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Assessment of climate change impact on temperature and rainfall trend in the Setifian High Plains of Algeria

Nour Elhouda Maria Chellil[1,2,*] and **Sabah Chermat**[1,3]

[1] *Laboratory Urban Project, City and Territory*
[2] *Department of Plant Biology and Ecology, Faculty of Nature and Life Sciences Setif 1 University - Ferhat Abbas. El Bez, Setif, 19000, Algeria*
[3] *Department of pharmacy, Faculty of Medicine, Setif 1 University Ferhat Abbas. El Bez, Setif, 19000, Algeria*

**Corresponding Author E-mail: maria.chellil@univ-setif.dz*

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Abstract— Within the scope of the global climate change, monitoring and assessment of meteorological parameters gain growing importance. Hence, the analysis of long-term climate series having either increasing or decreasing trend, makes relevance to the weather patterns, and often provides further prediction of extreme meteorological events in the near future.

In this perspective, this research purposes to investigate and interpret temperature and rainfall trends as well as the effect of climate change in three main districts from the Setifian High Plains region, namely, Setif, Ain Oulmene, and Boutaleb. Meteorological data were extracted from the TerraClimate dataset available at the Google Earth Engine platform over a 42-year-long period (from 1980 to 2021). Mann-Kendall, Spearman's rho, and Şen's trend tests were used to assess the trend, while Pettitt's test was applied to detect the change point in time series data. The Theil-Sen approach was used to estimate the slope magnitude in the series. Results showed significant increasing trends in the minimum, maximum, and average temperatures over time for all the three stations. The magnitude of the upward trend in temperature data was found to be at the rate of 0.023 to 0.03 °C per year for all stations. Pettitt's test found the year 1998 as a change point both for the maximum and average annual temperatures for all stations, while the year 2013 was detected as a change point in the minimum temperature for Ain Oulmene and Boutaleb stations. However, rainfall showed non-significant decreasing trends at 5% significance level for all stations.

This study concludes that there is an increase in climate variability over the sampling period, which reveal the necessity of adopting the suitable adaptation strategies for facing the impact of climate change.

Key-words: Algeria, climate change, change point, Pettitt's test, rainfall, semi-arid, Şen's trend test, temperature, trend analysis

1. *Introduction*

In our era, it is inevitable to talk about enormous, chronic environmental problems and challenges without addressing climate change. It is usually described as a phenomenon that has plagued our planet, often by directly or indirectly affecting ecosystems, cropping systems, lives, and livelihood of the society (*Sharma et al.,* 2021). In last decades, global warming became dominant, and it can be felt in different parts of the globe due to the new technologies' increased contribution to greenhouse gas emissions in the atmosphere. This situation could get worse, because of the deterioration of the normal behavior of the hydrological and meteorological parameters, particularly in terms of rainfall patterns and temperature. Various researches from different parts of the world found, that there are less rains and more elevated mean temperatures in average as a result of climate change. These changes will in turn lead to various weather events such as droughts, storms, floods, and heat waves (*Riedy*, 2016) either seeing at the global or regional scales. Therefore, due to changes in the water cycle and increased demands on water resources, the majority of people today experience food and water insecurity, especially in areas that are dry or semi-arid and have extremely erratic, inadequate, and unexpected rainfall events.

The Mediterranean area is one of the most responsive regions to global climate change (*Giorgi*, 2006), due to its location between the arid-warm climate of North Africa and the rainy, temperate climate of central Europe (*Giorgi* and *Lionello*, 2008). Based on global climate projections, the Mediterranean region's temperature will increase from 2 °C to 3 °C by 2050 and from 3 °C to 5 °C by 2100 (IPCC, 2007). Like the most countries of the Mediterranean Basin, Algeria has threatened, over time, by numerous meteorological hazards, and it tends to be more vulnerable to the impacts of climate change, because most parts of the country fall under arid and semi-arid climates. A study on analysis of drought showed that the northern part of Algeria will experience more dry periods, and the probability of occurrence of extreme events will increase from 0.2650 in 2005 to 0.5756 in 2041 (*Lazri et al.,* 2015). In this context, several studies across the northeast part of Algeria concluded, that arid and semi-arid zones have experienced a larger number of drought events with a significant warming, while the humid and sub-humid locations received more precipitation events (*Merabti et al.,* 2017; *Beldjazia et al.,* 2019).

