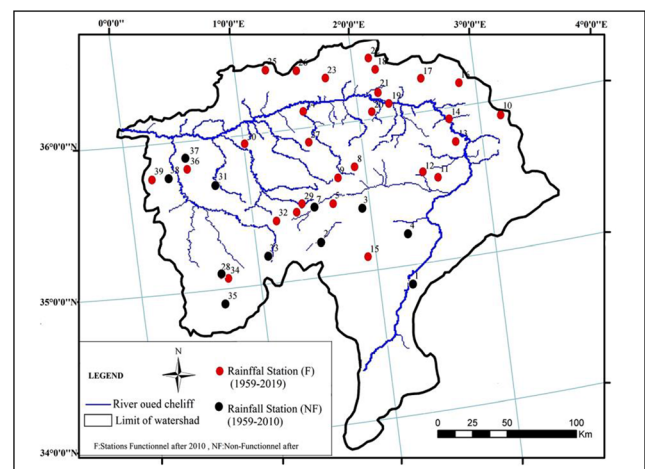
N-F no-functional station (1959-2010), *F* functional station (1959-2019),/ there is no recording after 2010

Table 2 Geographic characteristics of precipitation stations used in this study

Plain	Station N°	Station ID	Location		Elevation Z (m)	Record period (year)
			Longitude X	Latitude Y		
High Cheliff	5	010706	471.55	229.7	731	1960–2017
	8	011004	433.5	263.45	935	1959–2018
	3					
	9	011006	436.5	266.8	900	1959–2018
	10	011104	540.75	287.8	1250	1959–2019
	11	011206	491.3	249.35	665	1959–2018
	12	011207	480.8	252.8	690	1959–2017
Middle Cheliff	13	011208	507.1	272.25	643	1959–2016
	14	011301	503.8	287.9	630	1959–2017
	15	011302	435	200	610	1959–2018
	16	011404	513.5	312.6	932	1959–2016
	17	011405	487.25	318.4	460	1959–2017
	18	011605	456	329	440	1959–2018
	19	011606	463.2	304.25	425	1959–2018
	20	011607	450.15	299.5	660	1959–2018
	21	011702	439.5	332.55	230	1959–2018
	22	011803	452.15	337.05	850	1959–2018
	23	011904	419.8	327.3	190	1972–2019
Low Cheliff	24	012108	402	305.6	430	1959–2019
	25	012205	378.15	338.4	320	1959–2019
	26	012304	400	335	560	1959–2019
	27	012306	402.6	284.1	1050	1959–2017
	29	012503	392,95	242,05	790	1959–2018
	30	012605	256,4	286,15	140	1959–2018
	32	012908	373,4	232,8	1100	1959–2017
	34	013004	334,5	197	829	1959–2017
	36	013503	315,15	277,25	75	1959–2016
	39	013507	288,65	272	125	1960–2016

of 25 m. This allowed to obtain 09 points of measurement, for the study region: Chlef (roughness 0.01 m, wind speed 2.8 m/s), Djelfa (0.08 m, 2.7 m/s), El Bayadh (0.01 m, 3.9 m/s), Ksar El Chellala (0.08 m, 3.4 m/s); Mascara (0.05 m, 2.4 m/s), Miliana (0.5 m, 2.6 m/s); Mostaganem (0.01 m, 1 m/s), Saida (0.01 m, 2.6 m/s), Tiaret (0.02 m, 4.7 m/s) (Kasbadji Merzouk 1994; Aiche & Kashadji Merzouk, 1997). It is noticed that in summer, our region is exposed to southerly winds which are loaded with sand particles. These winds exert a corrosive action giving the effect of strafing. It is also exposed to north-easterly winds which contribute to the sweeping of fine particles and their uprooting from the soil. In winter, our region is exposed to north-western winds with precipitation (Benkaci et al. 2018).

Several pluviometric and pluviographic stations made it possible to regularly monitor meteorological conditions in the study area.

