Effect of autocorrelation on temporal trends in air-temperature in Northern Algeria and links with teleconnections patterns

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Received: 4 May 2021 / Accepted: 8 November 2021 / Published online: 24 November 2021
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Abstract
This study investigates the effect of autocorrelation on temporal trends and step change on a monthly, seasonal and annual temperatures of six meteorological stations over the North of Algeria. Afterwards, links between the general atmospheric circulation, via six climate indices, and temperature data are examined. The trends in temperatures are analysed using six different versions of the Mann-Kendall approach while, the step changes of the time series are defined using the original Pettitt test and the modified-Pettitt. The Statistical tests have shown an increase in annual temperatures from 0.8 to 0.9°C since the 1980s in the coastal regions and the 1990s on the highlands. This warming most often exceeds 1°C on a seasonal scale, particularly in summer; however, no significant trend is observed in the winter. On a monthly scale, the increase in temperatures is marked between April and October. The analysis of the relationships between six climate indices and average temperatures has shown that the inter-annual temperature variability is most often associated with the East Atlantic oscillation for the entire study area. The winter temperatures are influenced by the Mediterranean oscillation as well as the North Atlantic oscillation. The East Atlantic oscillation is the dominant mode of circulation in spring and summer, whereas in autumn, the temperatures are strongly linked to the West Mediterranean oscillation. However, no significant correlations have been observed between temperatures and the Arctic oscillation and El Nino southern oscillation.

1 Introduction

The global warming is one of the most sensitive issues of the twenty-first century; it is considered by many as the most crucial issue facing humanity nowadays (Durand 2007). For several years, the scientific community has been placing increasing importance on climate change, due to the changes observed over the last century. Indeed, since the mid-1970s the earth has experienced considerable climate variability characterised by a temperature increase of about 0.7°C (IPCC 2007, 2014). The global warming has resulted in the appearance and persistence of some extreme events such as droughts and floods, which have affected water availability, agriculture and other socio-economic factors (Radhouane 2013; Chebil et al. 2011; Boko et al. 2007; Sowers et al. 2011). The Mediterranean basin has suffered cumulative impacts of climate change and it is considered a hot-spot area that requires more attention for the implementation of adaptation measures (Giorgi 2006). In fact, an increase in temperatures has been observed in France (Chaouche et al. 2010), Spain (Ramos et al. 2012), Italy (Bartolini et al. 2012), Greece (Mamara et al. 2016; Feidas, 2016) and Turkey (Dogan et al. 2015). However, this upward trend varies considerably at both spatial and temporal scale and is most significant in spring and summer. Consistent with these results, the countries on the southern shore of the Mediterranean, including Algeria, have not been spared by the consequences of climate change (Price 2017). The observed annual and seasonal trends in mean temperature indicate a global warming that is significantly beyond the range of changes due to a natural variability (IPCC 2014). The annual temperature trend observed in Morocco and Tunisia shows an increase of 0.2 to 0.4°C per decade (Driouech et al., 2013). Dorté (2013) has found that the average temperatures in Tunisia was increased by about 1.4°C during the twentieth century from the 1970s onwards, while Filahi et al. (2016) noted a considerable increase in autumn and spring temperatures in Morocco during the period 1970–2012.
The air temperature plays a key role in understanding the complex climate system and it is one of the crucial variables affecting almost all environmental processes (Vancutsem et al. 2010). Besides, the identification of temperature trends is essential in the studies of the impacts of climate change on the hydrological cycle, environment and agriculture sectors (Yu et al. 2019).

A slight increase in temperature can trigger hydrological droughts and floods (Dai 2011) and even air pollution (Zhang 2017). A better understanding of the temporal variability of temperatures is essential for the implementation of more effective adaptation measures for sustainable water resources management.

In Algeria, although much work has been devoted to the study of regional and local climate (Meddi and Meddi, 2009; Bekkoussa et al. 2008; Medjerab and Henia 2005) few studies have addressed the characterisation of air temperature variation (Zeroual et al. 2017). To our knowledge, all previous studies have focused on the analysis of spatial and temporal variation in precipitations and the impact of climate change on water resources. Some of them reported a decrease in rainfall particularly in the north-western part of Algeria (Meddi and Meddi, 2009, Bekkoussa et al. 2008; Medjerab and Henia 2005; Taibi et al. 2013) as well as a lowering of groundwater levels and the drying up of some karst springs (Bensaoula et al. 2019; Bouabdelli et al. 2020). Additionally, Zeroual et al. (2019) found that the surface area of desert zones has increased considerably to the detriment of the warm temperate climate zone, which is entirely humid.

Furthermore, the statistical tests of Mann-Kendall (Mann 1945; Kendall, 1975) and Pettitt (1979) are among the methods of analysing the temporal variability of temperatures, most often used for trend analysis and step-change detection, respectively. However, studies have shown that it is essential to take into account the effect of auto-correlation when analysing the temporal variability of a data set (von Storch 1995; Serinaldi and Kilsby 2016; Yue et al. 2002; Piyoosh and Ghosh 2017; Zamani et al. 2017; Fathian et al. 2016; Data and Das, 2019). To this end, approaches have been developed to eliminate the influence of auto-correlation, such as the pre-whitening procedure (von Storch 1995), trend free prewhitening (TFPW) (Yue et al. 2002) and trend free prewhitening corrected unbiased (Serinaldi and Kilsby, 2016). On the other hand, other methods suggested a correction of the variance of the Mann-Kendall test through the use of empirical formulas (Hamed and Rao, 1998) and Monte Carlo simulations (Yue and Wang 2004). Due to the existence of long-term persistence within a climate dataset which can also influence the trend, another approach of the modified Mann-Kendall test has been proposed by Hamed (2008) and Kumar et al. (2009). All these methods are increasingly used in recent studies that aim to show the effect of auto-correlation in the analysis of trends in a time series data of climate (e.g. Zamani et al. 2017; Fathian et al. 2016; Data and Das, 2019). Consequently, one of the main objectives of this study is to characterise the long-term variability in temperatures in Northern Algeria through six meteorological stations distributed over the coastal region and the highlands, through the application of the various approaches mentioned below.

In northern Algeria, climate variability is associated with particular atmospheric circulation modes such as the North Atlantic Oscillation (NAO), the Mediterranean Oscillation (MO), the Southern Oscillation (ENSO) and the Western Mediterranean Oscillation (WeMO) (Taibi et al. 2017; Zeroual et al. 2017). In addition to these four circulation modes, the Eastern Oscillation (EA) and the Arctic Oscillation (AO) have also been shown to influence the temperature variability in the Mediterranean region (Toreti et al. 2010; Ríos-Cornejo et al. 2015). It has to be noted that little is known about the links between the temperatures of Northern Algeria and the atmospheric circulation patterns (e.g. Zeroual et al. 2017). Relevant to this, the second objective of this work is the analysis of the relations that might exist between temperature variability and climatic indices.

Furthermore, this study provides a complete analysis of the long-term temperature evolution, trend, break, persistence and their relationship with six modes of atmospheric circulation at different annual, seasonal and monthly time steps, which is significant for climate prediction on a regional scale, to carry out necessary socio-economic impact studies for the implementation of plans supporting the sustainable management of water resources and agriculture in Algeria. These approaches have already been the subject of many recent studies across the world (Plewa et al. 2019; Yu et al. 2019; Lee et al. 2019).

2 Materials and methodology

2.1 Study area

Our study is conducted in the northern part of Algeria (Fig. 1), which is bounded to the east by Tunisia, to the west by Morocco and the south by the Saharan Atlas. The study area is characterised by a Mediterranean climate over the coast and semi-arid on the highlands. The Landform is more accentuated in the East than the west of Algeria, and due to this, the precipitation ranges between approximately 700 mm to the East (Annaba) and less than 300 mm to the West (Oran). A rainfall gradient is also observed from the North to the South where the annual totals vary from approximately 600 mm (Algiers) to less than 200 mm (Djelfa).
2.2 Data description

Six temperature series are selected to characterise the spatiotemporal variability of annual and monthly temperatures in northern Algeria. The choice of the selected meteorological stations is based on the spatial representativeness and the availability of data. Indeed, according to Köppen’s classification doing by Zeroual et al. (2019) over Algeria, the climate type arid (B) extend over roughly 95% of the total surface area of the country, and warm temperate climate (C) account for only about 5% of this area. For climate type arid (B), the most common climate zone is the hot desert type (BWh), which covers more than 85% of the country, followed by the cold steppe (BSk) climate zone, covering about 5%. Type C climate zones are almost exclusively represented by the fully humid warm temperate climate with hot summer (Csa) climate zone. It is worth noting that, aside from the BWh and BWK zones, the other climate zones are exclusively found in northern Algeria, which is home to about 95% of its population.

Therefore, the six stations used are well representative of the climate zones of Northern Algeria where the majority of the Algerian population lives, namely:

- Fully humid warm temperate climate with hot summer climate zone is covered by three stations namely Annaba, Algiers and Oran stations. These three stations covered all of northern Algeria (East, Center and the West).

| Stations       | Latitude | Longitude | Altitude (m) | Study period    |
|----------------|----------|-----------|--------------|-----------------|
| Algiers (Dar el Beida) | 36°43′   | 03°15′E   | 25           | 1950–2016       |
| Annaba         | 36°50′   | 07°49′E   | 4            | 1950–2016       |
| Constantine    | 36°17′   | 06°37′E   | 694          | 1950–2016       |
| Oran           | 35°38′   | 00°36′W   | 90           | 1950–2016       |
| Mascara        | 35°13′   | 00°09′E   | 513          | 1977–2016       |
| Djelfa         | 34°20′   | 03°23′E   | 1180         | 1972–2016       |
The transition between the two climate zones of fully humid warm temperate climate and cold steppe is represented by Constantine station.

The Cold steppe climate zone is represented by Mascara station.

The Hot steppe climate zone is represented by Djelfa station.

Additionally, in order to highlight the effect of auto-correlation and LTP persistence in trend analysis, it is essential to choose stations with the longest available observation series to differentiate between trends due to human-induced climate change and natural variability. For this reason, we were only able to select six stations in the study area, the longest and most complete. The other stations have data from the late 1970s and the majority from the 1980s, which does not meet the objective of our work. The monthly data recorded in the six meteorological stations are available from 1950 to 2016 except for the stations of Djelfa and Mascara (Table 1). These data are collected from the National Meteorological Office (NMO).

### 2.3 Climate indices

The NAO, SOI and MO data are downloaded from the Climatic Research Unit website (http://www.cru.uea.ac.uk/cru/data/pci.htm), while the AO and EA indices are downloaded from the NOAA website (http://www.cpc.ncep.noaa.gov/products/precip/CWLink/daily_ao_index/ao.shtml and http://www.cpc.ncep.noaa.gov/data/teledoc/ea.shtml). The WeMO index is implemented by Martín-Vide and Lopez-Bustins (2006) from the University of Barcelona (http://www.ub.edu/ge/en/2016/06/08/wemo/).