In the Setifian High Plains region, where the climate is typically semi-arid, the climate change is on the rise due to its sensitive location, which conceives of the transition and interaction between the country's humid north and dry south climates. Considering the impact of climate change and other factors such as population growing, industrial and agro-pastoral activities, water deficit and land degradation are already in a critical level in this region. As per *Rouabhi* (2017), the performance of precipitation during the period 1991–2011 became slightly different and spatially more heterogeneous in the Setif region. Hence, a study of projecting future climate established by *Bouregaa* and *Fenni* (2014) found, that there will be a consistent increase in seasonal temperatures until 2075, despite the rainfall models' predictions of large seasonal variations. Since the issues related to the climate change effects on the Setifian High Plains area are less investigated, such identification and monitoring studies spanning past, present, and future times are crucial. For this reason, the assessment of local weather should receive particular interests for better understanding of the risks and challenges associated with the climate variation in this region.

One of the most essential tools of recognizing whether there is a rise, fall, or no change in meteorological variables is to examine their historical time series, especially with application of effective trend identification tests. Typically, numerous trend tests exist, which can be categorized according to the parametric or nonparametric methods. Furthermore, parametric trend tests are more powerful than nonparametric ones (*Shadmani et al.,* 2012). However, unlike the nonparametric trend methods that do not consider any assumption, the normal distribution should be followed when obtaining data for the parametric trend testing. In this context, a large number of scientists have targeted temperature and rainfall trends worldwide, employing various statistical techniques (*Alemu* and *Dioha,* 2020; *Ragatoa et al.,* 2018; *Sharma et al.,* 2021; *Yacoub* and *Tayfour*, 2019; *Patel* and *Mehta,* 2023, *Panwar et al.,* 2018; *Deb* and *Sil,* 2019).

The Mann-Kendall (MK test) and the Spearman's rho test (SR test) are two nonparametric tests commonly used to detect upward or downward trends in series of hydrometeorological and environmental data. These tests can deal with non-normal data, missing values, seasonality, censoring (detection limits), and serial dependence (*Hirsch* and *Slack*, 1984).

The Sen's detection trend test is an innovative trend analysis method, which is performed to detect the trend in the time series, especially in terms of low, medium, and high values of the data. This method is valid independently of the sample size, serial correlation structure of the time, and non-normal probability distribution functions (*Şen,* 2012).

The Theil-Sen approach is another nonparametric test used for the detection of trends in time series analysis. It is also used to compute the linear rate of change (slope) (*Hirsch et al.,* 1982). The Pettitt's test method (*Pettitt,* 1979) is usually employed to detect an abrupt change or a step change in time records.

The overall objective of this research is to clearly investigate the trend analysis of temperature and rainfall in the Setifian High Plains region focusing on three main districts: Setif, Ain Oulmene, and Boutaleb over a 42-year-long period through application of different nonparametric approaches. The MK test, the SR test, and the Şen's trend test were applied as a first attempt to identify the trends in the time series. Thereafter, the Theil-Sen approach was used to estimate the trend magnitude, while the Pettitt's test was used to detect the breaking year or the change point in the time series data. Moreover, this work aims to monitor the evolution of local climate for better looking at the effects of the climate change in the study area. Indeed, the results obtained were a function of help for local populations and decision makers to achieve the suitable adaptations strategies in the field of sustainable development to face climate change.

2. ***Study area and data used***

2.1. Study area

The Setifian High Plains region is located in the northeastern pert of Algeria, which lies in the administrative area of the Setif province between 35° to 36° 9′ N and 5° to 6° E (*Fig. 1*). Geographically, it is limited to the north by the Babor mountain chain and to the south by the El Hodna mountain chain with an area of about 4076.62 km^2. The region has a continental semi-arid climate. The annual rainfall of the region is varying from 443.31 mm to 334.44 mm from the north to the south, respectively. The hot season lasts for almost five months in the year, in which it starts from May and end up in September. The region has long been a favorable territory for agro-pastoral activities, which constitute high importance for the country by ensuring food security. As shown in *Fig. 1*, three pilot districts from the Setifian High Plains region, namely Setif (station 1), Ain Oulmene (station 2), and Boutaleb (station 3) were considered to this study. The geographical location of stations with corresponding mean values for the metrological variables are summarized in *Table 1*. The annual average of rainfall (1980–2021) in the study area varies from 334.44 mm in Boutaleb station to 360.82 mm in Ain Oulmene station, while Setif station receives the most of rainfall with an average of 443.31 mm. The mean annual values of minimum and maximum temperatures for the selected stations range from 8.61 °C to 8.83 °C and from 20.62°C to 20.85°C, respectively, while the mean annual value of average temperature is found to vary between 14.71 °C to 14.81°C.