**Fig. 2** Location of rainfall stations selected in the Cheliff watershed

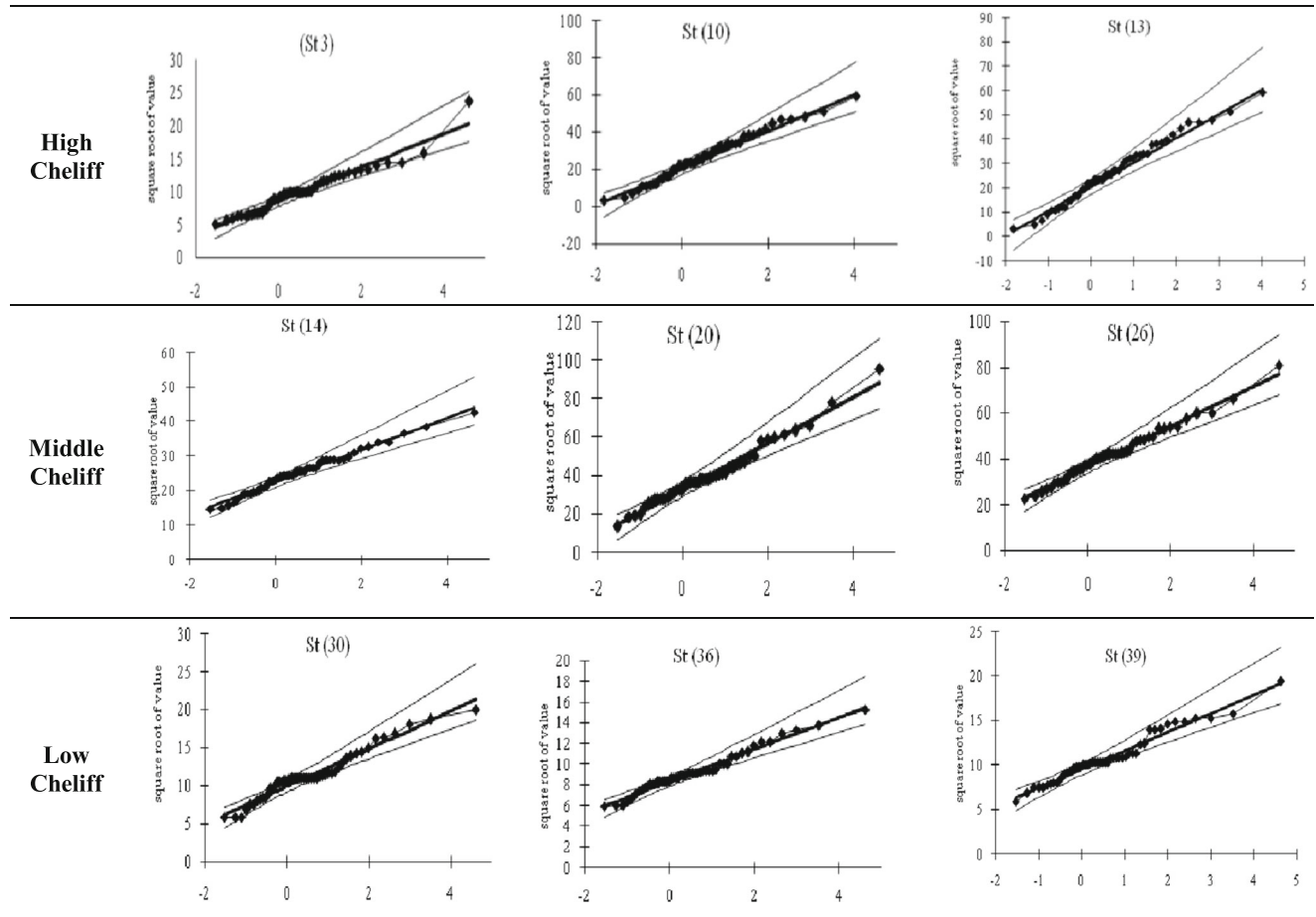


Fig. 3 Fit to a normal root distribution (for all the rainfall stations in the Cheliff watershed)

2.3 Observed data

Monthly rainfall data recorded at 28 stations for the period (1959/1960 to 2018/2019) have been used in this study. Data are extracted from dataset provided by the National Meteorology (ONM) and the National Hydraulic Resources Agency (ANRH), <http://www.anrh.dz/>, <http://www.meteo.dz/index.php>.

The choice of rainfall stations is based on the criteria of data quality and length of the rainfall series. The operating period differs from one workstation to another; for this, we have chosen a uniform study period of 60 years.

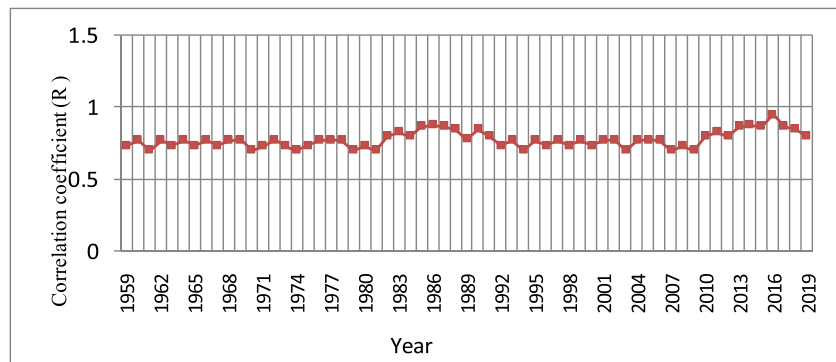
These stations are unevenly distributed from north to south; the greatest concentration is in the northern zone. Most homogeneous recording rain gauges were put into service in the 1970s.

All the rainfall data over the north-west and north-central Algeria recorded a breaking point located in the 1970s, which is linked to a decrease in rainfall (20% decrease in annual rainfall since 1970) (Meddi et al. 2010; Zeroual et al. 2017). This breaking point is caused by climate change and has also been detected in several regions of the Mediterranean basin (Brunetti et al. 2006; Ramadan et al. 2013; Scorzini and Leopardi 2019; Achour et al. 2020; Royé et al. 2020; Tsiros et al. 2020). The missing data in the precipitation time series (deviations not exceeding 5%) were calculated at the monthly scale by the normal ratio method. The missing value is estimated from neighboring stations through weighting precipitation by the ratios of the normal as suggested by Subramanya (1994).