The NAO index is defined as the difference of the atmospheric pressure at a sea level between Azores anticyclone (Lisbon) and the depression of Iceland (Reykjavik) (Hurrell, 1995). NAO has a north-south fluctuation in the air from the Arctic and Icelandic regions to the subtropical high-pressure belt, which has the effect of varying the intensity of the position of the Azores anticyclone and the Icelandic depression. This combined phenomenon forms a balancing effect: when the pressure is relatively high in the subtropical belt, it is relatively low in the polar region and vice versa.

The AO is a large-scale pattern of variability throughout the whole of the Northern hemisphere circulation closely linked to the NAO (Ríos-Cornejo et al. 2015). Thompson and Wallace (1998, Thompson et al., 2000) suggested that the NAO is the regional manifestation of the AO circulation mode. The AO index is defined by Thompson et al. (2000) as the leading EOF of the monthly mean SLP over the northern hemisphere north of 20N.

The EA pattern as defined by Wallace and Gutzler (1981) and Barnston and Livezey (1987) is considered as the second prominent mode of a low-frequency variability over the North Atlantic and it appears as a leading mode in all months (NOAA 2018). The EA is structurally similar to the NAO and consists of north-south dipole centres of anomalies covering the North Atlantic from east to west. The EA centres of the anomaly are displaced southeastward to the approximate nodal lines of the NAO model. For this reason, the EA is often interpreted as a NAO shifted towards the south. However, the lower-latitude centre contains a strong subtropical link in association with modulations in the subtropical ridge intensity and position. This subtropical link makes the EA pattern distinct from its NAO counterpart (NOAA 2018).

The MO designates the difference normalized pressure at the 500 hPa geo-potential height between Algiers and Cairo (Conte et al. 1989). The MO results from the opposite behaviour of barometric, thermal and rainfall variability between the western and eastern Mediterranean.

ENSO pattern is represented by the south oscillation index (SOI) which is defined as the difference between sea level pressure at Tahiti and Darwin (Trenberth 1997). Tahiti represents the high subtropical pressures of the eastern Pacific, and Darwin represents the low equatorial pressures of the northern Indian Ocean and Indonesia.

Martín-Vide and Lopez-Bustins (2006) proposed a new regional telecommunication index defined within the synoptic data from the western Mediterranean basin and its surroundings and they called the Western Mediterranean Oscillation (WeMO). The WeMO index indicates the pressure differences between the regions of the north of Italian peninsula and the south-west of the Iberian Peninsula.

### 2.4 Methods

#### 2.4.1 Autocorrelation

In any trend or step analysis exercise, it is important to evaluate the existence of serial correlation. In such cases, the presence of serial correlation in the time series can affect considerably the result of trend analysis. A positive autocorrelation can artificially induce trend in a time series (e.g. von Storch 1995; Kulkarni and von Storch 1995), while negative autocorrelation can weaken the trend already existed (Yue et al 2002). Such statistical features have serious implications for trend and step analyses. However, it is required to verify the autocorrelation of the temperature data before applying trend tests and step analysis. The autocorrelation of a time series ‘X_t’ means that this latter is linked with its own previous (t-K) or following (t + K) values (Cunderlik and Burn 2004). This dependence of time series is measured by the coefficients of autocorrelation $p_k$ at different lag-time (k). The
hypothesis of serial independence is checked by the t-test statistic (Mondal et al. 2012). The null hypothesis that \( \hat{\rho} = 0 \) is tested against the alternative hypothesis that \( \hat{\rho} \neq 0 \). If \( |t| > t_{\alpha/2} \) we reject the null hypothesis, at a significance level of \( \alpha \). In our case, the autocorrelation coefficient is calculated for a shift \( k=1 \) (Lag-1) at a significance level of 5\%. This method was applied using the R package fdaACF (Hyndman 2021), available in CRAN (http://cran.r-project.org/package=fdaACF).

### 2.4.2 Mann-Kendall test and Sen’s slope

The Mann–Kendall (MK) test (Mann 1945 and Kendall 1975) allows detecting the existence of a significant global trend within time series data as well as the direction of the trend. Trends are assessed by estimating the Sen’s slope (Sen 1968) associated with the Mann-Kendall test. It is a non-parametric method based on the median slope. The latter being less sensitive to outliers than traditional regression methods, it enables a more reliable assessment of the trend (Eichner et al. 2003).

### 2.4.3 Modified Mann-Kendall (MMK)

To eliminate the effect of autocorrelation on temporal trends in the time series, several authors have modified the Mann-Kendall test according to different approaches. As part of this work, six statistical modified tests based on three different approaches are used. The six tests were applied using the modified MK of R package (Patakamuri and O’Brien, 2019).

a) **Approaches based on prewhitening**

The three approaches used are those proposed by von Storch (1995) Yue et al. (2002) and Serinaldi and Kilsby (2016). Therefore, Von Storch (1995) developed the prewhitening method (MMK-PW) and has suggested using it when the series have a lag-1 autocorrelation; otherwise, the original Mann-Kendall test is sufficient. Afterwards, Yue et al. (2002) proposed the TFPW method to address the autocorrelation in time series data. However, Serinaldi and Kilsby (2016) have shown that the trend-free-pre-whitening approach (TFPW) does not consider the variance inflation of the uncorrelated residues and is not able to provide a pre-whitened of the time series used for the modified Mann–Kendall test. To that effect, it suggested the corrected and unbiased trend-free-pre-whitening (TFPWcu) approach (Serinaldi and kilsby 2016).

b) **Approaches based on variance correction**

The modification of the variance of Mann–Kendall test is an approach proposed by Hamed and Rao (1998) (MMKH) and Yue and Wang (2004) (MMKY). The correction of variances is done by empirical formulas for the MMKH test, while the MMKY test uses the Monte-Carlo simulations to remove the effect of the auto-correlation in the MK test.

c) **Long term persistence (LTP)**

Some studies have shown that long-term persistence (LTP), also known as the Hurst phenomenon, can underestimate the importance of the trend in the climate variability (Koutsoyiannis 2003; Koutsoyiannis and Montanari 2007; Hamed 2008). To this end, Hamed (2008) modified the MK test to consider this phenomenon in the time series. This method is used as part of this work to verify the long-term persistence of temperatures in Northern Algeria. For more information, the article of Kumar et al. (2009) illustrates in detail the different steps of this method.

### 2.4.4 Pettitt test

The Pettitt test (Pettitt 1979) is a non-parametric test used to verify the stationarity in the time-series of our data. The null hypothesis of this test means that the series is stationary while the alternative hypothesis means that the data series is not stationary and that a breakpoint of mean exists from a given date. The package trend (Pohlert et al., 2016) for R was used in this study to calculate breakpoint in temperature time series.

### 2.4.5 Modified Pettitt test using TFPW-cu

Serinaldi and Kilsby (2016) proposed the corrected and impartial TFPW (TFPW-cu) method to eliminate the effect of the autocorrelation of the Pettitt test (1979). This test is applied to detect a breaking point within series of autocorrelated data. The mathematical equations and the sequential steps of the framework are explained in more detail in Serinaldi and Kilsby (2016) and Achour et al. (2020).

### 2.4.6 Spearman’s correlation coefficient

To explore the links between average temperatures and climate indices, the Spearman’s correlation coefficient (Spearman 1904) is used. This test is well suited for monotonically related variables, even when their relationship is not linear (Coscarelli et al. 2013). Spearman’s correlation coefficient has been used in numerous studies to demonstrate the influence of general atmospheric circulation on climate variability (e.g. Rios-Cornejo et al. 2015; Coscarelli et al. 2013; Nojarov 2019; Sabziparvar and Jahromi, 2018etc.). The ppcor.R package (Kim 2015), available on CRAN at http://CRAN.R-Project.org/, is used for the calculation of the Spearman’s correlation coefficient.
3 Results and discussions

3.1 Autocorrelation analysis

Before analysing the trends in the temperature time series, we investigate the autocorrelation as suggested by Hamed and Rao (1998) and Serinaldi and Kilsby (2016). The autocorrelation is checked at the monthly, seasonal and annual time steps. Fig. 2 represents the auto-correlogram for each station in which the autocorrelation coefficient is determined for a lag-1. The temperature series are autocorrelated to the significance threshold of 5% when its value is greater (lower) than the nominal significance level. The results highlight the presence of an autocorrelation for all the annual average temperature series. At the seasonal scale, the autocorrelation is observed in autumn, spring and summer at the stations of Algiers, Annaba, Oran and Constantine, while it is observed in spring and summer at Mascara and only in autumn at Djelfa station. Winter temperature series are not auto-correlated for all stations.

On a monthly scale, the presence of autocorrelation in the data series differs from one station to another (Fig. 2). The monthly temperatures for April, June, July, and August are autocorrelated at Algiers station, while at Annaba and Constantine stations, autocorrelation is observed only in August and October. At Oran station the autocorrelation is highly present since it is detected within the monthly series going from March to August. The monthly data series for March, June and August are also autocorrelated at the Mascara station, contrary to the Djelfa station which is characterised by the absence of autocorrelation on a monthly scale. The results also show that the autocorrelation detected within the different data series is positive, which, according to Hamed and Rao (1998), further increase the probability of detecting a trend whereas it did not exist. It therefore becomes essential to eliminate autocorrelation to analyse temperature trends, by applying the different methods illustrated in section (2.4).

3.2 Analysis of the temperature trend

The Mann-Kendall test is most often used to analyse trends in time series data. However, the presence of autocorrelation may influence the results obtained. For this purpose, we analyse the trend of the mean temperature series using the original Mann-Kendall test as well as six other MMK tests.
developed using different approaches in order to eliminate the effect of autocorrelation. This consists of comparing for each station the results of the Z obtained by the seven statistical tests with the different time steps annual, seasonal, and monthly, only for the auto-correlated series. When the series are not auto-correlated, only the original Mann-Kendall test is applied. A trend is considered to be significant when Z is greater (or less) than 1.96 (−1.96). The Sen’s slope is also calculated to measure the magnitude of warming (or to quantify the variation in temperatures by decades).

### 3.2.1 Annual temperature trend

The comparison between the versions of the MMK based on different approaches compared to the traditional Mann-Kendall test shows overall that the MMK-pw and MMK-TFPW-cu tests are the most effective in eliminating the effect of the autocorrelation. These two tests can reduce the Z-statistic by more than 50% until the total elimination of the trend for some temperature series, while other approaches generally do not exceed 30%, contrary to the MMK-TFPW test which often shows an increase in the Z-statistic. These percentages can be explained by not taking into account the increase in variance (Serinaldi and Kilsby, 2016). Concerning the detection of long-term persistence, we find that the LTP test greatly reduces the number of temperature series with a significant trend by the original MK test as well as the other tests. The H coefficient, which varies on average between 0.3 and 0.7, is able to detect the presence of long-term persistence for some temperature series, however, its elimination makes the trend insignificant for all temperature series.

**For Algiers station**, the analysis of the trend in annual temperatures series by the MK test highlights a significant positive trend ($Z = 3.99$) (Table 2). This time series is auto-correlated by eliminating the effect of autocorrelation using the different approaches of MMK and also showed the presence of a positively significant trend except for the LTP test (Table 2). The results show a slight decrease in the Z value after elimination of the autocorrelation by removing the effect of the Hurst coefficient ($H$) compared with the original MK ($2.97 < Z < 3.13$) except for the TFPW method which shows an increase in the $Z$ ($Z = 4.69$). However, the LTP method shows the presence of long-term persistence ($H = 0.7$ with $p$-value $= 0.009$) and their removal from the time series makes the trend not significant ($Z = 1.53$).