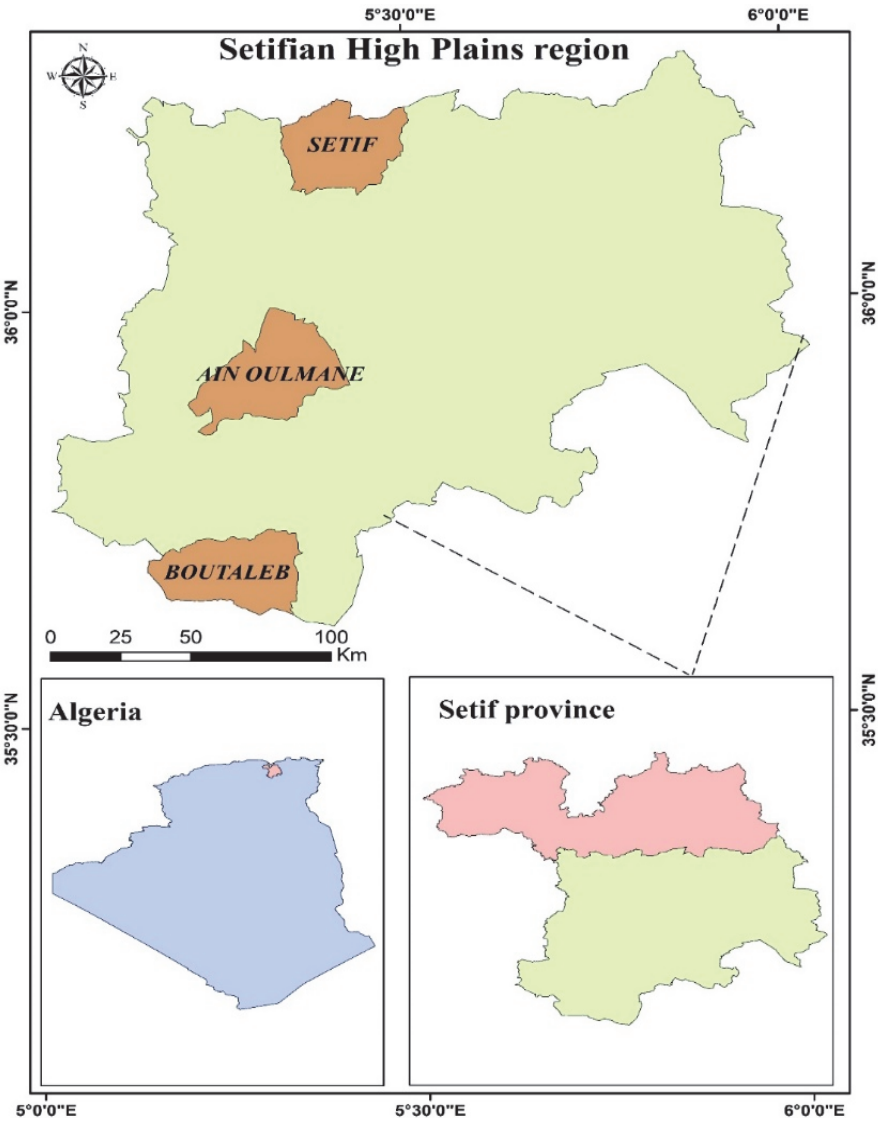

Fig. 1. Location of the study area.

Table 1. Geographic coordinates of the stations with their annual mean values for the meteorological variables for the period 1980-2021.

