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Spatial and temporal of variation of meteorological drought and precipitation trend analysis over whole Mauritania

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ABSTRACT

Using monthly precipitation data from 15 stations, well spread over whole Mauritania, and recorded for a long period of time (1919–2016) of almost 100 years, a classification of drought is performed, based on its intensity and duration. For this purpose, the gamma-Standardized Precipitation Index (gamma-SPI) is used to detect drought events (drought frequency, duration and intensity). The Mann-Kendall Test (MK test) is employed for the trend analysis of the precipitation data at all stations and the Thiel-Sen Approach is used to calculate the magnitude of the slopes of the trends. The drought analysis results show that there were severe and extreme drought conditions seen all over the country, especially in 1970s and 1980s. This serious case seems to be emerging in early 2010s. The drought conditions in recent years seems to be more pronounced in the central and southern regions of the country. The trend analysis results reveal that there is no depletion observed in precipitation at the northern region. The total deficit in precipitation is about 100 mm or less during almost 100-year period at the western region. However, the results show that there is pronounced decrease in precipitation at the southern region, reaching to almost a total of 300 mm deficit in nearly 100-year period.

1. Introduction

Droughts can affect geographically larger areas and last significantly longer than other natural hazards. Due to climate change, droughts are expected to occur more frequently and at a greater intensity (Wilby and Dessai, 2010). Many sub-Saharan African economies are widely perceived as being particularly vulnerable to the effects of drought as a result of the lack of water for agriculture and livestock. It is reported by OFDA (Office of Foreign Disaster Assistance) that droughts of 1980s had adversely affected more than 40 million people (Wilhite, 1996) while 1991–1992 droughts had affected 20 million people in the sub-Saharan African region (Wilhite, 2000).

Mauritania is a sub-Saharan's country which is affected by the climate change (Coyah et al., 2015). Beginning with the late 1960s, much of Mauritania had experienced severe drought, which peaked in the mid-1970s and lasted for several decades (Spinage, 2012). The drought had reduced the crop yield and thus increased the food price in the local markets bringing financial burden to the people. The drought effects are still visible in the country where one can see the carcasses of dead livestock scattered throughout the landscape. According to WFP (the World Food Programme) more than a million people in the country did not have enough food and water. Children were among the most affected ones, with more than 110.000 children under five had suffered from acute malnutrition.

Assessment of droughts is thus important in the planning and management of water resources in Mauritania. This would help to combat the drought which, unlike other natural disasters such as earthquakes and floods, creep slowly. Yacoub and Tayfur (2017) carried out the drought assessment for Trarza region, which is very important part of the country with regard to water supply. The main source of groundwater in Mauritania is Trarza Aquifer, which covers about 40,000 km^2 Senegal River is Mauritania's only permanent waterway, which is 1086 km long between Mauritania and Senegal flowing through a valley up to 19 km wide (https://en.wikipedia.org/wiki/Senegal_River). The river is at the same time forms the southern border of Trarza region. It is benefited from the river by the activities of irrigation, navigation, drinking, and hydro power generation. They investigated the drought in Trarza Region by employing three different SPI (Standard Precipitation Index) methods, namely the normal-SPI, the log-SPI, and the gamma-SPI, in addition to the PN (Percent of Normal), CZI (Chinese z-Index), and Deciles methods at different time scales. They employed 40 years of precipitation data measured at three stations in the basin. Their investigation revealed that the gamma-SPI better represents the occurrences of the droughts in Trarza region. Therefore, this index is employed in this study to investigate the drought for the whole country.