**For Annaba station**, the analysis of annual temperatures by the MK test highlights a significant positive trend ($Z = 4.03$) (Table 2). The elimination of autocorrelation by the PW, TFPW, TFPW-cu, MMKH and MMKY tests also shows a positive trend, the $Z$ statistic is 2.17, 4.04, 2.18, 2.62, 3.22 respectively. On the other hand, a presence of long-term persistence is detected ($H = 0.69$ with $p$-value $= 0.004$) and their elimination from the time series makes the trend not significant ($Z = 1.75$).

**At Oran station**, the analysis of annual temperatures by the MK test shows a significant positive trend ($Z = 3.69$) (Table 2). The two prewhitening methods PW and TFPW-cu highlight the absence of a significant trend with $Z$ values of 1.69 and 1.86 respectively, while the tests TFPW, MMKH and MMKY show respectively a significant trend with $Z$ values of 3.95, 1.98, 2.63. However, the LTP method shows the presence of long-term persistence ($H = 0.8$ with $p$-value $= 0.00$) and their removal from the time series makes the trend not significant ($Z = 1.17$).

**At Constantine station**, the analysis of trends in annual temperatures by all the statistical tests shows a significant positive trend which results in an increase of $0.16^\circ C$/decade. On the other hand, LTP does not detect long-term persistence ($H = 0.48$ with $p$-value $= 0.617$ and $Z_{LTP} = 1.61$).

**In Mascara station**, the analysis of annual temperatures (autocorrelated series) during the period 1977–2016 by all of the statistical tests shows a significant positive trend which results in an increase of $0.4^\circ C$/decade (Table 2). However, the LTP method shows the presence of long-term persistence ($H = 0.7$ with $p$-value $= 0.009$) and their removal from the time series makes the trend not significant ($Z = 1.81$).

The annual temperatures observed at Djelfa station during the period 1972–2016 show a significant positive trend detected by all of the statistical tests as well as the absence of long-term persistence, which confirms the magnitude of the trend (Table 2).

On the annual scale, the significant positive trends observed for all stations show an increase of 0.1 to $0.4^\circ C$/decade which is more pronounced in the semi-arid regions represented by Djelfa and Mascara stations. Such a temperature increase has already been noted by Driouech et al. (2013) in Morocco and Tunisia, by Zeroual et al. (2017) in Algeria and other countries around the Mediterranean (Chaoouche et al. 2010; Ramos et al. 2012; Bartolini et al. 2012; Mamara et al. 2016; Feidas 2016; Dogan et al. 2015).

### 3.2.2 Seasonal and monthly temperature trend

Overall, the analysis of temperature trend by MK and MMK tests for all stations, at the seasonal scale, shows a no significant trend in winter while a positive significant trend is observed in spring, summer and autumn which is manifested during the months from April to May. The number of monthly temperature series indicating the presence of long-term persistence is greater at the Oran and Mascara stations located in the west of the country; however, the elimination of the persistence by the LTP test shows the absence of the significant trend for all of these series.

At Algiers station, all statistical tests show a positive non-significant trend in winter, with a $Z$ which varies between
| Tests | Algiers | Annaba | Constantine |
|-------|---------|---------|-------------|
| Z-MK  | 1.14    | 1.78    | 0.75        |
| Z-PW  | 1.07    | 1.52    | 0.72        |
| tfpw  | 1.03    | 1.62    | 0.73        |
| tfpw-cu | 1.14  | 1.91    | 0.75        |
| mmkh  | 1.14    | 1.80    | 0.75        |
| MK-LTP H Estimate | 0.36   | 0.44   | 0.50       |
| p-value for H | 0.38 | 0.95 | 0.51 |
| MK-LTP | 1.40 | 1.65 | 0.59 |

**Table 2** Mann-Kendall Z value and Sen’s slope. The significant trends at the 95% confidence level are shown in bold.
| Tests   | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | DJF | MAM | JJA | SON | Ann. |
|---------|------|------|------|------|-----|------|------|------|------|------|------|------|------|-----|-----|-----|-----|
| tfpw-cu |  0.99 |  0.52 |  0.81 |  3.60 |  2.77 |  2.71 |  3.65 |  2.68 |  -0.55 |  2.72 |  0.99 |  0.44 |  0.67 |  3.13 |  3.31 |  2.16 |  2.37 |
| mmkh    |  1.12 |  0.46 |  0.67 |  2.68 |  2.49 |  2.45 |  3.65 |  2.03 |  -0.28 |  3.17 |  1.07 |  0.55 |  0.71 |  2.53 |  3.05 |  2.09 |  2.83 |
| MK-LTP  | H Estimate |  0.36 |  0.39 |  0.54 |  0.54 |  0.48 |  0.59 |  0.59 |  0.64 |  0.57 |  0.36 |  0.46 |  0.70 |  0.62 |  0.65 |  0.70 |  0.48 |
|         | p-value for H |  0.38 |  0.56 |  0.24 |  0.23 |  0.63 |  0.08 |  0.38 |  0.08 |  0.02 |  0.13 |  0.37 |  0.78 |  0.00 |  0.04 |  0.02 |  0.62 |
| MK-LTP  |  1.21 |  -0.46 |  0.50 |  1.93 |  1.91 |  1.59 |  2.61 |  1.38 |  -0.17 |  2.13 |  0.55 |  0.87 |  1.15 |  1.61 |  1.75 |  1.13 |  0.61 |
| Sen's Slope (°C/decade) |  0.1 |  -0.05 |  0.07 |  0.26 |  0.27 |  0.31 |  0.29 |  0.2 |  -0.03 |  0.37 |  0.09 |  0.04 |  0.05 |  0.2 |  0.27 |  0.15 |  0.16 |
| Mascara | Z-MK |  1.22 |  1.31 |  1.82 |  2.75 |  3.70 |  3.69 |  2.98 |  3.06 |  1.41 |  3.23 |  1.02 |  0.37 |  -0.01 |  3.86 |  4.07 |  2.80 |  4.42 |
|         | Z-PW |  1.16 |  1.23 |  0.63 |  2.42 |  2.83 |  2.15 |  1.86 |  1.55 |  1.02 |  2.69 |  0.80 |  0.75 |  0.12 |  2.58 |  2.10 |  1.84 |  2.01 |
|         | tfpw-cu |  1.14 |  1.14 |  1.33 |  2.95 |  3.48 |  3.65 |  2.61 |  2.81 |  1.50 |  3.24 |  0.80 |  0.58 |  0.12 |  3.73 |  3.77 |  2.56 |  4.35 |
|         | mmkh |  1.23 |  1.31 |  1.41 |  4.55 |  3.70 |  3.21 |  4.96 |  3.06 |  1.71 |  2.81 |  1.02 |  0.37 |  -0.02 |  3.86 |  3.33 |  2.18 |  3.49 |
| MK-LTP  | H Estimate |  1.28 |  1.50 |  1.38 |  2.71 |  4.07 |  3.09 |  2.83 |  2.49 |  1.13 |  3.90 |  1.01 |  0.59 |  -0.01 |  3.72 |  3.61 |  2.59 |  3.48 |
|         | p-value for H |  0.33 |  0.22 |  0.76 |  0.36 |  0.28 |  0.63 |  0.50 |  0.66 |  0.64 |  0.43 |  0.42 |  0.20 |  0.45 |  0.37 |  0.52 |  0.56 |  0.70 |
| MK-LTP  |  1.42 |  -2.18 |  0.65 |  2.90 |  5.11 |  1.81 |  2.11 |  1.38 |  0.68 |  2.77 |  0.89 |  0.68 |  -0.01 |  4.01 |  2.68 |  1.65 |  1.81 |
| Sen's Slope (°C/decade) |  0.22 |  -0.26 |  0.25 |  0.54 |  0.92 |  0.74 |  0.78 |  0.61 |  0.25 |  0.67 |  0.02 |  0.07 |  - |  0.55 |  0.67 |  0.38 |  0.42 |
| Djelfa   | Z-MK |  1.41 |  -0.05 |  2.15 |  2.58 |  2.18 |  1.14 |  4.17 |  4.07 |  1.51 |  3.40 |  0.80 |  0.58 |  0.69 |  2.97 |  3.79 |  3.70 |  4.14 |
|         | Z-PW |  1.12 |  -0.03 |  1.97 |  2.34 |  1.75 |  0.84 |  3.66 |  2.91 |  1.04 |  2.86 |  0.90 |  0.29 |  0.39 |  1.99 |  2.63 |  2.22 |  2.17 |
|         | tfpw-cu |  1.00 |  -0.03 |  2.38 |  2.24 |  1.91 |  0.86 |  4.10 |  3.87 |  1.12 |  3.31 |  0.98 |  0.23 |  0.39 |  2.58 |  3.49 |  3.35 |  3.77 |
|         | mmkh |  1.41 |  -1.11 |  2.15 |  2.58 |  2.18 |  1.14 |  9.69 |  4.07 |  1.65 |  2.73 |  0.80 |  0.58 |  0.32 |  2.98 |  3.79 |  3.70 |  4.14 |
| MK-LTP  | H Estimate |  1.76 |  -0.05 |  1.87 |  2.73 |  2.38 |  1.10 |  8.16 |  4.29 |  1.55 |  3.99 |  0.75 |  0.72 |  0.69 |  3.17 |  3.93 |  3.48 |  3.77 |
|         | p-value for H |  0.28 |  0.36 |  0.62 |  0.50 |  0.25 |  0.54 |  0.20 |  0.45 |  0.38 |  0.41 |  0.56 |  0.31 |  0.49 |  0.32 |  0.47 |  0.56 |  0.56 |
| MK-LTP  |  1.99 |  -0.05 |  1.09 |  1.86 |  3.40 |  0.72 |  7.73 |  3.36 |  1.55 |  3.15 |  0.48 |  0.76 |  0.52 |  3.70 |  3.00 |  2.25 |  2.50 |
| Sen's Slope (°C/decade) |  0.2 |  - |  0.37 |  0.53 |  0.58 |  0.2 |  0.54 |  0.53 |  0.21 |  0.68 |  0.12 |  0.08 |  0.08 |  0.44 |  0.43 |  0.37 |  0.29 |
0.7 and 0.8. In spring, the MK, TFPW and MMKY tests show a positive significant trend in the autocorrelated temperatures series (1.98 <Z <2.87), while the TFPW-cu and MMKH tests do not show a significant trend, the Z value being 1.56 and 1.63 respectively. The LTP method shows the presence of long-term persistence (H = 0.75 with p-value = 0.000) and their removal from the time series makes the trend not significant (Z = 0.98). The Sen’s slope shows an increase in temperatures of 0.13 °C/decade. In summer, all of the statistical tests indicate a positive significant trend (3.74 <Z <4.51) with the absence of long-term persistence (Z-LTP = 2.52). The autocorrelation observed in this data series has no effect on the result obtained by the original MK that shows the magnitude of the trend during this season which results in an increase by 0.3°C/decade. In autumn, an increase of 0.17 °C/decade is observed. Indeed, the original MK test indicates a positive significant trend (Z = 3.37). The analysis of the temperatures after elimination of the autocorrelation by the PW, TFPW, TFPW-cu, MMKH and MMKY tests also shows a significant trend; the values of Z are respectively 2.68, 3.46, 2.72, 2.52, and 2.92. However, the LTP method shows the presence of long-term persistence (H = 0.64 with p-value = 0.025) and their removal from the time series makes the trend not significant (Z = 1.73).