District	Lat (°N)	Long (°E)	Alt (m)	P (mm)	T_{min} (°C)	T_{max} (°C)	T_{avg} (°C)
Setif (station1)	36.15	5.43	948-1224	443.31	8.79	20.62	14.71
Ain Oulmene (station 2)	35.90	5.28	900-1272	360.82	8.83	20.79	14.81
Boutaleb (station 3)	35.66	5.32	680-1767	334.44	8.61	20.85	14.73

2.2. Data used

To study the situation, trend of monthly series of temperature and rainfall data ranging from 1980 to 2021 (42 years) were collected from the TerraClimate dataset available for downscaling at the Google Earth Engine platform. This dataset of a high-spatial resolution (1/24°, ~4 km) is derived from the combination of the high spatial resolution of the WorldClim dataset and the high temporal resolution of other sources such as the Climate Research Unit global climate dataset (CRU Ts4.0), and the Japanese 55-year Reanalysis (JRA-55) (*Abatzoglou et al.,* 2018). It allows obtaining for global terrestrial surfaces monthly climate and climatic water balance data of various elements (rainfall, maximum and minimum temperatures, wind speed, evapotranspiration, and solar radiation). The selected data are of good quality having continuous record since 1958, which make it well suited for climatic and hydrological studies (*Salhi et al.,* 2019; *Kessabi et al.,* 2021; *Khan et al.,* 2020).

Further, to understand the possible impact of the climate change on regimes, characteristics, and variability for different climatic components, a regional-scale research is particularly important. Thus, rainfall as well as minimum and maximum temperature data were used as key meteorological elements in the current investigation, to find annual trends and monitor changes over the time period. The mean monthly data of rainfall is extracted for the years 1980–2021 (42 years), whereas the monthly average temperature is computed by using averaging function for available data of minimum and maximum temperatures in the corresponding month.

3. ***Methodology***

Trend analysis is one of the most frequently performed techniques to give an idea about the variation in the meteorological parameters attributable to the potential climate change effects. In this study, different methods are adopted for computing the annual time series trends of temperature and rainfall data over a 42-year-long period (1980–2021). Firstly, the statistical Mann-Kendall (MK) and Spearman's rho (SR) tests, besides the graphical approach of Şen's test are useful to identify the existence of trend, weather it is rising or falling. Next, the Theil-Sen method (*Theil,* 1950; *Sen,* 1968) is employed to find the proper slope magnitude. Finally, the Pettitt's test is applied to detect the change point in the time series (*Pettitt,* 1979).

A brief description of the methods adopted for the analysis is presented as follows.

3.1. Mann–Kendall test

This is a well-known nonparametric test that was developed by *Mann* (1945) and *Kendall* (1975). It is also performed to statistically detect monotonic upward or downward trends in a series of climate data. The MK test is based on two hypotheses; the null hypothesis (H_0) expresses the no existence of trend, which means the data are identically distributed, while the alternative hypothesis (H_1) elucidates that the variable follows a significant rising or declining trend in time (*Shadmani et al.,* 2012).

Let $x_1, x_2, \ldots, x_n$ represent n data points where x_j represents the data point at time j. Then the Mann-Kendall statistic (S) is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(x_j - x_k)\,, \tag{1}$$

where the sign function is given as:

$$sgn\,(x_j - x_k) = \begin{cases} +1 & if \quad x_j > x_k \\ 0 & if \quad x_j = x_k \\ -1 & if \quad x_j < x_k \end{cases} \,. \tag{2}$$

x_j and x_k refer to the sequential data values of the time series, n is the data set record length. In case where n is superior than 10, S is calculated by the original variance of S as

$$Var\,(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i-1)(2t_i+5)}{18}\,, \tag{3}$$

where p is the number of tied groups and t_i is the number of data points in the p^{th} group.

A very high positive value of S represents an indicator of an increasing trend, while a very low negative value signifies a trend of decreasing performance over time. However, for statically quantify the significance of trend, it is necessary to compare the significance level α with the computed probability P value. If P value tends to be less than 5%, it denotes significant trend, while, the reverse is true if P value is greater than 5%, and this indicates the absence of trend in the data.

3.2. Spearman's rho test

The Spearman's rho (SR) test is another rank-based nonparametric statistical test that can also be used to detect monotonic trend in time series (*Yue et al.,* 2002). Charles Spearman initially proposed it in 1904, nevertheless, this test is widely used to check the validity of one of the two traditional hypotheses. The null hypothesis (H_0) is that all the data in the time series are independent and identically distributed, while the alternative hypothesis (H_1) is that increasing or decreasing trend exists (*Shadmani et al.,* 2012). The SR statistic (D) is given by the following formula:

$$D = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2 - 1)} \quad , \tag{4}$$

where R_i is the rank of the ith observation X_i in the time series and n is the sample size. According to the SR statistic, positive D values indicate upward trends, while negative values indicate downward trends in the time series. At the significance level of 5%, if $P \leq 0.05$, then the existence of trend is considered statically significant.