Table 3 Statistical characteristics of precipitations (P) at the selected rainfall stations in the studied plains

Plain	Number of rainfall stations	Average (mm)	Standard deviation (mm)	Median (mm)	Maximum (mm)	Minimum (mm)
High Cheliff	7	427	95.9	435.9	790	167
Middle Cheliff	14	393	87.7	388.7	739	225
Low Cheliff	6	360	72.2	352.1	621	206

Fig. 4 The annual correlation of all stations in the Cheliff watershed



It is important to note that all-time series were found to be without outliers using the Grubbs test (Grubbs 1950).

The search for a break in the rainfall data series was carried out by a set of statistical stationarity tests grouped together in the Khronostat software (1998) developed by the IRD. The homogeneity of the data series was tested according to Buishand (1982) and Alexandersson (1986), the rank correlation test (Kendall), the Pettitt test, the Bayesian method of Lee and Heghinian, and the segmentation of González-Rouco et al. (2001). These tests have been used in several studies carried out on rainfall in Africa (Gautier et al. 1998; Paturol et al. 1998, 2004; Servat et al. 1999; Lee et al. 2019) and in several Mediterranean countries. The choice of these tests is based on the robustness of their basis and on the conclusions of the simulation study carried out by Lubes-Niel et al. (1998).

We note that climatic and hydrological data in Algeria are almost available. Most of the climatic and hydrological gauges-instruments were installed after independence (1962), and only a few of them were used during French colonization (Taibi et al. 2013).

All information on the pluviometric stations concerned is given in Tables 1 and 2, while the location of stations in the Cheliff watershed is shown in Fig. 2.

2.4 Data homogenization

The study of the statistical distribution of annual precipitation in Algeria has been the subject of numerous

works, including that of Chaumont and Paquin (1971). The latter noted that the statistical distribution of annual precipitation presented a clear positive asymmetry; he recommended two distribution models: a log-normal distribution in the “Mediterranean” regime and a root-normal in the “sub-tropical” regime (Fig. 3).

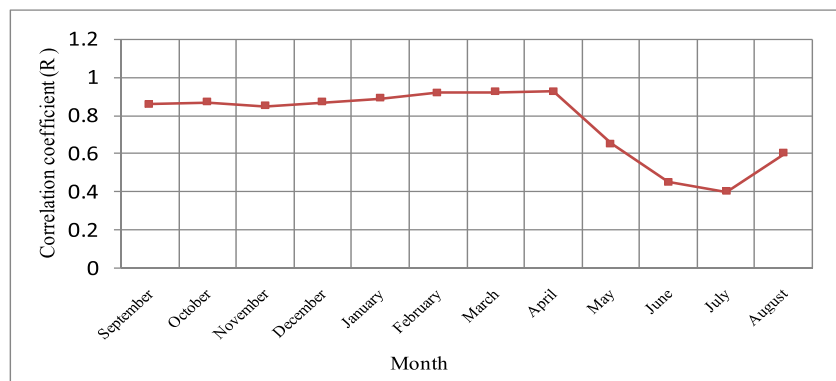
This observation was certified by the National Water Resources Agency (ANRH) within the framework of the UNDP (1989) project and by Meddi (1995).

Several statistical methods are used to test the homogeneity of rainfall series before use (Meddi and Hubert 2013). The homogeneity of the pluviometric series is assessed by the nonparametric Mood’s median test (Siegel and Castellan 1988). The random variable X represents the maximum annual rain series of the considered stations, and N is the size of each series. The application of this test consists in determining of the median of this sample and sorting its values by ascending order, then enumerating the elements located on both sides of the median, by assigning (+) sign to the values higher than the median and (-) for the values which are lower. The number of values lower and higher than the median is equal and represents the noted quantity N_s .

The quantity T_S is equal to the size of the greatest continuity of (+) or (-) signs in the time series.

Hypothesis test of the median for a threshold of significance of 95% is validated if:

Fig. 5 The monthly correlation of all stations in the Cheliff watershed



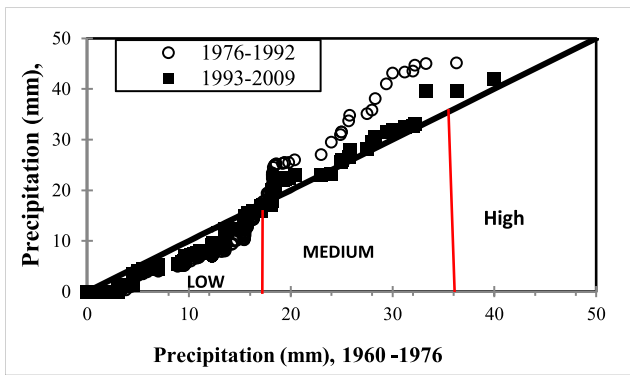


Fig. 6 Scatter diagram of innovative partial trend analysis

$$\begin{cases} Ns > \frac{1}{2} (N + 1 - \mu_{1-\frac{\alpha}{2}} \sqrt{N + 1}) \\ T_s < 3.3 (\text{Log}_{10} N + 1) \end{cases} \quad (1)$$

where $\mu_{1-\alpha/2} = 1.96$; it represents the value of the standardized normal distribution, corresponding to the probability $1 - (\alpha/2)$, $\alpha = 5\%$ (error of first kind). Since the test of the medians was positively verified for all stations, the available pluviometric data series are homogeneous and of good quality.