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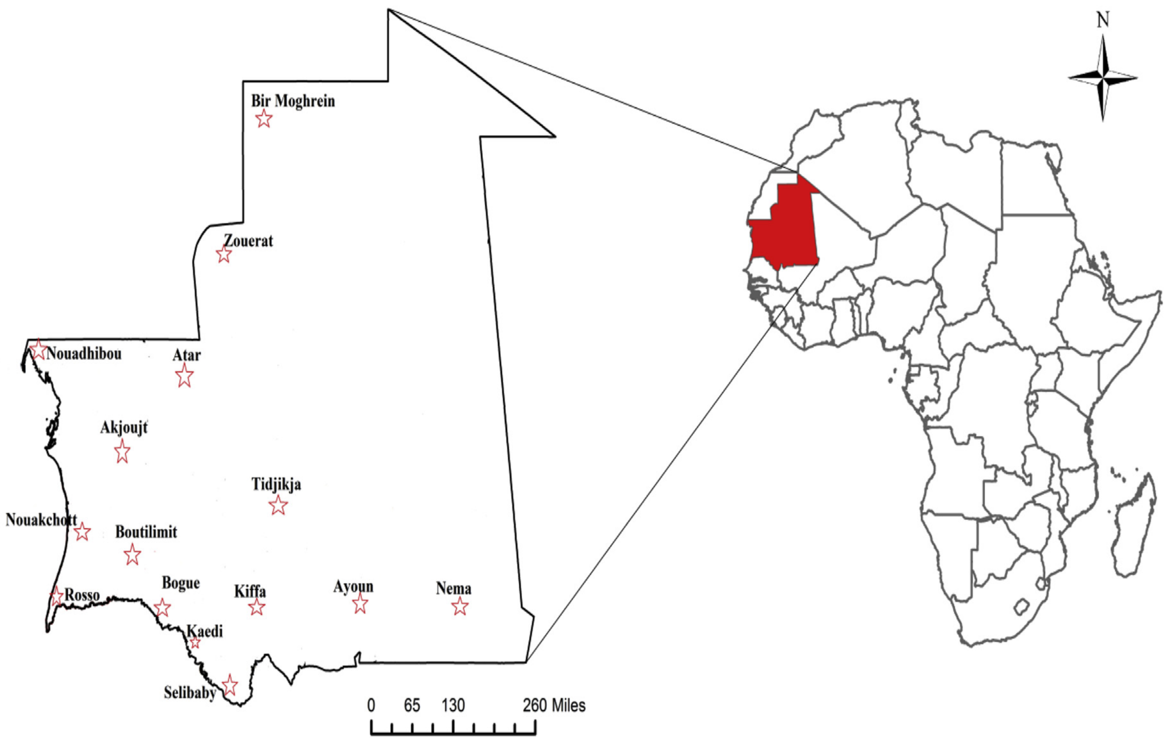

Fig. 1. Map of Mauritania and the locations of the meteorological stations.

The SPI is a common method employed by many researchers to assess the historical drought occurrences for many regions of the world. Keskin et al. (2009) employed the SPI for meteorological drought analysis at nine stations located around the Lakes District in Turkey. Djerbouai and Souag-Gamane (2016) employed the SPI at three time scales (SPI-3, SPI-6 and SPI-12) as the drought quantifying parameter for Algerois Basin in North Algeria. Li et al. (2016), by SPI,using 21 rainfall stations and 7 hydrometric stations in the Luanhe River Basin of northeast China, performed short term prediction of drought severity class. Bazrafshan (2017), gathering the precipitation data from 15 longest record (1951–2014) meteorological stations in Iran, quantified the long-term drought behavior. Gao et al. (2018), using the SPI as the drought indicator, performed drought monitoring (1981–2015) for 29 meteorological stations over Haihe River Basin in China. Bae et al. (2019), investigated drought propogation from meteorological, agricultural to hydrologicalin South Korea. Singh et al. (2019), carried out the spatial and temporal assessment of drought hazard over Krishna River Basin in Indiausing long-term (January 1901–December 2002) precipitation data. Anshuka et al. (2019), carried outa review of SPI studies, therein one can find many more applications and discussions.

Another important issue for the planning and management of water resources in any basin is to observe the trend of precipitation, which is closely related to the monitoring of the meteorological drought. The precipitation trend at meteorological stations for the whole Mauritania is also carried out in this study, using the Mann-Kendall Test (MK test) (Mann, 1945; Kendall, 1975) and the Thiel-Sen Approach (TS approach) (Thiel, 1950; Sen, 1968). The MK test is used for the trend identification while the TS approach is employed to calculate the slopes of the trends. Yacoub and Tayfur (2019), carried out the trend analysis of annual temperature and precipitation time series data of 40 years collected from the three stations to detect the impacts of climate change on water resources in Trarza region, Mauritania, employing the Mann–Kendall, the Spearman's rho, and the Şen trend test (Sen, 2012, 2017; Oztopal and Sen, 2017) for the trend identification and the Pettitt's test to detect the change point of the series while the Theil–Sen approach was used to estimate the magnitude of the slope in the series.