3.3. Şen's trend test

This innovative approach developed by *Şen* (2012) aims for extracting trend graphically. First, in order to evaluate trend in meteorological variables, time series are divided into two equal halves, and then they are independently ranked in ascending (or descending) order (*Wu* and *Qian,* 2017). In practical applications, a scatter of points along the 1:1 (45°) straight-line implies no trend, and accordingly, any plot appearance above (below) this line reveals increasing (decreasing) trends (*Şen,* 2012). To make a detailed interpretation, the scatter diagram is split into three verbal clusters as low, medium, and high data values (*Pastagia* and *Mehta,* 2022).

3.4. Theil-Sen approach

This approach (*Theil,* 1950; *Sen,* 1968) is commonly used to provide the magnitude of the slope (change per unit time) after the trend detection has been assessed by both the MK and SR tests within the time series. It is another nonparametric method based on the median slope, which can be calculated as:

$$\beta = median\left[\frac{X_j - X_i}{j - i}\right] \qquad \text{for all } i < j \ , \tag{5}$$

where X_i and X_j denote the sequential data values of the time series in the years i and j, and β is the estimated magnitude of the trend slope in the data series.

3.5. Pettitt's test

As a typical nonparametric approach to study change point problems, the Pettitt's test method (*Pettitt,* 1979) has been widely used to detect an abrupt change or a step change in the mean value of the distribution of hydrometeorological variables (*Xie et al.,* 2013). When a sequence of random variables with n sample size is divided into two samples ($X_1, X_2, \ldots, X_t$) and ($X_{t+1}, X_{t+2}, \ldots, X_n$), then the sudden change point in record is assumed to occur at time *t*. The test statistic U_t can be generated as:

$$U_t = \sum_{i=1}^{t} \sum_{j=i+1}^{n} sgn\left(x_i - x_j\right), \tag{6}$$

where the sign function is given as:

$$sgn\,(x) = \begin{cases} +1 & if & x > 0 \\ 0 & if & x = 0 \\ -1 & if & x < 0 \end{cases}. \tag{7}$$

The maximum probable and significant change point $|U_t|$, affected mostly at time *t*, is approximately evaluated by the following formula:

$$P(t) = 2exp\left(\frac{-6U_t^2}{n^2 + n^3}\right). \tag{8}$$

Note that if p value is inferior to the significance level α = 0.05, the alternative hypothesis is accepted, and a statically significant change point exists at the time *t*.

In this research, the statistical significance of trends and their breakpoints in time series analyzed by the MK, SR, and Pettitt's tests are conducted utilizing the *trend* package in the *Rstudio* software*,* while the *ggplot2* package was used to plot the graphs of Şen's trend.

4. ***Results and discussions***

4.1. Temperature trends

MK, SR, and Şen tests were used to assess the trends for mininimum, maximum, and average annual temperatures, while Pettitt's test was applied to detect the change point in time series of each stations data from 1980 to 2021. The summary of practical results is presented in *Table 2*.

It is clear from *Table 2*, that the analysis of annual temperatures shows a positive trend for the three stations. The MK and SR tests indicate similar results revealing that a significant increasing trend exists consistently for the minimum, maximum, and average annual temperatures with $P \leq 0.05$ at all the three stations.

Beside the identification of the existence of trends by the MK and SR tests, the Theil-Sen approach may also conducted to estimate the magnitude of the slope (change per unit time). As given in *Table 2*, the slope of the significant increasing trend in the average annual temperature ranged from 0.025 °C/year at Setif to

0.027°C/year at Ain Oulmene, and 0.028 °C/year at Boutaleb. This result is somehow agree with that of *Boudiaf et al.* (2020), who reported that the annual average temperature across the Setif region having a rising trend at a slope equals to 0.03. Our findings are also in accordance with the world situation, where the global surface temperature trend is about 0.02 ± 0.01°C/year, while in the Mediterranean region, the trend is about 0.03°C/year (UNEP, 2020).

Table 2. Temperature analysis results detected by the MK, SR, Theil-Sen, and Pettitt's tests at the 5% significance level.