The estimation of the missing data and the extension of the short series was done by the linear regression method; it consists in estimating the unknown pluviometric variables of certain stations from the observations of other neighboring stations taken as a basis, it is necessary as a preliminary that certain conditions are satisfied (Table 3), in particular the linearity of the regression and the adjustment to a normal law of variables confronted. The filling of gaps by simple regression is based on the significant correlation coefficients (Figs.4 and 5).

The filling of the gaps by regression based on the most significant correlation coefficients is not always reliable at annual scales because the annual correlation coefficients are not always representative of the real climatic conditions of the basin, because the climatic regimes are very nuanced from one region to another. It was essential to take into account the geographical realities of the whole region (Fig. 4).

On the other hand, at monthly scale, the degree of correlation is different from 1 month to another. The correlation is

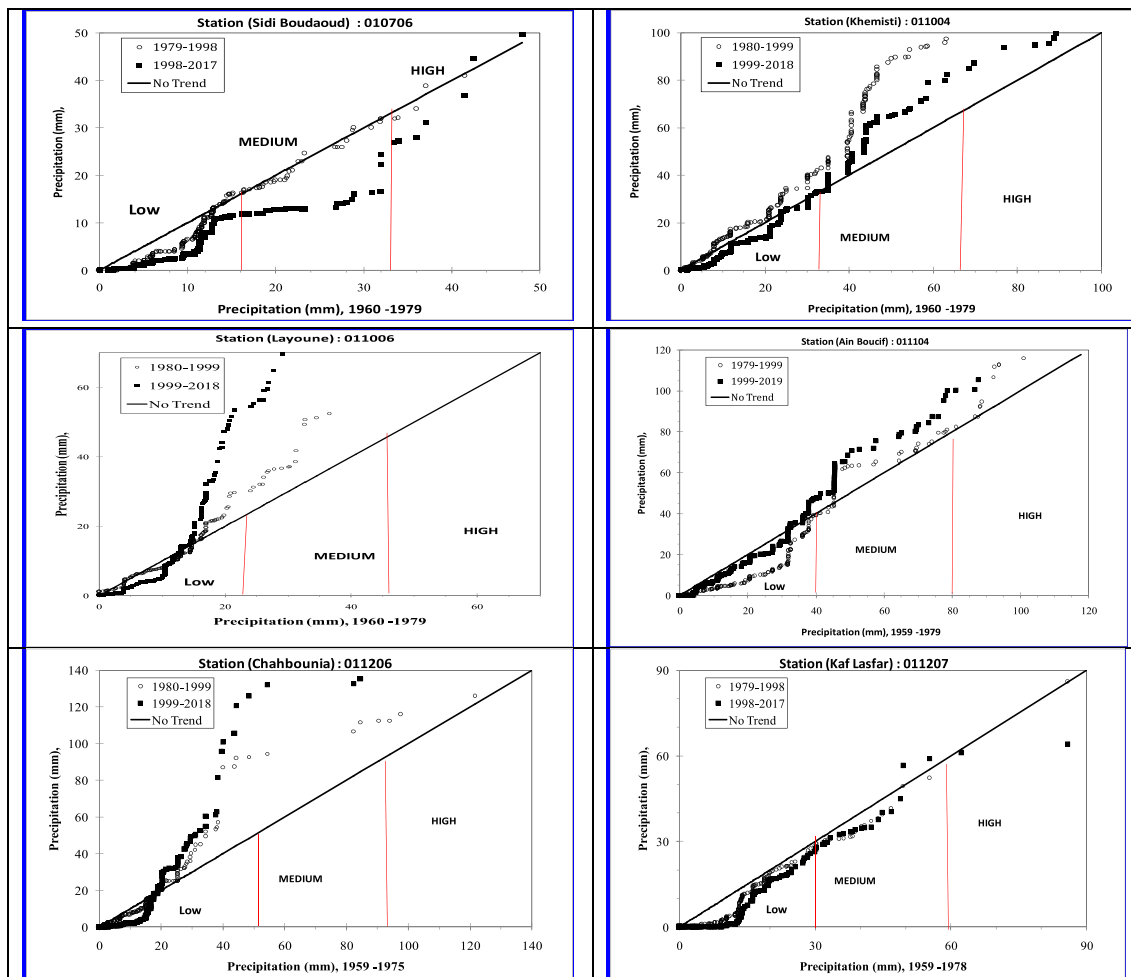


Fig. 7 Innovative trend scatter diagrams for all stations

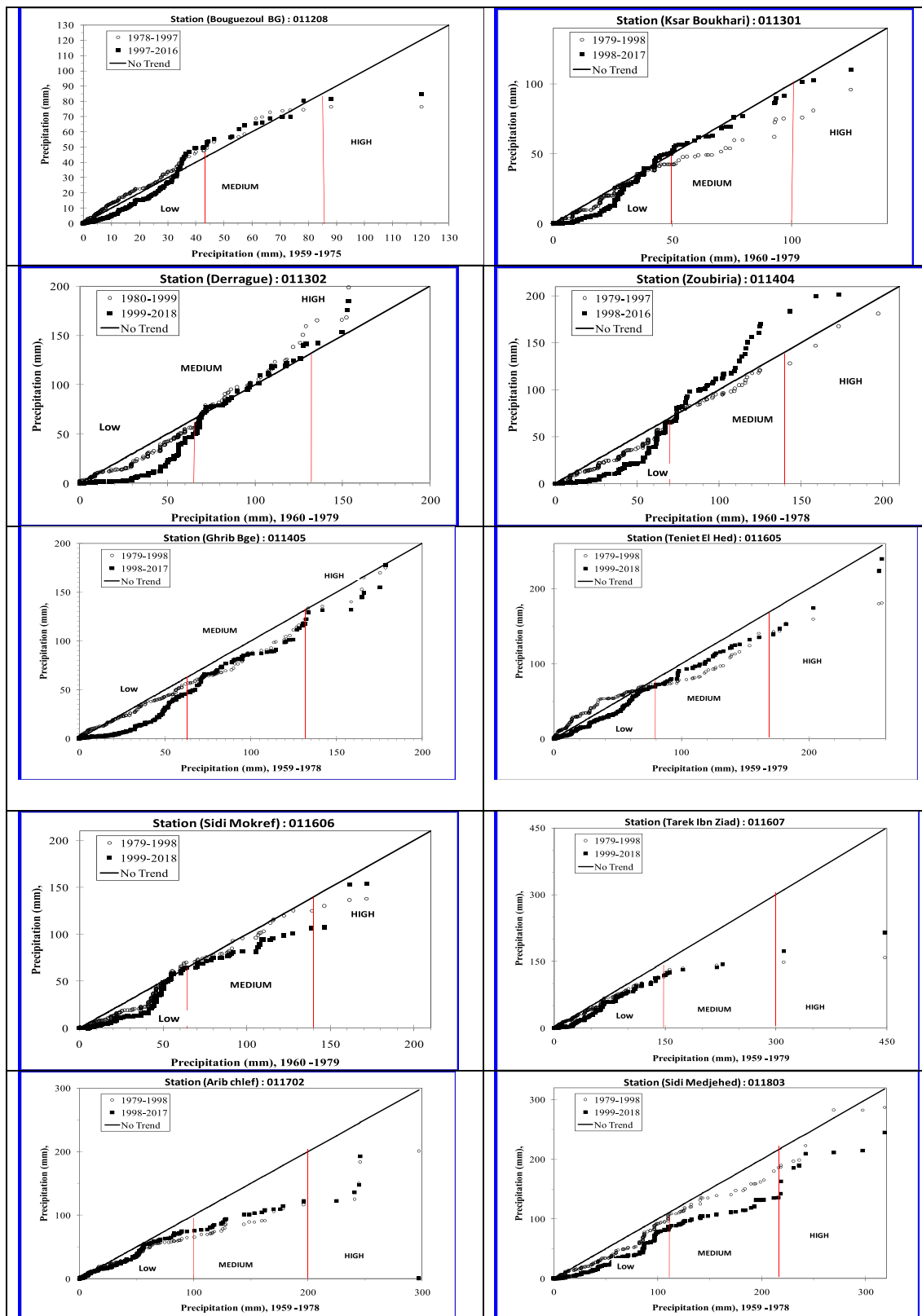
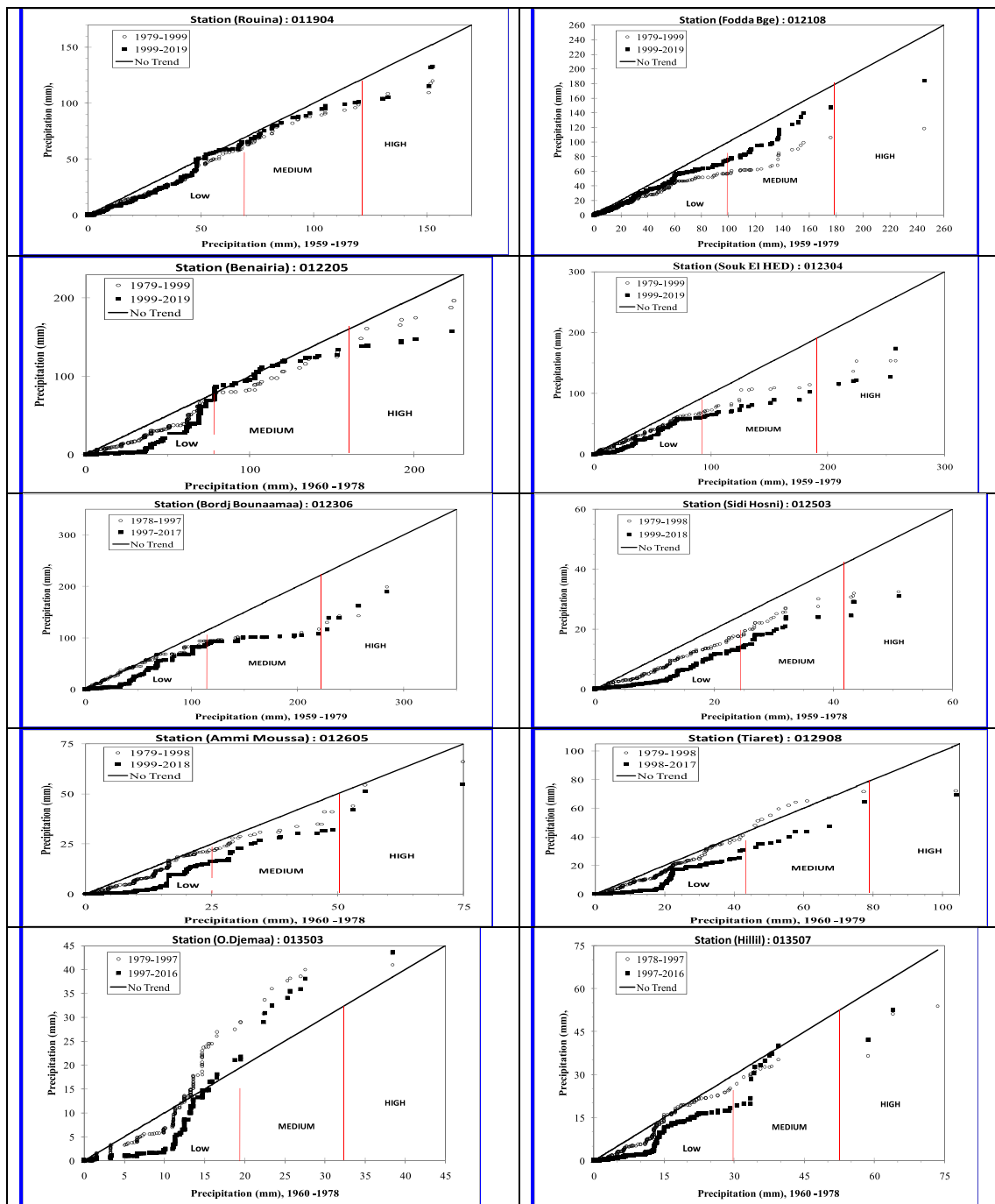