At monthly scale, all of the statistical tests show a positive trend without significance in January, March, September, November and December, while a non-significant negative trend is observed in February. MK test shows a significant positive trend in April (Z = 2.83). Even if the elimination of the autocorrelation effect by the various tests indicates a decrease in the Z value (2.20 <Z <2.82), the trend remains significant, which shows the extent of the warming during this month which is 0.17 °C/decade. In contrast, the LTP method shows the presence of long-term persistence (H = 0.67 with p-value = 0.007) and their removal from the time series makes the trend not significant (Z = 1.29). In May, the Mann-Kendall test highlights a significant positive trend (Z = 2.25) with an increase in temperatures of around 0.2 °C/decade. The monthly autocorrelated temperatures observed in June, July and August indicate a significant positive trend by all of the statistical tests as well as the presence of long-term persistence. The registered Z_{LTP} is 2.13 (June), 2.85 (July) and 2.13 (August) respectively (Table 2). The impact of global warming in the summer months translates into a dramatic rise in temperatures of around 0.3°C/decade. The month of October recorded a significant positive trend much more important than the other months which is manifested by a significant rise in temperatures of around 0.33°C/decade.

At Annaba stations, all of the statistical tests indicate a positive trend without significance in winter temperatures series (0.81 <Z <1.20). In spring, a significant positive trend is observed, after eliminating the effect of autocorrelation (2.15 <Z <4.34). However, the LTP method shows the presence of long-term persistence (H = 0.66 with p-value = 0.012) and their removal from the time series makes the trend not significant (Z = 1.69). The recorded Sen’s slope is around 0.14°C/decade. In summer and autumn, a significant positive trend is detected by all of the statistical tests, which translates into an increase of around 0.2°C/decade. The elimination of autocorrelation does not influence the result obtained by MK (Table 2) and the LTP test reveals a long-term persistence in autumn (H = 0.62 with p-value = 0.042), despite their elimination, the trend remains significant (Z = 2.05).

At monthly scale, all of the statistical tests indicate a positive non-significant trend in January, March, September, November and December, as well as a non-significant negative trend in February. In April and May, a significant positive trend is highlighted by all the statistical tests (Table 2) which shows an increase of about 0.2 °C/decade. No long-term persistence is detected in April and May, which register a Z of 2.05 and 2.11 respectively. All of the statistical tests show a significant positive trend in June and July, with an increase of 0.18 and 0.23 °C/decade respectively. On the other hand, long-term persistence is detected only in August (H = 0.6 with p-value = 0.042). The analysis of autocorrelated temperatures time series of August by the MK test shows a positive significant trend (Z = 2.42). The TFPW, MMKH and MMKY tests show the same result, contrary to the PW and TFPW-cu and LTP tests which indicate the absence of a significant trend after elimination of the effect of autocorrelation and long-term persistence. The month of October recorded a significant increase in temperatures of about 0.3 °C/decade. All the statistical tests show a significant trend in the auto-correlated time series (2.96 <Z <3.88) as well as the absence of long-term persistence (Z = 2.64).

At Oran station, all of the statistical tests show a positive trend without significance in winter temperatures (1.03 <Z <1.31). In spring, the auto-correlated temperature series shows a significant positive trend (Z_{MK} = 3.07) characterised by an increase of 0.16 °C/decade. The elimination of the effect of autocorrelation by the tests PW, TFPW-cu and MMKH, LTP respectively generates Z values of 1.49, 1.54, 1.64 and 0.92, while the tests TFPW and MMKY respectively indicate Z values of 3.33 and 2.12. In this case, the methods developed by Von storch (1995), Serinaldi and Kilsby (2016) and Hamed and Rao (1998) are the most effective to eliminate the effect of autocorrelation. In summer, all of the statistical tests show a significant positive trend (2.18 <Z <3.23) in the auto-correlated temperature series which is manifested by an increase of 0.18 °C/decade. However, the elimination of long-term persistence made the trend not significant (Z_{Ltp} = 1.52). In the autumn season, the analysis of the auto-correlated time series by the MK test shows a significant positive trend characterised by an
increase of 0.13°C/decade. On the other hand, the PW and TFPW-cu tests indicate a non-significant trend (Z = 1.93), while the TFPW, MMKH and MMKY tests give Z values of 2.60, 2.23 and 2.09 respectively and the elimination of the long-term persistence made the trend not significant (ZLtp = 1.30).

On a monthly scale, the analysis of the temperature series in January, February, March, November and December by all the statistical tests shows a positive trend without significance as well as the presence of long-term persistence in March. In April, the auto-correlated temperature series shows a significant positive trend accompanied by an increase of 0.2°C/decade. The statistic Z calculated for the MK, TFPW, TFPW-cu, MMKH and MMKY tests are 3.28, 3.34, 2.03, 3.89 and 2.77 respectively, while the PW test highlights an insignificant trend (Z = 1.83) and the LTP test detects long-term persistence (H = 0.63 with p-value = 0.027 and ZLtp = 1.70).

The analysis of the May temperature series by the MK test reveals a significant positive trend characterised by an increase of 0.18 °C/decade, while all the approaches used to eliminate the autocorrelation effect and the LTP indicate a non-significant trend (Table 2) except the TFPW method (Z = 2.38). In June and July all statistical tests (except LTP) indicate a significant positive trend even after elimination of the autocorrelation effect (Table 2). These 2 months recorded an increase of 0.25 and 0.2°C/decade respectively.

The analysis of the temperature series for August shows a significant positive trend detected by all of the statistical tests except TFPW-cu which indicates a Z value of 1.95 as well as the presence of long-term persistence (H = 0.62 with p-value = 0.052 and ZLtp = 1.50). The Sen’s slope shows an increase in temperatures of 0.14 °C/decade. The MK test indicates a significant positive trend in the temperatures observed in September and October, with an increase of 0.13 and 0.27°C/decade respectively.

At Constantine station, the winter temperatures observed in Constantine present a positive trend without significance (Table 2). In spring, the temperature analysis by the MK test shows a significant positive trend characterised by an increase of 0.2 °C/decade. After eliminating the autocorrelation effect, the TFPW, MMKH and MMKY tests always indicate the presence of the significant trend, unlike the PW and TFPW-cu tests that show an insignificant trend, and notes a Z value of 1.94 and 1.89 respectively. The elimination of long-term persistence made the trend not significant (Z = 1.71). In the summer season, an increase of 0.27°C/decade of temperatures is observed. In fact, all of the statistical tests (except LTP) show a significant positive trend in temperatures, which highlights the extent of warming during this season (Table 2). In autumn, the analysis of the auto-correlated series of temperatures by the MK, TFPW, MMKH and MMKY tests presents a significant positive trend (2.09 <Z <2.70), while the PW and TFPW-cu tests indicate a positive trend without significance with the statistic Z of 1.74 and 1.79 respectively. The elimination of long-term persistence also made the trend not significant (Z = 1.13). However, the Sen’s slope indicates an increase of 0.15 °C/decade.

At monthly scale, the Mann-Kendall test shows a non-significant positive trend in January, March, November and December and a non-significant negative trend in February and September (Table 2). The months of April, May, June and July recorded increases of 0.26, 0.27, 0.31 and 0.29 °C/decade, respectively. Indeed, the Mann-Kendall test (as well as the other tests) shows a significant positive trend (Table 2). The analysis of the auto-correlated temperature series for August by the MK, TFPW, MMKH and MMKY tests shows a significant positive trend (2.03 <Z <2.68), while the PW and TFPW-cu tests do not show significant trend and indicate Z values of 1.60 and 1.75 respectively. The Sen’s slope shows an increase of 0.2°C/decade. In October, all of the statistical tests show a positive trend in the auto-correlated temperature series (254 <Z <3.41) as well as the absence of long-term persistence (H = p value = Z = 2.13). The Sen’s slope indicates a significant increase in temperatures of around 0.4°C/decade which demonstrates the extent of the warming during this month.

At Mascara station, temperatures do not show a significant trend in winter, while in spring and summer (autocorrelated series), a significant positive trend is demonstrated by all of the statistical tests which are reflected respectively by an increase of 0.55 and 0.67 °C/decade. The LTP test also indicates the absence of long-term persistence in spring (H = 0.37 with p-value = 0.778) and summer (H = 0.52 with p-value = 0.294) which have a significant trend with Z of 4.01 and 2.68 respectively. The elimination of the autocorrelation effect does not influence the temperature trend given the extent of the warming observed in spring and summer. The MK test also indicates a positive trend in temperatures in autumn, which is manifested by an increase of 0.38 °C/decade. On a monthly scale, the MK test highlights an insignificant trend in temperatures in January, February, March, September, November and December. The temperatures observed in April and May show a significant positive trend (Table 2) which reflects respectively into an increase of 0.54 and 0.92°C/decade. In June, the MK test shows a significant positive trend in temperatures which is manifested by an increase of 0.74 °C/decade. This trend also persists after eliminating autocorrelation, which shows the extent of warming during this month. A significant positive trend is also observed in July, the Sen’s slope associated with the MK test shows an increase of 0.78°C/decade. In August, the MK, TFPW, MMKH and MMKY tests show a significant positive trend while the PW and TFPW-cu tests show a non-significant trend. The Sen’s slope associated with the
MK test shows an increase of 0.61 °C/decade. The MK test shows a significant positive trend in temperatures in October accompanied by an increase of around 0.7°C/decade. The LTP method shows the presence of long-term persistence only for June (H = 0.63 with p-value = 0.047) and September (H = 0.64 with p-value = 0.041) and their removal from the time series makes the trend not significant (Z = 1.81 and Z = 0.68).

At Djelfa station, the MK test does not present a significant temperature trend in winter, unlike spring and summer which are marked by a positive trend and register an increase of 0.44, 0.4°C/decade respectively. In autumn, all the tests show a positive trend in temperatures as well as the absence of long-term persistence (Z = 2.25) which shows the intensity of warming during this season in the region of Djelfa. The Sen’s slope associated with the MK test indicates an increase of 0.37 °C/decade. At monthly scale, all-temperature time series are not auto-correlated. The MK test indicates that there is no significant trend in January, February, June, September, November and December. The analysis of temperatures in March, April and May shows a significant positive trend which reflects respectively into an increase of 0.4°C, 0.53 and 0.6°C/decade. The temperatures in July and August also show a significant positive trend which is translated respectively into an increase of 0.54 and 0.53 °C/decade. The month of October is distinguished, as for the other stations, by a significant rise in temperatures of around 0.7°C/decade.

### 3.3 Identification of change point

The statistical Pettitt test (1979) is used to detect a change point in mean values of statistical series and thus identify the date of the change. However, when the time series data is auto-correlated, it becomes necessary to apply the modified Pettitt test based on the TFPW-cu approach developed by Serinaldi and Kilsby (2016). If the autocorrelated time series of temperature at a given time scale presents a change point using the original Pettitt’s test, so, the Pettitt test using TFPWcu will be subsequently selected.