Station	Annual temperature	MK (S)	P value	SR (D)	P value	Trend	B (rate of increase) (°C/year) 1980-2021	Pettitt's test (change point)	B (rate of increase (°C/year) 1980-2000	B (rate of increase (°C/year) 2001-2021
Setif	T_{min}	335	0.000*	0.511	0.001*	Rising	0.023	—	0.036	0.046
	T_{max}	347	0.000*	0.559	0.000*	Rising	0.025	1998*	0.047	0.030
	T_{avg}	347	0.000*	0.553	0.000*	Rising	0.025	1998*	0.041	0.037
Ain Oulmene	T_{min}	345	0.000*	0.528	0.000*	Rising	0.023	2013*	0.035	0.056
	T_{max}	363	0.000*	0.576	0.000*	Rising	0.028	1998*	0.048	0.035
	T_{avg}	359	0.000*	0.560	0.000*	Rising	0.027	1998*	0.041	0.047
Boutaleb	T_{min}	335	0.000*	0.512	0.001*	Rising	0.025	2013*	0.036	0.062
	T_{max}	381	0.000*	0.604	0.000*	Rising	0.030	1998*	0.048	0.038
	T_{avg}	369	0.000*	0.570	0.000*	Rising	0.028	1998*	0.041	0.047

* Trends statistically significant at the 5% significance level

Similar significant increasing tendencies were seen in the annual maximum and minimum temperatures. The annual maximum temperature varied with the rates of 0.025 °C/year, 0.028 °C/year and 0.03 °C/year at stations Setif, Ain Oulmene, and Boutaleb, respectively. The same trend was seen in the annual minimum temperature, which varied between the rates of 0.023 °C/year at both Setif and Ain Oulmene stations to 0.025 °C/year at Boutaleb. It is clear from the results, that the observed rise in the annual average temperature is more influenced by the maximum than the minimum temperature. In general, the temperature increase results of this study are partially in agreement with the tendencies found by *Rouabhi et al.* (2018), stating that the annual minimum temperature records the highest raise compared to the annual maximum temperature within the study period (1981–2015).

Moreover, the Sen's slope values calculated in two periods: 1980–2000 and 2001–2021 showed the increase of the average temperature in the first period (1980–2000) for Setif compared to Ain Oulmene and Boutaleb, where the rise is remarkable in the last period (2001–2021). Ultimately, these spatiotemporal variabilities of temperatures seem to indicate the potential evolution of the distribution of bioclimates in this territory, sometimes with the shift of a bioclimatic stage (*Djellouli et al.,* 2020).

Based on the Pettitt's method for detecting the sudden changes in the annual temperatures (minimum, maximum, and average), our results show that it can be found two significant change points, which were detected in 1998 for both the maximum and average annual temperatures at all stations. Whereas the time change point for the minimum annual temperature is noticed in the year 2013, except for Ain Oulmene and Boutaleb stations (*Table 2*). This suggests that the maximum temperature reflects on a quick variability under climate change effect, while the minimum and average temperature are affected tardier. It should be also noted that the two breaking years that occurred in 1998 and 2013 are in conformity with the extent of the global warming trend. Meteorological specialists have determined that 2013 and 1998 are ranked as the fifth and eighth hottest years on record since 1880 (NOAA, 2017).

In terms of the evaluation of low, medium, and high values of the annual temperatures (minimum, maximum, and average), the Şen trend graphs reveal that all the three stations exhibited similar temperature variabilities. Hence, via the layout of the scatter point that is well concentrated above the line, an upward trend is clearly determined. It is also observed that the medium clusters have much higher distribution and tend to increase more than the low and high clusters (*Fig. 2*).

The overall interpretation for the results discussed above is that the impact of climate change appears more influential and earlier detectable at Boutaleb station followed by Ain Oulmene and Setif stations. This can be explained by the geographic position of Boutaleb, which is located in the extreme southern part of the study region in confrontation with the warmly Sirocco wind coming from the Sahara, especially during th summer and autumn periods. Consequently, this situation calls for more drought events and a hotter climate in the entire Setifian High Plains region.