Fig. 7 (continued)

important in winter (January, December, February) and at the end of spring (May) whereas, it is lower in summer and more

particularly for the month of August which is characterized by showers stormy (Fig. 5).



*(N), (M) and (S): Respectively indicate the trend of "Neutral", "Mild (slight)" and "Steep" (slopes)
 * The Exponents (+) and (-): Show Upward and Downward trends.

Fig. 7 (continued)

2.5 Innovative trend methodology

2.5.1 Partial trend

In the present study, each precipitation time series is subdivided into two or more equal sub-series from the first date to the last date, so that the existence of the trend between the two halves can be compared. Each sub-series

is sorted in an ascending order then, the 1st sub-series (X_i) is plotted on the X axis while the other sub-series (X_j) is plotted on the Y axis (the 2nd and 3rd parts of the whole series in this case) via the Cartesian coordinate system (Fig. 6).

- If data are collected on line 1:1 (45°) with an error of $\pm 5\%$, there will be no trend (a time series without trend).

Table 4 Temporal trend classification

Station N°	Station ID	Low	Medium	High	Explanation
5	010706	M ⁻	S ⁻	M ⁻	Slight downward trend appears for low and high precipitation ranges while the medium classes have steep downward trend from 1998 to 2017, whereas the period from 1979 to 1998 does not have any trend in the medium and high classes
8	011004	M ⁻	S ⁺	S ⁺	Both periods have highly upward trends at high and medium classes
9	011006	M ⁻	S ⁺	N	In both durations, medium range precipitations indicate a high upward trend
10	011104	M ⁻	M ⁺	M ⁺	Medium precipitations have mild upward trends in both periods while the low precipitations have mild downward trend for 1979–1999
11	011206	S ⁺	S ⁺	S ⁺	The only distinctive feature lies in the high and medium precipitation range, also at the end of the low class, where there are steep upward trends in both durations
12	11207	M ⁻	M ⁻	N	There is a slight downward trend in low and medium classes for both durations
13	11208	M ⁻	M ⁺	S ⁻	High precipitation range has steep upward trends in both durations
14	011301	M ⁻	N	N	None of the periods have significant trends for the period from 1998 to 2017 but medium and high precipitations have mild upward trends from 1979 to 1999
15	011302	S ⁻	M ⁺	S ⁺	There are steep downward and upward trends during low and high precipitation ranges in both durations, respectively. The period from 1980 to 1999 also has mild upward trend in medium class
16	011404	M ⁻	M ⁺	S ⁺	Both periods have slight downward trend in low precipitation. The 1998–2016 period has a slightly upward trend in medium class and a steep upward trend in high class.
17	011405	M ⁻	M ⁻	M ⁻	There is a slight downward trend for all precipitations in both durations
18	011605	M ⁻	M ⁻	M ⁻	There is a slight downward trend for all precipitations in both durations
19	011606	M ⁻	M ⁻	M ⁻	In both durations, mild downward trend occurs in the low, medium, and high classes
20	011607	M ⁻	S ⁻	S ⁻	There is a steep downward trend in medium and high precipitations during the periods from 1979 to 1998 and from 1999 to 2018
21	011703	M ⁻	S ⁻	S ⁻	There is a mild downward trend in low precipitation for both periods while medium and high classes show steep downward trends.
22	011803	M ⁻	M ⁻	M ⁻	There is a slight downward trend in low, medium, and high precipitations of both durations
23	11904	M ⁻	N	S ⁻	There is a slight downward trend in low precipitations for both durations. High class has a steep downward trend for the period of 1979–1999 and 1999–2019.
24	12108	M ⁻	S ⁻	S ⁻	There is a slight downward trend in low class while the medium and high classes have steep downward trend in both periods
25	12205	M ⁻	M ⁻	M ⁻	Both periods have mild downward trend at low, medium, and high class
26	12304	M ⁻	S ⁻	S ⁻	Both periods have slightly downward trend for the low precipitations while the medium and high classes have steep downward trend
27	12306	M ⁻	S ⁻	S ⁻	Both periods have steep downward trend at high and medium precipitations
29	12503	M ⁻	S ⁻	S ⁻	There is a slight downward trend for the low precipitation, whereas there is a steep downward trend for the medium and high precipitations in both durations
30	12605	M ⁻	M ⁻	M ⁻	There is a slight downward trend for all precipitations in both durations
32	12908	M ⁻	M ⁺	S ⁻	High precipitation range has steep downward trends in both duration
34	13004	N	N	N	There is almost no trend in both periods.
36	13503	M ⁻	S ⁺	S ⁺	Both durations have highly upward trend at high and middle classes
39	13507	M ⁻	M ⁻	S ⁻	There is a slight downward trend in both durations at low and medium precipitation classes but highly downward trends occur at high precipitation.