The modified Pettitt test using TFPWcu consists of splitting the initial series into two sub-series based on the change point obtained from original Pettitt’s test and computed the difference of the means (Δ) of the two sub-series, lag-1 autocorrelation coefficient  \( \hat{\rho} \) after elimination of point change, the first stage corrected  \( \hat{\rho}_k \) coefficients and finally, the second stage corrected (\( \hat{\rho}^* \)) lag-1 autocorrelation coefficient. Table 3 shows values before and after removing autocorrelation of test statistic KT, year in which change point has appeared and p-value and the parameters of Pettitt test using TFPWcu (\( \Delta, \hat{\rho}, \hat{\rho}_k^* \) and \( \hat{\rho}^* \)).

### 3.3.1 Change point in annual temperature

Analysis of annual temperature series using original pettitt’s test shows a point change at all stations. After removing the autocorrelation using the TFPW-cu approach, it is found that values of KT statistic are decreased, while the p-values are increased compared with the original Pettitt’s test. However, for the Algiers, Oran, Annaba and Constantine stations, the break in the temperature series remains significant after the application of the TFPW-cu approach and the break date is often the same except for Constantine. While, at Djelfa and Mascara stations, the modified Pettitt test eliminates the change point for annual auto-correlated temperature series.

In Algiers meteorological station, it is found that the significance of the Pettitt test at a different time scale agrees perfectly with the results of the Mann-Kendall test. Using the Pettitt test, the annual temperature has change point in the year 1984 (+0.9°C) with an increase of 0.9°C (p-value < 0.0001). After corrected and unbiased trend free prewhitening (TFPWcu), the annual series is tested again for a shift using Pettitt’s test. The results show that, in principle, all KT values are decreased (Table 3), while the p-values are increased relative to original Pettitt’s test but they remain significant (p-values < 0.05). Thus, the change point is affirmed in the same years 1984.

The analysis of temperature time series of Annaba station using the original Pettitt test has shown that the annual temperature has change point in the year 1980 with an increase of 0.8°C (p-value < 0.0001). After corrected and unbiased trend free prewhitening (TFPWcu), the change point is confirmed in the same years as that found by the original Pettitt test.

The analysis of temperature time series of Oran station using original Pettitt test shows that the annual temperature has a change point in the year 1986 with an increase of 0.8°C (p-value < 0.0001). After using TFPWcu approach, the date of change point has been brought upward by seven years (1993).

At Constantine station, the analysis of temperature time series using original Pettitt test shows that the annual temperature has change point in the year 1984 with an increase of 0.9°C (p-value < 0.0001). After using TFPWcu approach, it is found that all KT values are decreased (Table 3), while the p-values are increased relative to original Pettitt’s test but they remain significant (p-values < 0.05). Also, the change point is affirmed in the same years by the modified Pettitt test using TFPWcu.

At Mascara station, the analysis of temperature time series using original Pettitt test has shown that the annual temperatures have a change point in the year 1996 with an increase of 0.9°C (p-value = 0.00). After corrected and unbiased trend free pre-whitening (TFPWcu). The results show
Table 3  Change point for Original and Modified Pettitt’s test

| Stations | Time série | Original Pettitt test | Modified Pettitt test using TFPWcu | Difference of temperature (°C) |
|----------|------------|-----------------------|-----------------------------------|-------------------------------|
|          |            | Kt Year                | $\rho$-value                       | $\Delta$ (mm) $\rho^*$ $\rho^*$ $\rho$ Kt Year $\rho$-value | T°C Before | T°C after | $\neq$ |
| Algiers  | Jan.       | 195 No break 0.73      |                                   |                               |               |               |       |
|          | Feb.       | 231 No break 0.54      |                                   |                               |               |               |       |
|          | Mar.       | 315 No break 0.19      |                                   |                               |               |               |       |
|          | Apr.       | 567 1995 0.00 -1.00   | 0.29 0.31 0.30 -0.07 491 1995   | 0.01                           | 14.7          | 15.8        | 1.1 |
|          | May        | 564 1987 0.00 -1.06   | 0.13 0.15 0.14 -0.01 513 1985   | 0.01                           | 17.7          | 18.8        | 1.1 |
|          | Jun.       | 677 1981 <0.0001 -1.27 | 0.28 0.29 0.29 -0.07 530 1984   | 0.00                           | 21.3          | 22.6        | 1.3 |
|          | Jul.       | 764 1981 <0.0001 -1.49 | 0.26 0.28 0.27 -0.01 645 1981   | 0.00                           | 24.1          | 25.7        | 1.7 |
|          | Aug.       | 766 1985 <0.0001 -1.51 | 0.24 0.26 0.25 0.06 595 1985    | 0.00                           | 25.0          | 26.6        | 1.7 |
|          | Sep.       | 482 1985 0.01 -0.90   | 0.19 0.20 0.20 -0.01 406 1985   | 0.04                           | 23.0          | 23.9        | 1.0 |
|          | Oct.       | 662 1984 <0.0001 -1.57 | 0.10 0.12 0.11 -0.18 647 1984   | <0.0001                       | 18.9          | 20.6        | 1.7 |
|          | Nov.       | 304 No break 0.23      |                                   |                               |               |               |       |
|          | Dec.       | 218 No break 0.61      |                                   |                               |               |               |       |
|          | DJF        | 232 No break 0.56      |                                   |                               |               |               |       |
|          | MAM        | 652 1986 0.00 -0.78   | 0.46 0.49 0.47 0.01 437 1985    | 0.03                           | 15.1          | 16.0        | 0.9 |
|          | JJA        | 858 1981 <0.0001 -1.33 | 0.33 0.35 0.34 0.00 661 1981    | 0.00                           | 23.4          | 24.9        | 1.5 |
|          | SON        | 821 1982 <0.0001 -1.02 | 0.30 0.32 0.31 -0.19 626 1982   | <0.0001                       | 18.9          | 20.0        | 1.1 |
| Annaba   | Ann.       | 834 1984 <0.0001 -0.78 | 0.46 0.48 0.47 -0.15 624 1984   | 0.00                           | 17.3          | 18.2        | 0.9 |
|          | Jan.       | 300 No break 0.23      |                                   |                               |               |               |       |
|          | Feb.       | 181 No break 0.81      |                                   |                               |               |               |       |
|          | Mar.       | 280 No break 0.30      |                                   |                               |               |               |       |
|          | Apr.       | 608 1980 0.00 -0.9    | 0.21 0.23 0.23 -0.05 494 1980   | 0.01                           | 14.6          | 15.5        | 0.9 |
|          | May        | 527 1992 0.00 -1.0    | 0.07 0.09 0.08 0.00 503 1992    | 0.01                           | 17.8          | 18.9        | 1.1 |
|          | Jun.       | 506 1992 0.00 -0.9    | 0.10 0.12 0.11 0.04 491 1987    | 0.01                           | 21.3          | 22.2        | 0.9 |
|          | Jul.       | 732 1981 <0.0001 -1.2 | 0.20 0.22 0.21 -0.10 619 1981   | 0.00                           | 23.8          | 25.1        | 1.3 |
|          | Aug.       | 662 1985 <0.0001 -1.1 | 0.22 0.24 0.24 0.13 533 1985    | 0.00                           | 24.9          | 26.0        | 1.1 |
|          | Sep.       | 447 1980 0.02 -0.7    | 0.10 0.11 0.11 0.02 394 No break | 0.06                           | 23.0          | 23.8        | 0.8 |
|          | Oct.       | 699 1985 <0.0001 -1.6 | 0.23 0.25 0.24 -0.13 564 1984   | 0.00                           | 19.2          | 20.9        | 1.7 |
|          | Nov.       | 450 1982 0.02 -0.7    | 0.36 0.38 0.37 0.04 452 1980    | 0.02                           | 15.1          | 15.8        | 0.7 |
|          | Dec.       | 235 No break 0.52      |                                   |                               |               |               |       |
|          | DJF        | 324 No break 0.19      |                                   |                               |               |               |       |
|          | MAM        | 690 1980 <0.0001 -0.7 | 0.36 0.38 0.37 0.04 452 1980    | 0.02                           | 15.1          | 15.8        | 0.7 |
|          | JJA        | 815 1981 <0.0001 -1.0 | 0.24 0.26 0.25 0.02 633 1981    | <0.0001                       | 23.3          | 24.4        | 1.1 |
|          | SON        | 811 1980 <0.0001 -1.0 | 0.28 0.30 0.29 -0.15 620 1980   | 0.00                           | 19.1          | 20.2        | 1.1 |
| Annaba   | Ann.       | 879 1980 <0.0001 -0.7 | 0.45 0.47 0.45 -0.10 558 1980   | 0.00                           | 17.3          | 18.1        | 0.8 |
Table 3 (continued)

| Stations | Time série | Original Pettitt test | Modified Pettitt test using TFPWcu | Difference of temperature (°C) |
|----------|------------|-----------------------|------------------------------------|-------------------------------|
|          |            | Kt Year | p-value | Δ (mm) | ρ̂ | ρ̂* | ρ* | ρ | Kt Year | p-value | T°C Before | T°C after | ≠ |
| Oran     | Jan.       | 244     | No break | 0.48   | −0.7 | 0.28 | 0.30 | 0.29 | 0.05 | 284 No break | 0.29 | 15.3 | 16.5 | 1.1 |
|          | Feb.       | 180     | No break | 0.81   | −1.1 | 0.31 | 0.33 | 0.32 | −0.03 | 449 1991 | 0.02 | 18.4 | 19.6 | 1.2 |
|          | Mar.       | 442     | 1986    | 0.02   | −1.1 | 0.35 | 0.37 | 0.36 | −0.05 | 438 1991 | 0.02 | 21.8 | 23.1 | 1.3 |
|          | Apr.       | 592     | 1994    | 0.00   | −1.3 | 0.32 | 0.34 | 0.33 | 0.02  | 526 1992 | 0.00 | 24.8 | 26.1 | 1.2 |
|          | May        | 554     | 1991    | 0.00   | −1.1 | 0.29 | 0.30 | 0.30 | 0.03  | 457 1997 | 0.01 | 25.3 | 26.5 | 1.2 |
|          | Jun.       | 661     | <0.0001 | −1.1   | 0.26 | 0.28 | 0.27 | 0.05 | 0.05  | 499 1985 | 0.01 | 23.1 | 23.7 | 0.6 |
|          | Jul.       | 588     | 1993    | 0.00   | −1.2 | 0.03 | 0.05 | 0.05 | −0.16 | 557 1984 | 0.00 | 18.9 | 20.2 | 1.2 |
| Oct.     | 553       | 1984    | 0.00    | −1.2   | 0.57 | 0.59 | 0.57 | 0.04 | 0.04  | 405 1991 | 0.04 | 15.8 | 16.9 | 1.1 |
| Nov.     | 234       | No break | 0.52    | −0.9   | 0.37 | 0.39 | 0.38 | 0.05 | 0.05  | 514 1988 | 0.00 | 24.0 | 25.1 | 1.1 |
| Dec.     | 300       | No break | 0.23    | −0.8   | 0.25 | 0.27 | 0.26 | −0.12 | 484 1982 | 0.01 | 18.9 | 19.8 | 0.9 |
| DJF      | 326       | No break | 0.19    | −0.5   | 0.55 | 0.57 | 0.56 | −0.09 | 429 1993 | 0.03 | 17.6 | 18.5 | 0.8 |
| MAM      | 700       | 1993    | <0.0001 | −0.9   | 0.57 | 0.59 | 0.57 | 0.04 | 0.04  | 405 1991 | 0.04 | 15.8 | 16.9 | 1.1 |
| JJA      | 736       | 1988    | <0.0001 | −1.0   | 0.37 | 0.39 | 0.38 | 0.05 | 0.05  | 514 1988 | 0.00 | 24.0 | 25.1 | 1.1 |
| SON      | 597       | 1982    | 0.00    | −0.8   | 0.25 | 0.27 | 0.26 | −0.12 | 484 1982 | 0.01 | 18.9 | 19.8 | 0.9 |
| Ann.     | 749       | 1986    | <0.0001 | −0.5   | 0.55 | 0.57 | 0.56 | −0.09 | 429 1993 | 0.03 | 17.6 | 18.5 | 0.8 |
Table 3 (continued)