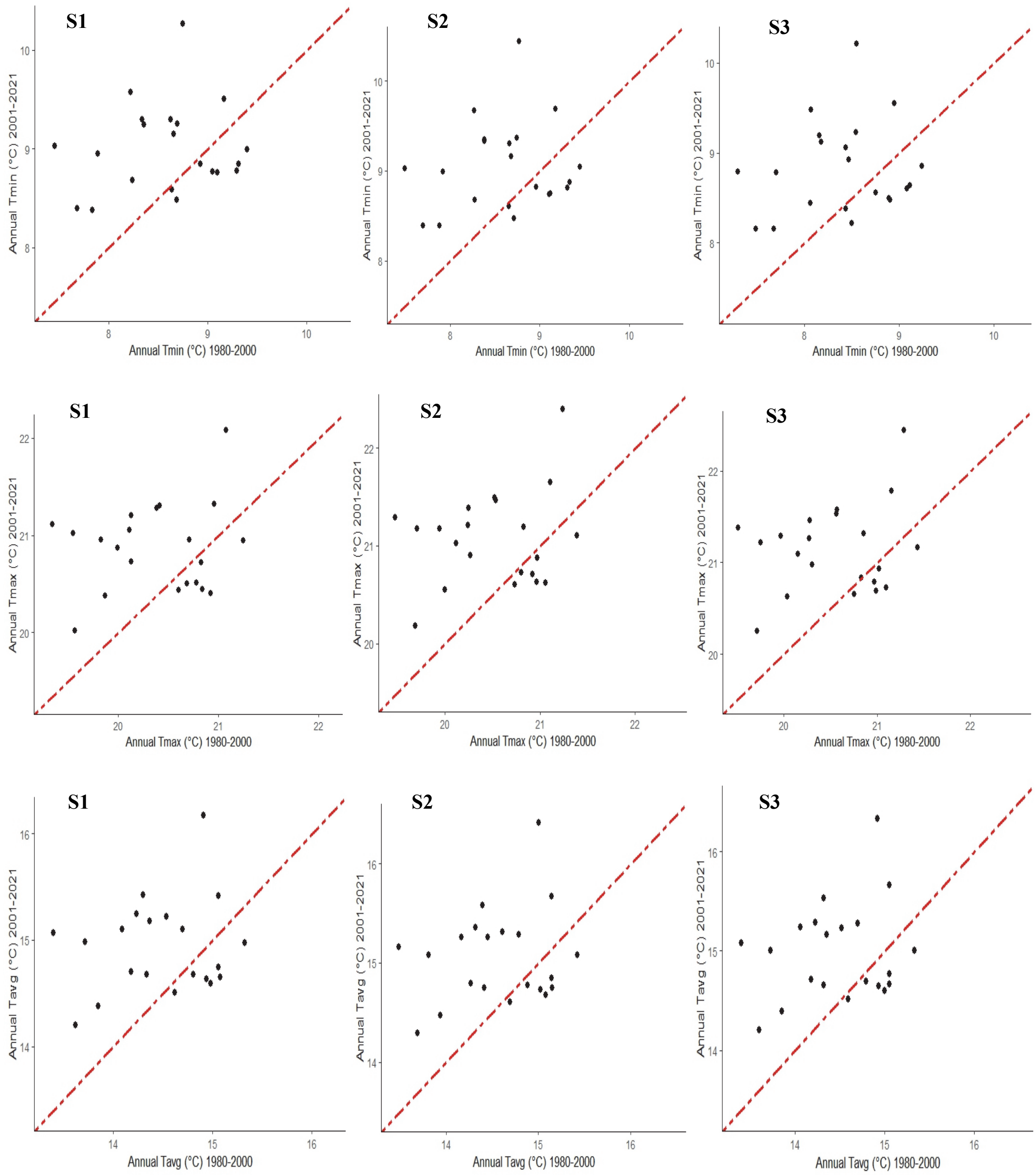

Fig. 2. Annual minimum, maximum and average temperatures (°C) at Setif (S1), Ain Oulmene (S2), and Boutaleb (S3) stations by Şen's trend test in the period of 1980-2021.

4.2. Rainfall trends

Trend analysis of the annual rainfall was carried out on the time series of the three main stations of Setif, Ain Oulmene, and Boutaleb. It is clear from the results presented in *Table 3*, that the MK and SR tests show the same results at all the stations by detecting non-significant decreasing trends during the investigated period (1980–2021).

Correspondingly, an overall trendless is observed through the data group behaviors in the Şen graphs. As it is shown in *Fig. 3*, for all three stations, the scatter point distributes on both sides of the 1:1 line. This plot appearance implies that the increasing and decreasing tendencies occurred within the same time clearly indicating a non-monotonic trend in rainfall. *Boudiaf et al.* (2021) also reported that rainfall in Setif region has a decreasing trend during the period 1982–2019.