The MK test and the TS approaches are also commonly employed in the literature. Zarei et al. (2016) investigated the trend of changes in drought severity based on the application of Reconnaissance Drought Index (RDI) evaluated from 1980 to 2010 at 16 synoptic stations. They investiagted the trends at different time series of RDI (1, 3, 6 and 12 monthly time series). Zhao et al. (2017), explored the spatial and temporalcharacteristics of temperature and precipitation. Al-Mamoon and Rahman (2017), investigated the spatial and temporal distributions of rainfall in Qatar. They used rainfall data from 29 rain gauges covering period of 1962–2010 and a combination of Mann–Kendall and Spearman's Rho tests to identify trends in the rainfall data. These approaches are also employed in trend analysis of hydrological time series data, such as flow rate (Dabanlı et al. 2016-; Zarei et al., 2016; Foulon et al., 2018).

The objective of this study to carry out the analysis of drought for the whole Mouiritania and to investigate the trend of precipitation at all stations scatterred all over the country. These outcomes would help the authorities to develop drought mitigation measures and combat against this natural disaster. This is very important for a semi-arid developing country, such as Mouiritania that has experienced and endored severe drought conditions and the adverse effects of climate change would make this problem significant in near future. This study would be, to the knowledge of the authors, the first one carrying out drought and trend anlysis for whole Mouiritania. To this end, it employes the gamma-SPI method for the drought analysis, and the MK and TS approach for the trend analysis.

2. Study area and data

2.1. Study area

Mauritania is a Sahelo-Saharan country which is located in the north-west of Africa between 15° and 27°N and 5° and 17° W, and it has a total area of 1,030,000 km^2 (see Fig. 1). Three quarters of the country is covered by the Sahara desert, which characterized by an absence of vegetation cover, water scarcity, and sporadic precipitation. The estimated population as of 2019 is about 4.622.899 and the population density in Mauritania is 5 persons per km^2. The total renewable surface water resources is estimated to be 11 km^3/year and total groundwater resources is estimated to be 3.7 km^3 in Mauritania.

Annual temperature variations in the country are small yet the diurnal variations can be extreme. Most rain falls during the short rainy season (from July to September) and average annual precipitation varies from 600 mm in the far south to less than 100 mm in the northern two-thirds of the country (the Saharan Zone). Rain usually falls as isolated storms dropping large amounts of water in short periods of time and it is possible that there may not be rain in some locations of the Saharan Zone for several years. The climate of the Senegal River Valley contrasts to that of the Saharan zone. The annual rainfall is higher here than in other regions, ranging from 400 to 600 mm, usually falling between May and September. Temperatures are cooler and subject to less annual and diurnal variation than in other regions. The climate is humid and temperate in the Coastal Zone which is 754 km long. Rainfall in this zone is minimal occurring between July and September and temperatures are moderate, varying from 32 to 19 °C.

2.2. Data

Long-term (almost 100 years) monthly-recorded precipitation historical records are used to investigate the precipitation trends and drought in Mauritania. The data used in this study are obtained from the National Office of Meteorology of Mauritania. Fifteen rainfall stations, as shown in Fig. 1, were employed in this study. As seen in Fig. 1, the stations are mostly located in the western and southern parts of the country and there is no station located in the desert part. Table 1 summarizes the latitude, longitude, and altitude information for each station. It also includes information on annual precipitation (min., max., and mean values) and recording periods for each station. As seen in Table 1, the recording periods vary from 1919 to 2015 (96 years) at Kaedi station to 1949–2016 (67 years) at Ayeon station. The longest recording period is 96 years and the shortest recording period is 67 years.

The rainfall regime in Mauritania can be characterized by great variability in both time and space. Fig. 2 graphically presents the annual mean precipitation values for each station. As seen, the mean values significantly vary over the whole country from almost 550 mm at station Selibaby in the south to 26 mm at Nouadhibou station on the west. As shown in Fig. 2, the mean rainfall in the southern part of the country reaches its highest value of 547 mm in Selibaby station and its lowest value of 239 mm in Ayoun station, which is located in a semi-arid environment and exposed to large rainfall variations. In the north western part of Mauritania, the mean rainfall varies from 100 mm in Atar station to 25 mm in Nouadhibou station (see Fig. 2). The northwest of Mauritania is in arid zone and it is characterized by low rainfall. In the western part of the country, the mean rainfall varies from 170 mm in Boutilimit station to 80 mm in Akjoujt station (see Fig. 2). The highest rainfalls recorded in the last century were detected in 1936 (1100 mm in Selibaby and 662.8 mm in Kiffa stations) and in 1947 (611.8 mm in Rosso) as shown in Table 1. The minimum rainfalls recorded were detected in 1970s, 1980s and 1990s in all the stations, except at station of Selibaby where the minimum precipitation recorded was detected in 2013 as 195 mm. Fig. 3 shows the annual average rainfall for whole Mouritania from 1949 to 2015. As seen; until 1970 the average value is 240 mm, then in between 1970 and 1990 (almost 2 decades) this value drops to 140 mm and then back to 200 mm from 1990 to present time.