| Stations | Time sérises | Original Pettitt test | Modified Pettitt test using TFPWcu | Difference of temperature (°C) |
|----------|--------------|-----------------------|----------------------------------|-------------------------------|
|          |              | Kt Year p-value       | Δ (mm) ρ^ ρ^* ρ^* ρ Kt Year p-value | T°C Before T°C after ≠ |
| Constantine | Jan.        | 240 No break 0.49     | -1.44 0.13 0.15 0.14 -0.11 466 1996 0.01 | 12.3 13.7 1.4 |
|          | Feb.         | 188 No break 0.77     | -1.62 0.02 0.03 0.03 -0.02 502 1992 0.01 | 16.5 18.2 1.7 |
|          | Mar.         | 345 No break 0.13     | -1.71 0.20 0.22 0.21 -0.04 484 1992 0.01 | 21.5 23.4 1.9 |
|          | Apr.         | 499 1997 0.01         | -1.53 0.13 0.15 0.15 -0.02 601 1981 0.00 | 24.8 26.5 1.6 |
|          | May          | 497 1992 0.00         | -1.21 0.23 0.25 0.24 0.14 449 1985 0.02 | 25.1 26.3 1.2 |
|          | Jun.         | 559 1992 0.00         | -1.88 0.23 0.25 0.24 -0.17 547 1985 0.00 | 16.0 18.0 2.0 |
|          | Jul.         | 709 1981 <0.0001      | -1.13 0.27 0.29 0.28 -0.06 435 1993 0.02 | 12.9 14.1 1.2 |
|          | Aug.         | 602 1985 0.00         | -1.38 0.34 0.36 0.35 0.03 555 1981 0.00 | 23.7 25.3 1.5 |
|          | Sep.         | 286 No break 0.27     | -1.02 0.34 0.36 0.35 -0.13 432 1986 0.03 | 16.3 17.4 1.1 |
|          | Oct.         | 671 1985 <0.0001      | -0.83 0.43 0.45 0.43 -0.15 496 1984 0.01 | 15.2 16.1 0.9 |
|          | Nov.         | 337 No break 0.14     |                           |                               |
|          | Dec.         | 184 No break 0.79     |                           |                               |
|          | DJF          | 224 No break 0.60     |                           |                               |
|          | MAM          | 601 1993 0.00         |                           |                               |
|          | JJA          | 801 1981 <0.0001      |                           |                               |
|          | SON          | 681 1986 <0.0001      |                           |                               |
|          | Ann.         | 757 1984 <0.0001      |                           |                               |
Table 3 (continued)

| Stations | Time series | Original Pettitt test | Modified Pettitt test using TFPWcu | Difference of temperature (°C) |
|----------|-------------|-----------------------|------------------------------------|-------------------------------|
|          | Kt Year p-value ρ Δ (mm) ρ^ ρk* ρ^* ρ Kt Year p-value T°C Before T°C after ≠ |                      |                                    |                               |
| Mascara  | Jan. 111    | 0.26 -0.99 0.39 0.43 0.40 0.23 114 No break 0.41 11.4 12.46 1.1 |                                    |                               |
|          | Feb. 119    | 0.44 -1.19 0.14 0.17 0.16 0.05 166 No break 0.08 15.8 13.8 1.2 |                                    |                               |
|          | Mar. 224    | 1993 0.01 -1.91 0.20 0.23 0.22 -0.03 184 0.04 19.1 17.2 1.9 |                                    |                               |
|          | Apr. 268    | 1997 0.00 -1.95 0.39 0.42 0.40 -0.16 174 0.06 22.1 21.1 1.7 |                                    |                               |
|          | May 222     | 1997 0.01 -1.68 0.28 0.31 0.29 0.10 164 0.03 25.9 25.9 27.6 1.7 |                                    |                               |
|          | Jun. 227    | 1985 0.00 -2.80 0.40 0.43 0.41 0.10 144 0.02 20.6 20.6 27.8 1.7 |                                    |                               |
|          | Jul. 224    | 1997 0.01 -1.83 0.07 0.10 0.10 -0.23 164 0.04 24.7 24.7 26.7 1.7 |                                    |                               |
|          | Aug. 208    | 1998 0.01 -1.83 0.07 0.10 0.10 -0.23 180 0.04 19.5 19.5 19.5 1.8 |                                    |                               |
|          | Sep. 101    | No break 0.56 -1.40 0.27 0.30 0.29 -0.09 82 No break 0.78 17.8 17.8 17.8 1.8 |                                    |                               |
|          | Oct. 227    | 1985 0.00 -1.83 0.07 0.10 0.10 -0.23 164 0.04 24.7 24.7 26.7 1.7 |                                    |                               |
|          | Nov. 18     | No break 0.37 -1.83 0.07 0.10 0.10 -0.23 164 0.04 19.5 19.5 19.5 1.8 |                                    |                               |
|          | Dec. 64     | No break 0.37 -1.83 0.07 0.10 0.10 -0.23 164 0.04 24.7 24.7 26.7 1.7 |                                    |                               |
|          | DJF 67      | No break 0.95 -1.19 0.36 0.39 0.37 0.10 180 0.04 19.5 19.5 19.5 1.8 |                                    |                               |
|          | MAM 268     | 1996 0.00 -1.19 0.36 0.39 0.37 0.10 180 0.04 19.5 19.5 19.5 1.8 |                                    |                               |
|          | JJA 292     | 1997 0.00 -1.61 0.42 0.45 0.43 0.02 176 0.04 24.7 24.7 26.7 1.7 |                                    |                               |
|          | SON 193     | 2000 0.00 -0.86 0.22 0.25 0.24 -0.22 150 No break 0.14 18.7 18.7 18.7 0.9 |                                    |                               |
|          | Ann 260     | 1996 0.00 -0.88 0.55 0.59 0.56 -0.12 160 No break 0.10 16.6 16.6 16.6 0.9 |                                    |                               |
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Table 3 (continued)

| Stations | Time series | Original Pettitt test | Modified Pettitt test using TFPWcu | Difference of temperature (°C) |
|----------|-------------|-----------------------|-----------------------------------|-------------------------------|
|          |             | Kt | Year | ρ-value | Δ (mm) | ρ* | ρ* | ρ | Kt | Year | p-value | T°C Before | T°C after | ≠   |
| Djelfa   | Jan.        | 149 | No break | 0.24 | - | - | - | - | - | - | - | - | - | - |
|          | Feb.        | 103 | No break | 0.66 | - | - | - | - | - | - | - | - | - | - |
|          | Mar.        | 195 | 1999 | 0.04 | -1.56 | 0.03 | 0.06 | 0.05 | -0.22 | 198 | No break | 0.06 | 8.4 | 9.6 | 1.2 |
|          | Apr.        | 206 | 1982 | 0.04 | -1.36 | 0.05 | 0.07 | 0.07 | -0.16 | 275 | 1992 | 0.00 | 25.6 | 26.9 | 1.3 |
|          | May         | 169 | No break | 0.13 | -1.40 | 0.25 | 0.28 | 0.27 | -0.12 | 208 | 1985 | 0.05 | 24.5 | 26.0 | 1.4 |
|          | Jun.        | 150 | No break | 0.24 | -1.36 | 0.05 | 0.07 | 0.07 | -0.16 | 275 | 1992 | 0.00 | 25.6 | 26.9 | 1.3 |
|          | Jul.        | 279 | 1992 | 0.00 | -2.05 | 0.13 | 0.15 | 0.15 | -0.09 | 236 | 1998 | 0.02 | 14.4 | 16.2 | 1.9 |
|          | Aug.        | 278 | 1985 | 0.00 | -1.31 | 0.08 | 0.11 | 0.10 | -0.02 | 189 | 1982 | 0.09 | - | - | - |
|          | Sep.        | 170 | No break | 0.13 | -1.23 | 0.14 | 0.17 | 0.16 | -0.24 | 200 | No break | 0.06 | 11.8 | 13.0 | 1.2 |
|          | Oct.        | 233 | 1998 | 0.01 | -1.14 | 0.22 | 0.25 | 0.24 | -0.10 | 238 | 1992 | 0.01 | 24.1 | 25.3 | 1.2 |
|          | Nov.        | 188 | No break | 0.07 | -0.90 | 0.29 | 0.32 | 0.31 | -0.07 | 164 | No break | 0.19 | 14.73 | 15.63 | 0.9 |
|          | Dec.        | 106 | No break | 0.63 | -0.77 | 0.40 | 0.43 | 0.41 | -0.12 | 194 | No break | 0.08 | 14.17 | 14.93 | 0.8 |
|          | DJF         | 142 | No break | 0.41 | -1.23 | 0.14 | 0.17 | 0.16 | -0.24 | 200 | No break | 0.06 | 11.8 | 13.0 | 1.2 |
|          | MAM         | 255 | 1985 | 0.02 | -1.14 | 0.22 | 0.25 | 0.24 | -0.10 | 238 | 1992 | 0.01 | 24.1 | 25.3 | 1.2 |
|          | JJA         | 336 | 1992 | 0.00 | -0.90 | 0.29 | 0.32 | 0.31 | -0.07 | 164 | No break | 0.19 | 14.73 | 15.63 | 0.9 |
|          | SON         | 282 | 1998 | 0.00 | -0.77 | 0.40 | 0.43 | 0.41 | -0.12 | 194 | No break | 0.08 | 14.17 | 14.93 | 0.8 |

Note: Table shows the effect of autocorrelation on the temporal trends of air temperature in Northern Algeria. The modified Pettitt test using TFPWcu method is applied to identify breaks in the time series.
that the p-value is increased beyond the threshold of the significance of 5% for annual (p-value = 0.1).

At Djelfa station, the analysis of temperature time series using original Pettitt test has shown that the annual temperature has change point in the year 1993 with an increase of 0.8°C (p-value = 0.00). After using TFPWcu approach, the results show that the p-value calculated for the annual auto-correlated temperature series is close to the critical value (0.05) that’s why the detected change point has been eliminated.