Investigating of changes in climate variables reflects that higher temperatures and reduced amount of rainfall will increase the risk in water availability inducing a significant vulnerability in the Setifian High Plains region by progressively modifying its bioclimatic stage from semi-arid to arid.

Table 3. Rainfall analysis results detected by the MK, SR, Theil-Sen, and Pettitt's tests at the 5% significance level.

Station	MK (S)	P value	SR (D)	P value	Trend	B (rate of increase (mm/year)	Pettitt's test (change point)
Setif	-61	0.516	-0.101	0.525	Falling	—	—
Ain Oulmene	-57	0.544	-0.089	0.5735	Falling	—	—
Boutaleb	-59	0.530	-0.084	0.5982	Falling	—	—

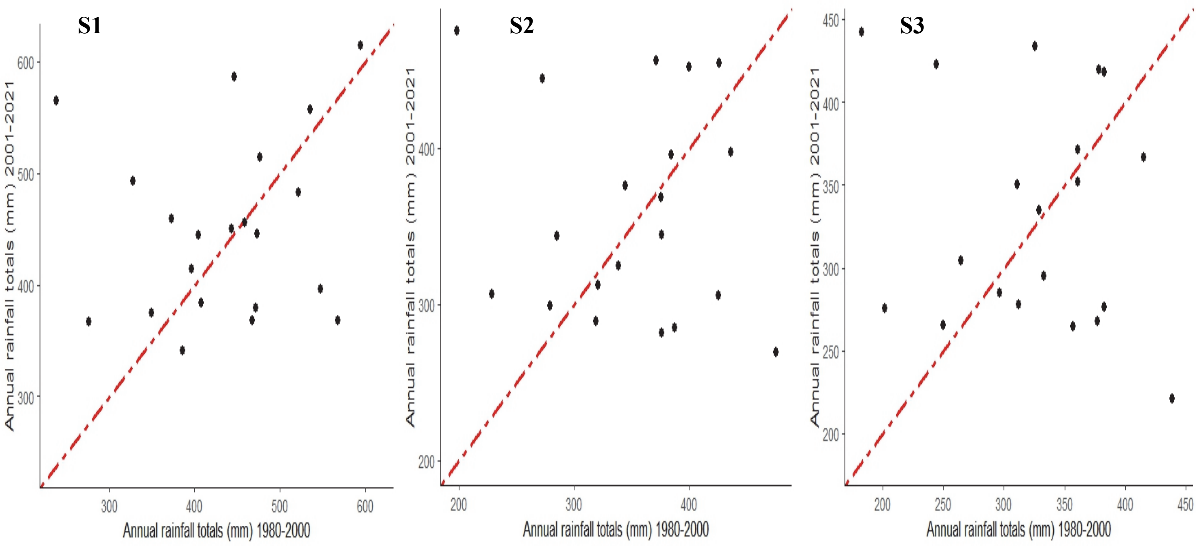

Fig. 3. Annual rainfall (mm) at Setif (S1), Ain Oulmene (S2), and Boutaleb (S3) stations by Şen's trend test from 1980 to 2021.

5. ***Conclusions***

In the present research, we performed a trend analysis of temperature and rainfall under climate change over the Setifian High Plains region in Algeria, focusing on three major stations: Setif, Ain Oulmene, and Boutaleb. Based on a 42-year-long period (1980–2021), the annual temperature and rainfall time series were assessed by utilizing various nonparametric trend detection methods. It can be concluded that the overall significant increase trends of the temperature led to demonstrate the changes in temperature during last 42 years. Consequently, the annual average temperature is slightly increasing between 0.025 and 0.028 °C/year inducing a warming and more drought events in the region, which also falls under a semi-arid climate. For maximum and average annual temperatures, all the stations detect the year 1998 as an abrupt change, while the minimum temperature detects the year 2013 as change point particularly at Ain Oulmene and Boutaleb stations. Besides this, a declining trend appears in the annual rainfall time series also, for all stations, but it is not statistically significant. Therefore, increasing temperature and decreasing rainfall are already a major trouble that can affects the environment and threat natural life.

Our findings of this study highlight the climatic variation in the whole studied region induced by the global trend of climate change. Furthermore, this contribution would serve as a useful guide for more effective monitoring and analysis on the effects of climate change, especially in semi-arid and arid climates, in order to help adopting suitable adaptation strategies and development decisions to face climate change.

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