(N), (M), and (S) respectively indicate the trend of “Neutral,” “Mild (slight),” and “Steep” (slopes)
The exponents (+) and (-) show upward and downward trends

- If data are in the triangular area below the 1:1 line, it can be said that there is a downward trend in the time series.
- If data are in the upper triangular area of the 1:1 line, it can be said that there is an upward trend in the time series (Şen 2012, Şen et al. 2013).

In the current study, time series was divided into 3 equal subsets, and the first sub-series was located on the X-axis whereas the other consecutive two parts were plotted on Y-axis (Öztopal and Şen 2017). Thus, the variation of precipitations can be observed with low, medium, and high values and for two different periods.

The IPTM has the advantage to give categorical trend behavior of the studied time series compared to the classical MK test which provides a monotone holistic trend without any categorization of the time series (Dabanlı et al., 2016). The IPTM does not replace the MK test; however, it gives more information that can be better understood in the next sections.

3 Results

3.1 Temporal trend classification

The temporal trend analysis with respect to high, medium, and low categories can be observed in innovative trend scatter diagrams for the whole 28 stations (Fig. 7). Table 4 describes the trends of each rainfall station by taking into account different durations.

N, M, and S in Table 4, respectively, indicate the trend of “neutral,” “mild (slight),” and “steep” slopes; on the other hand, the exponents + and - show upward and downward trends.

3.2 Spatial trend classification

Through the previous results of partial temporal trends, after splitting the chronological series into two or more halves and sorting the data of each subseries in an ascending order, this proposed methodology can be explained graphically in terms of three groups:

- Low precipitation trends
- Medium precipitation trends
- High precipitation trends

Figures 8, 9, and 10 illustrate maps of high, medium, and low precipitation trends in the Cheliff watershed.

The low precipitation results during the recording period at the 28 stations show that one station experienced a neutral condition, and 26 have a slight downward trend condition at the Cheliff watershed. It should be

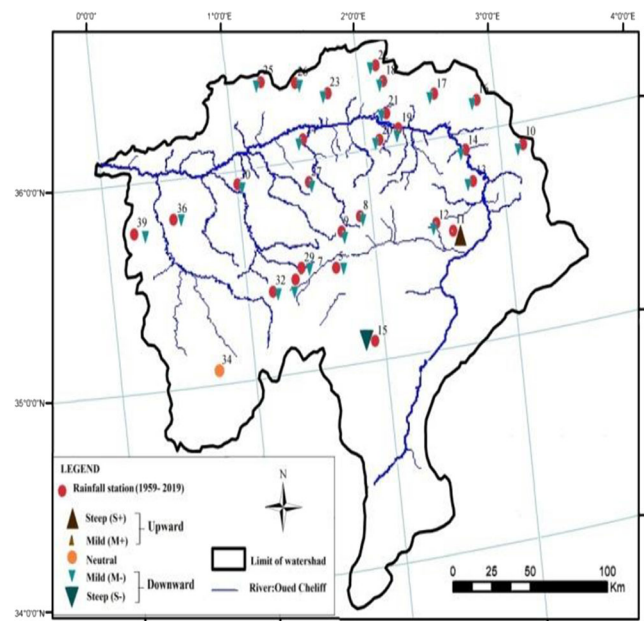


Fig. 8 Low precipitation trends

noticed here that among the overall results there is no downward trend in low precipitation (Fig. 8).