Overall, the modified test of Pettitt shows an increase of 0.8 to 0.9°C for the annual temperatures observed from the 1980s except for Djelfa and Mascara stations. There are similarities with the results obtained throughout the Mediterranean region as in Morocco (Filahi et al. 2016), in Italy (Bartolini et al. 2012; Caloiero et al. 2017) in Greece (Feidas, 2016) and Spain (Del Río et al. 2011; Ramos et al. 2012).

3.3.2 Change point in seasonal and monthly temperature

Analysis of seasonal and monthly temperature shows that the break detected in the temperature series by original Pettitt test remains significant after the application of the TFPW-cu approach and the break date is often the same or shifted from 1 year to 3 years. While, at Djelfa and Mascara stations, the modified Pettitt test eliminates the change point for all auto-correlated temperature series regardless of the time scale.

In Algiers station, spring, summer and autumn data series have reflected a shift respectively in the year 1986 (+ 0.9°C), 1981 (+1.5°C) and 1982 (+1.1°C) having all p-values less than 0.0001. The winter season has not detected any change point at 5% significance level. After corrected and unbiased trend free prewhitening (TFPWcu) spring, summer and autumn temperature series are tested again for a shift using Pettitt’s test. The results show that, in principle, all KT values are decreased (Table 3), while the p-values are increased relative to original Pettitt’s test but they remain significant (p-values < 0.05). Thus, the change point is affirmed in the same years 1981 and 1982, by the modified Pettitt test using TFPWcu, for respectively summer and autumn temperature series. For the spring temperature data, the date of change point has been brought backwards by 1 year (1985) compared with the original Pettitt’s test.

The analysis of monthly temperatures series using the original Pettitt test shows no break in time series of January, February, Mars, and December, while a breakpoint is observed in April (+0.9°C), May (+1.1°C), June (+0.9°C), July (+1.3°C), August (+1.1°C), September (+0.8°C), October (+1.7°C) and November (+0.8°C) respectively at the date 1980, 1992, 1992, 1981, 1985, 1980, 1985 and 1982. The p-value is generally less than 0.0001 except September (0.02). After using TFPWcu approach, the temperature series of August and October are tested again for a shift using Pettitt’s test. The results showed that KT values are decreased (Table 3) despite p-values remain significant (p-values = 0.00). The date of change point detected by the modified Pettitt test is affirmed in the same years in August, while, the date of change point has been brought backwards by 1 year (1984) compared with the original Pettitt’s test.

At Annaba station, spring, summer and autumn data series have reflected a shift respectively in the year 1980 (+ 0.7°C), 1981 (+1.1°C) and 1980 (+1.1°C) all having p-values less than 0.0001. The winter season has not detected any change point at the significance level of 5%. After corrected and unbiased trend free prewhitening (TFPWcu), spring, summer and autumn temperature series are tested again for a shift using Pettitt’s test. The results show that all KT values are decreased (Table 3), while the p-values are slightly increased relative to the original Pettitt’s test but they remain significant (p-values < 0.05). For the change point, it is confirmed in the same years as that found by the original Pettitt test.

The analysis of monthly temperatures series using original Pettitt test shows no trend in time series of January, February, March, and December, while a breakpoint is observed in April (+0.9°C), May (+1.1°C), June (+0.9°C), July (+1.3°C), August (+1.1°C), September (+0.8°C), October (+1.7°C) and November (+0.8°C) respectively at the date 1980, 1992, 1992, 1981, 1985, 1980, 1985 and 1982. The p-value is generally less than 0.0001 except September (0.02). After using TFPWcu approach, the temperature series of August and October are tested again for a shift using Pettitt’s test. The results showed that KT values are decreased (Table 3) despite p-values remain significant (p-values = 0.00). The date of change point detected by the modified Pettitt test is affirmed in the same years in August, while, the date of change point has been brought backwards by 1 year (1984) compared with the original Pettitt’s test.

Spring, summer and autumn data series of Oran station have reflected a shift respectively in the year 1993 (+ 1.1°C), 1988 (+1.1°C) and 1982 (+0.9°C) with p-values less than 0.0001. The winter season has not detected any change point at 5% significance level. After using TFPWcu approach, it is found that all KT values are decreased (Table 3), while the p-values are increased relative to original Pettitt’s test but they remain significant (p-values < 0.05). The change point is confirmed in the same years by the modified Pettitt test using TFPWcu for both summer and autumn, while the date of change point has been brought backward by two years for spring (1991) compared with the original Pettitt’s test.

The analysis of monthly temperatures series using original Pettitt test shows no trend in January, February, November and December, while a breakpoint is observed in Mars (+1.1°C), April (+1.1°C), May (+1.2°C), June (+1.3°C),
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July (+1.2°C), August (+1.2°C), September (+1.6°C) and October (+1.2°C) respectively at the dates 1986, 1994, 1991, 1995, 1993, 1985, 1982 and 1984. The p-value is generally less than 0.0001 except for March (p-value = 0.02) and September (p-value = 0.03). After using TFPWcu approach, the temperature series of Mars, April, May, June, July and August are tested again for a shift using Pettitt’s test. The results show that KT values are decreased (Table 3) but p-values remain significant (p-values = 0.00) except for March where TFPWcu approach has successfully eliminated the effect of autocorrelation (p-value = 0.29). The date of change point detected by the modified Pettitt test is affirmed in the same years only for May and August, while, it has been brought backwards by 3 years for both April (1991) and June (1992) compared with the original Pettitt’s test and been brought upward by for years in July (1997).

At Constantine station, the data series of spring, summer and autumn have reflected a shift respectively in the year 1993 (+1.2°C), 1981 (+1.5°C) and 1986 (+1.1°C) with p-values less than 0.0001. The winter season has not detected any change point at a significance level of 5%. After using TFPWcu approach, it is found that all KT values are decreased (Table 3), while the p-values are increased relative to original Pettitt’s test but they remain significant (p-values < 0.05). Also, the change point is affirmed in the same years by the modified Pettitt test using TFPWcu.

The analysis of monthly temperatures series using the original Pettitt test shows no trend in January, February, March, September, November and December, while a change point is observed in April (+1.4°C), May (+1.7°C), June (+1.9°C), July (+1.6°C), August (+1.2°C), and October (+2°C) respectively for the following years 1997, 1992, 1991, 1998, 1985 and 1985. After using TFPWcu approach, the temperature series of August and October are tested once again for a shift using Pettitt’s test. The results show that KT values are decreased (Table 3) but p-values remain significant (p-values = 0.00). The date of change point detected by the modified Pettitt test is affirmed during the same years for both months compared with the original Pettitt’s test.

The seasonal data series of spring, summer and autumn at Mascara station have reflected a shift respectively in the year 1996 (+1.3°C), 1997 (+1.6°C) and 2000 (+0.9°C) with p-values of 0.001, 0.002 and 0.04 respectively (Table 3). The winter season has not detected any change point. After corrected and unbiased trend free pre-whitening (TFPWcu), the change point of spring and summer temperature series are checked again using Pettitt’s test. The results show that the p-value is increased beyond the threshold of the significance of 5% for summer temperature (p-value = 0.06). For spring season, the change point date has been brought backwards by 4 years (1992) compared with the original Pettitt’s test.

For monthly temperatures series analysis using original Pettitt test, no break in January, February, September, November and December is detected, while a change point is observed in March (+1.1°C), April (+1.2°C), May (+1.9°C), June (+1.9°C), July (+1.7°C), August (+2.3°C), and October (+1.9°C) respectively for the following years 1988, 1996, 1993, 1997, 1997, 1985 and 1998 with the p-value less than 0.03. The p-value calculated after using TFPWcu approach increased beyond the threshold of the significance of 5% for March (0.41), June (0.06) and August (0.32) series.

Analysis of seasonal time series observed at Djelfa station using original Pettitt test shows a change in spring, summer and autumn respectively in the years 1985 (+1.2°C), 1992 (+1.2°C) and 1998 (+0.9°C) corresponding to p-values of 0.02, 0.0004 and 0.0004 (Table 3). Winter season has not detected any change point. After using TFPWcu approach, the results show that the p-value calculated for autumn auto-correlated temperature series is close to the critical value (0.05) that’s why the detected change point has been eliminated. The analysis of monthly temperatures series using the original Pettitt test shows no break in time series of January, February, May, June, September, November and December, while a change point is observed in March (+1.2°C), April (+1.6°C), July (+1.3°C), August (+1.4°C), and October (+1.9°C) respectively at the years 1999, 1982, 1992, 1985 and 1998. It is noted here that at the monthly scale, all of the temperature series are not auto-correlated.

Overall, the point change observed at the annual scale is the annual temperature trend supposed to be associated with an increase in the temperatures of autumn, spring and summer while no significant change is observed in winter. There are similarities with the results obtained throughout the Mediterranean region. Indeed, Toreti et al. (2010) noted positive trends in Italy between 1970 and 1980 in autumn, spring and summer, while the winter shows no significant trend. An increase in temperatures in spring and summer has also been observed in Morocco (Filali et al. 2016), in Italy (Bartolini et al. 2012; Caloiero et al. 2017) in Greece (Feidas, 2016) and Spain (Del Rio et al. 2011; Ramos et al. 2012). Furthermore, considerable warming during all seasons has been noted in Lebanon (Ramadan et al. 2013) as well as in Tunisia (Dorte 2013).

In whole, the temperature variability observed on a monthly scale is generally manifested during the months from April to October. The month of October has been characterised by a strong temperature increase of about 2°C observed since the mid-1980s for the coast and since the end of the 1990s for the high plateaus. In Greece, Mamara et al. (2016) found an increase in temperatures between May and October, while Del Rio et al. (2011) noted an increase in temperatures in Spain during March, June and August.
3.4 Links between climate indices and temperature

At the annual scale, the Spearman’s correlation coefficient highlights a strong statistically positive correlation between the EA index and all of the annual temperature series (Table 4). The correlation coefficient varies between 0.37 and 0.72 and the stations located to the east of the study area have the highest level of correlation.

Statistically, significant negative correlations not exceeding 0.33 are also observed between the WeMO index and the annual temperatures coastal stations (Algiers, Oran and Annaba), while a coefficient correlation of −0.57 is observed...
at Mascara station. Indeed, Zerroual et al. (2017) highlighted the influence of this mode of circulation on the annual temperatures of northern Algeria during the period 1972–2013. Thus, the present result shows that the WeMO index affected annual temperatures in the Mediterranean area long before 1972.

We also note that no significant correlations between the annual temperatures and the NAO, SOI, AO and MO indices, except in Djelfa station where a significant negative correlation with NAO is observed (R = 0.34). However, this correlation is weaker compared to the EA indices.