For “medium” precipitations, downward trends are observed in Fig. 6; 9 stations have steep upward conditions in the east of the watershed, while 8 stations have medium downward trends and growing trends in the north and east of the basin. Also, there are 3 stations that show a strong upward trend in the center of the Cheliff watershed, 5 stations have medium upward trends, and there are 3 neutral stations.

The scatter of “high” precipitation trends shows that 4 places have a neutral condition, 7 locations are in a slightly downward trend condition, while 13 stations have steep downward trends and 4 stations show steep upward trends (Fig. 7).

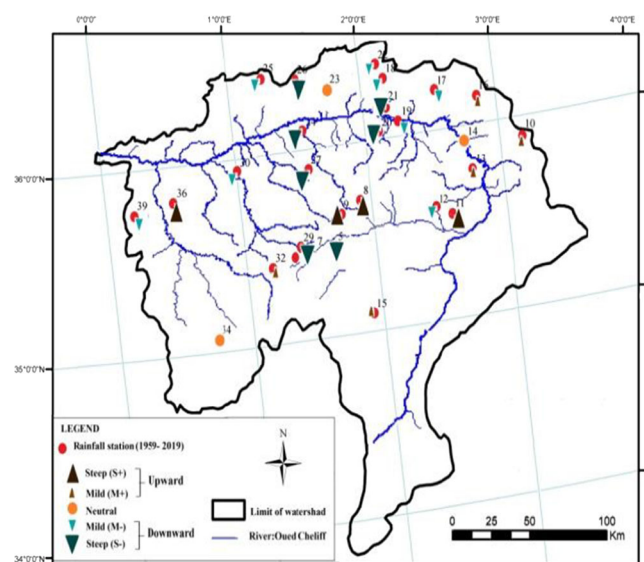


Fig. 9 Medium precipitation trends

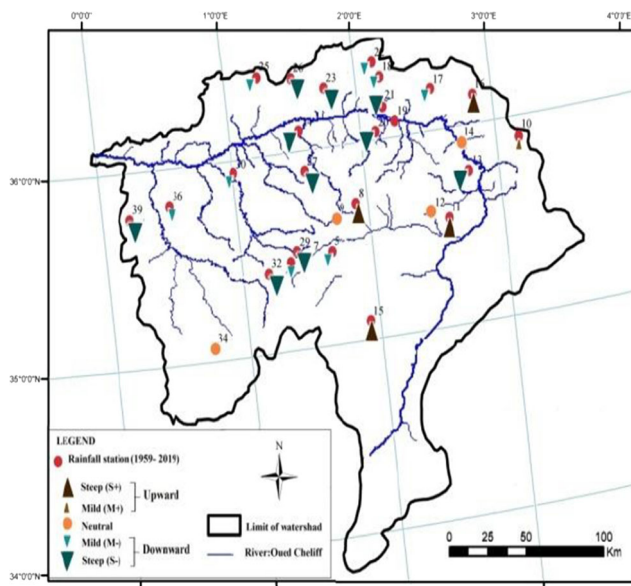


Fig. 10 High precipitation trends

4 Conclusion

This article has focused on the Methodology of Innovative Partial Trends (IPTM), which classifies trends into series groups of studied hydrological variability “low, medium, high”. In each series based on the values of qualitative slopes, trends are also classified into low, medium, high, neutral, increasing (upward), or decreasing (downward) type. This trend analysis provides a view for the variables: meteorological, hydrological, and climatological conditions in past and future changes.

In this context, the annual precipitation trends in a semi-arid Mediterranean environment (northern Algeria) have been studied by the slope estimator of Sen. To this end, the recordings of 28 rainfall stations on the entire Basin of Cheliff for the period from 1959 to 2019 were analyzed.

A precise database has been established leading to rather satisfactory results wherein findings related to low rainfall show that 90% of the stations have a medium slightly downward trend condition, and only 3% have a strong downward trend in the east of the Cheliff watershed. It should be noted that among the overall results there is no upward trend, which explains that these negative trends can affect agriculture and water supply in the region. For “middle” rainfall trends, 50% of stations have strongly downward conditions in the center part of the watershed, while 21% stations have mild downward trends in the north and east of the basin. Also, the dispersion of “high” precipitation trends shows that 70% stations have steep downward trend conditions in the southeast watershed, while 31% stations have high downward trends

This precision of spatial and temporal trends, thus, makes it possible to establish maps of regional trends “high,” “average,” “low,” and increasing/decreasing for the whole region

of the study. The results presented can be an important contribution for decision makers in the water sector and other operators, economic, industrial, and environmental partners. It can also be a step towards the development of statistical methods to estimate the precipitation variable in the short and long terms.

Finally, it would be interesting for future studies to compare trends found in the study area with the results of other tests to detect trends. It is also recommended to examine other meteorological variables available in the study area to approve future climate change.

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Data availability The data used in this research will be available (by the corresponding author), upon reasonable request.

Declarations

Ethics approval The authors confirm that this article is original research and has not been published or presented previously in any journal or conference in any language (in whole or in part).

Conflict of interest The authors declare that they have no conflict of interest.

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