For a seasonal time-scale, the relationships analysis between temperatures and the six climatic indices highlights highly significant correlations with the EA index for the different seasons of the year. In the winter, correlation coefficients of 0.43 to 0.54 are observed between the EA index and the temperatures of the six stations in northern Algeria. However, there is no strong correlation with the other circulation modes. In the spring, EA also appears to be the dominant mode of circulation influencing the variability of temperatures during this season over the selected stations of the study area. Spearman’s correlation coefficients vary between 0.31 and 0.60 (Table 4). In summer, the Spearman coefficient highlights strong correlations between the temperatures of the six stations and the EA index characterised by a correlation coefficient of 0.40 to 0.69. Significant negative correlations stand out between the NAO index and the temperatures of Annaba, Constantine and Djelfa that show a correlation coefficient of −0.32, −0.32, −0.39 respectively (Table 4). Significant negative correlations are also recorded between the WeMO index at the Algiers, Mascara and Djelfa stations, which recorded a correlation coefficient of approximately −0.27, −0.44 and −0.36, respectively. However, the EA index remains the most dominant in summer for all stations. In autumn, the Spearman coefficient shows that WeMO is the dominant mode of circulation influencing temperatures over the study area. A significant negative correlations appear between the WeMO index and the temperatures of the six stations of the study area with a correlation coefficient varying from −0.28 to −0.67 (Table 4). A significant positive correlations stand out between the EA index and only coastal stations (0.25 < r < 0.31).

To better understand the variability in temperatures on a monthly scale, it is determined for each month the dominant circulation mode for the entire study area.

In general, for January, significant correlations are observed between temperatures and the EA, AO, NAO and MO indices (Table 4). However, MO seems to be the most dominant mode of circulation in January for all stations with a correlation coefficient varies between −0.38 and −0.63. We also note the strong influence of the EA index at the Annaba and Constantine stations located in the east of the country, with correlation coefficients of 0.48 and 0.41 respectively.

In February, high positive correlations are observed between the EA index and the temperatures of the entire study area. The correlation coefficient varies between 0.62 and 0.84, while no significant correlation is observed with the other climatic indices.

The EA index also appears to be the dominant mode of circulation influencing the temperatures over of the study area in March with a correlation coefficient that ranges between 0.28 and 0.43.

In April, the temperatures values are significantly correlated with the EA, MO and WeMO climatic indices. At the coastal stations of Algiers, Annaba and Oran, EA is the dominant mode of circulation with a correlation coefficient varying between 0.45 and 0.55. In Constantine and Djelfa, the highest correlations are observed with the EA and MO index, while Mascara is strongly correlated with WeMO (r = −0.43).

In May, significant positive correlations are observed between the EA index and all considered stations. The correlation coefficient varies between 0.37 and 0.60. To the east of the study area, we note the presence of significant negative correlations between the WeMO index and the temperatures series of Annaba and Constantine which show respectively an r of −0.28 and −0.26. However, EA remains the most dominant mode of circulation.

In June, low statistically significant positive correlations are observed between the EA index and the temperatures in the coastal zone (0.26<r<0.28). In the highlands, the temperatures data of Mascara and Djelfa show a significant negative correlation with the WeMO index with the values of −0.43 and −0.30, while the Constantine temperatures data are weakly correlated with the EA index (r = 0.27).

In July, the highest correlation coefficients are observed with the EA index at the stations of Oran, Mascara and Djelfa, while the NAO index is the highest correlated in Algiers, Annaba and Constantine stations (Table 4).

In August, the highest correlation coefficients are observed with the EA index at all stations (0.31<r<0.54), except for Annaba station that show a significant negative correlation with NAO index (r = −0.34) (Table 4).

In September, significant correlations are recorded between temperatures series and the EA and WeMO indices at the coastal stations, while on the highlands, the EA index is the most dominant (Table 4) except for Mascara stations where temperatures are strongly correlated with WeMO index (r = −0.55).

In October, the strongest correlations are observed with the WeMO index over the entire study area (10.371 <r <10.521). In November, statistically significant correlations are distinguished between the temperatures of the coastal stations and the indices EA, NAO, WeMO and
MO; however, EA is the dominant mode of circulation (0.34 < r < 0.46). In the highlands, the NAO index is the best correlated with Mascara and Djelfa that showed respectively a correlation coefficient of −0.64 and −0.53. temperatures at Constantine stations are significantly correlated with EA index (r = 0.39).

The temperatures variability in December is influenced by different circulation modes particularly EA, MO and NAO. For the coastal stations, the correlation coefficient varies between 0.57 and 0.65 with the EA index and between −0.45 and −0.48 with the MO index, while the coefficients between temperatures and the NAO index vary between −0.36 and −0.39 (Table 4). Regarding the highlands, in Constantine, the EA index is the most dominant mode of circulation (r = 0.57) followed by the MO index (r = −0.48). In Mascara and Djelfa, it is rather MO which appears as the dominant mode of circulation (0.471 < r < 0.661) followed by NAO (0.471 < r < 10.661) then EA (0.47 < r < 0.59).

According to these outcomes, it is supposed that the EA index affects the variability in temperatures during the different months of the year; however, during winter (December and February) and spring (March, April and May months) that it has the greatest influence. According to NOAA (2018), the positive phase EA is associated with above-average surface temperatures in Europe (Mediterranean) during all the month. So, the positive phase of EA is associated with the increase in temperatures observed over the study area. These results are in line with studies conducted by Ramadan et al. (2012), Ríos-Cornejo et al. (2015), Rust et al. (2015), Toreti et al. (2010) which found strong correlations between annual temperatures and EA.

In December and January, the MO index has a great influence on the temperatures over the study area. Dünkeloh and Jacobbeit (2003) considered that MO is strongly linked in winter to the Arctic (AO) and North Atlantic (NAO) oscillations. In fact, the results clearly showed the influence of these three modes of circulation on the temperatures of the study area in December and January. However, MO is the most dominant mode. These results corroborate with the work of Sušelj and Bergant (2006) who found significant correlations with NAO and MO but they are stronger with MO at the scale of the Mediterranean basin. In Lebanon, Ramadan et al. (2012) also found significant negative correlations with MO in winter, as did Nastos et al. (2011) in Greece. NAO also influences the temperatures during the winter months (December and January) over the entire study area and during the summer months (July and August) for the high plateaus, which coincides with the study of Ramadan et al. (2012) who found negative correlations with NAO in Lebanon in summer, autumn and winter. Negative correlations between temperatures and NAO have also been confirmed for the entire western Mediterranean region by Hurrell (1995) and Trigo et al. (2004). Strong positive phases of NAO tend to be associated with above normal temperatures in the eastern USA and northern Europe and below normal temperatures in Greenland and often in southern Europe and the Middle East (NOAA 2018), which explains the negative correlations between this index and the monthly temperatures in our study area. It is probably for this reason that the temperatures of Northern Algeria do not show a significant trend in winter (Tables 2 and 3). The results obtained show that AO influences the temperatures of northern Algeria in December and January just like NAO but in a moderate way. According to Marshall et al. (2001), NAO can be considered as the regional expression of AO. Wang et al. (2005) have shown that AO influences the variability of winter temperatures in the European, Asian and African continents, while the NAO is more regional and mainly influences North-West Africa. Türkeş and Erlat (2009) have also shown that the positive phase of NAO is associated with lower winter temperatures in Turkey, as did Rust et al. (2015) who found negative correlations with NAO for all of North Africa in January. This confirms the results set out above.

The AO index recorded a downward trend during the period 1950–1970, then an upward trend between 1970 and 1990 and a downward trend during the period 1990–2010, which indicates its multi-decadal variability (Tanaka and Tamura 2016). The negative phase of AO observed between 1990 and 2010 — while temperatures on a global scale have continued to increase — shows that this index does not participate in global warming in recent years (Tanaka and Tamura 2016). This negative phase probably influenced the temperatures in our study area, which did not record significant warming in winter (Tables 2 and 3).

The WeMO index appears to be the dominant mode of circulation in the autumn, its negative phase observed since 1990 (http://www.ub.edu/gc/en/2016/06/08/wemo/) supposed to explain the significant increase in temperatures recorded particularly in October for all the selected stations in the study area (Tables 2 and 3). Indeed, Martín et al. (2012) found that the high temperatures are associated with negative WeMO values, while low temperatures values are correlated with positive WeMO values in the North-West Mediterranean. Ríos-Cornejo et al. (2015) also found negative correlations with the WeMO in April, May, June, September and October in the North and West regions of Spain, with a correlation coefficient varies between −0.36 and −0.41.

ENSO has always been considered responsible for global warming. Some studies have highlighted the influence of ENSO on the average temperatures (Hafez and Robaa 2008; Latif and Keenlyside 2009). However, the results obtained show no significant correlation between the temperatures of northern Algeria and the SOI index for all the stations, which coincides with the work carried out by Zeroual et al.
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(2017) in Algeria, Ramadan et al. (2012) in Lebanon and Rust et al. (2015) on the Euro-Mediterranean region.

4 Conclusion

The objective of this work is the analysis of the variability of mean temperatures in northern Algeria and its relationship with the general atmospheric circulation through six meteorological stations. Recent studies have shown that it is necessary to remove the effect of autocorrelation when analysing trends or breaks in the time series of auto-correlated hydro-climatic data using different approaches to identify trends and acceptably to find their significance.

To do this, a comparison between several statistical tests, using different approaches, is carried out on all temperature series at different time scales. It appears that all these approaches do not systematically eliminate the trend observed in an autocorrelated series. However, for some temperature series, the PW and TFPW-cu preblanking methods have been found to be the most effective in eliminating the autocorrelation effect. However, the elimination of the persistence effect by the LTP test rendered the trends insignificant. Our objective is not to highlight the best suitable test to analyse trends or breaks, but to use more than one approach to identify trends and find their significance in an acceptable way for consideration in planning action and decision making and for coping with global warming.

The coastal region of Algeria is marked by a warming of 0.8 to 0.9°C observed since the 1980s. This warming most often exceeds 1°C on a seasonal scale, particularly in summer, while no significant trend is observed in winter. On the highlands, the warming is most noticeable on a monthly scale between April and October, exceeding 1°C and reaching 2°C in October. These findings show that global warming has also affected the Algerian interior as far as more than 100 km from the Mediterranean Sea.

The interannual variability in temperatures in northern Algeria is influenced by the EA index. This circulation pattern seems to affect every month of the year. Its positive phase is responsible for the temperature increase. On the other hand, the absence of warming during the winter months seems to be associated with the activity of the NAO and the MO, known for their influence, particularly in January, by a drop in temperatures in the Mediterranean region. The WeMO is very active in autumn and seems to explain the observed warming, especially in October.

Finally, this work has shown that the observed large-scale warming affects the different regions of Algeria. The impact of this warming has already been felt in the past through a long period of drought characterised by a significant rainfall deficit strongly affected the availability of water resources for drinking water supply and agriculture in Algeria. However, taking into account the climate projections indicated by the IPCC in 2014, this warming is likely to increase further and could reach 4°C by the end of the century, if no mitigation measures are taken, which will worsen the current situation. For this reason, adaptation measures are needed by carrying out socio-economic and environmental impact studies.

Acknowledgements The authors would like to thank The National Office of meteorology (office National de Météorologie) for providing data series.

Author contribution All authors contributed to the study conception and design. Data collection and analysis were performed by [Taïbi S.] and [Zeroual A.]. The first draft of the manuscript was written by Taïbi S. and all authors discussed the results and contributed to the final manuscript [Taïbi S.] and [Zeroual A.] revised the manuscript.

Availability of data and material Not applicable

Code availability Not applicable

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Conflict of interest The authors declare no competing interests.

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