The rainy season in Mauritania extends over a period of four months, from June to October. Fig. 4 shows the monthly mean rainfall values from 1919 to 2017 for whole Mauritania.

3. Methods

3.1. Gamma-SPI method

SPI can be calculated based on long-term precipitation records for a desired period for any location. The long-term rainfall records is first fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI becomes zero and as such, values above zero indicate wet periods and values below zero indicate dry periods (McKee et al., 1993). The SPI is simple, flexible and effective for drought monitoring at different timescales (Hayes et al., 1999).

Use of different types of statistical distributions can affect SPI values as the SPI is based on fitting of a distribution to precipitation series. Some of commonly applied distributions include gamma (Edwards, 1997), Pearson Type III (Guttman, 1999), log-normal, extreme value, and exponential distributions (Lloyd-Hughes and Saunders, 2002; Madsen et al., 1998; Thom, 1966; Todorovic and Woolhiser, 1976).

Yacoub and Tayfur (2017) employed the normal-SPI, the log-SPI, and the gamma-SPI, PN, CZI, and Deciles methods at different time scales for assessing drought at Trarza region of Mauritania and found out that the gamma-SPI better captures the occurrences of the historical droughts. Therefore, it is employed in this study. The probability density function of the gamma distribution is expressed as (Thom, 1958; Sonmez et al., 2005; Angelidis et al., 2012);

$$f(x, \alpha, \beta) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{x/\beta} \quad for\ \ x, \alpha, \beta > 0 \tag{1}$$

where α and β are the shape and scale parameters, respectively. x is the rainfall amount and $\Gamma(\alpha)$ is the Gamma function defined by the integral (Gasiorek and Musiał, 2015)of the following form (Equ. 2), as follows;

Table 1
Annual rainfall characteristics.

Station	Latitude	Longitude	Altitude (m)	Time period	Maximum (mm) – (year)	Minimum (mm)- (year)	Mean rainfall (mm)
Kaedi	16.15	−13.5	21.00	1919–2015	762.0 - (1936)	108.3-(1991)	339.04
Ayoun	16.65	−9.60	228.92	1949–2016	498.7- (1958)	89.60 - (1980)	239.49
Akjoujit	19.74	−14.38	118.38	1933–2015	225.5 - (2003)	0.00 - (1994)	84.40
Atar	20.50	−13.05	220.91	1922–2015	244.1 - (1927)	7.10–(1978)	99.29
Bir Moghrein	25.23	−11.57	367.98	1942–2016	235.5 - (2003)	0.00 - (1978)	49.70
Boughe	16.59	−14.25	16.91	1920–2016	587,0 - (1927)	82.0 - (1983)	269.89
Boutilimit	17.54	−14.69	48.59	1921–2016	405.0- (1955)	25.3 - (1987)	171.13
Kiffa	16.62	−11.40	118.66	1922–2015	662.8 - (1932)	100.3- (1982)	304.91
Nouadhibou	20.94	−17.03	12.00	1922–2015	104.4 - (1938)	0.00 - (1977)	25.61
Nema	16.61	−7.25	264.57	1923–2016	506.2 - (1954)	42.9- (1983)	250.76
Nouakchott	18.07	−15.95	4.44	1931–2016	267.0 - (1956)	2.70 - (1977)	110.79
Selibaby	15.15	−12.18	61.98	1933–2016	1100- (1936)	195.1- (2013)	547.42
Tidjikja	18.55	−11.43	392.59	1922–2015	471.0- (1966)	28.7 - (1996)	128.89
Zouerat	22.73	−12.47	356.35	1938–2016	206.1- (1969)	3.40 - (1970)	59.42
Rosso	16.51	−15.8	6.26	1934–2016	611.8-(1947)	41.1 - (1983)	256.41

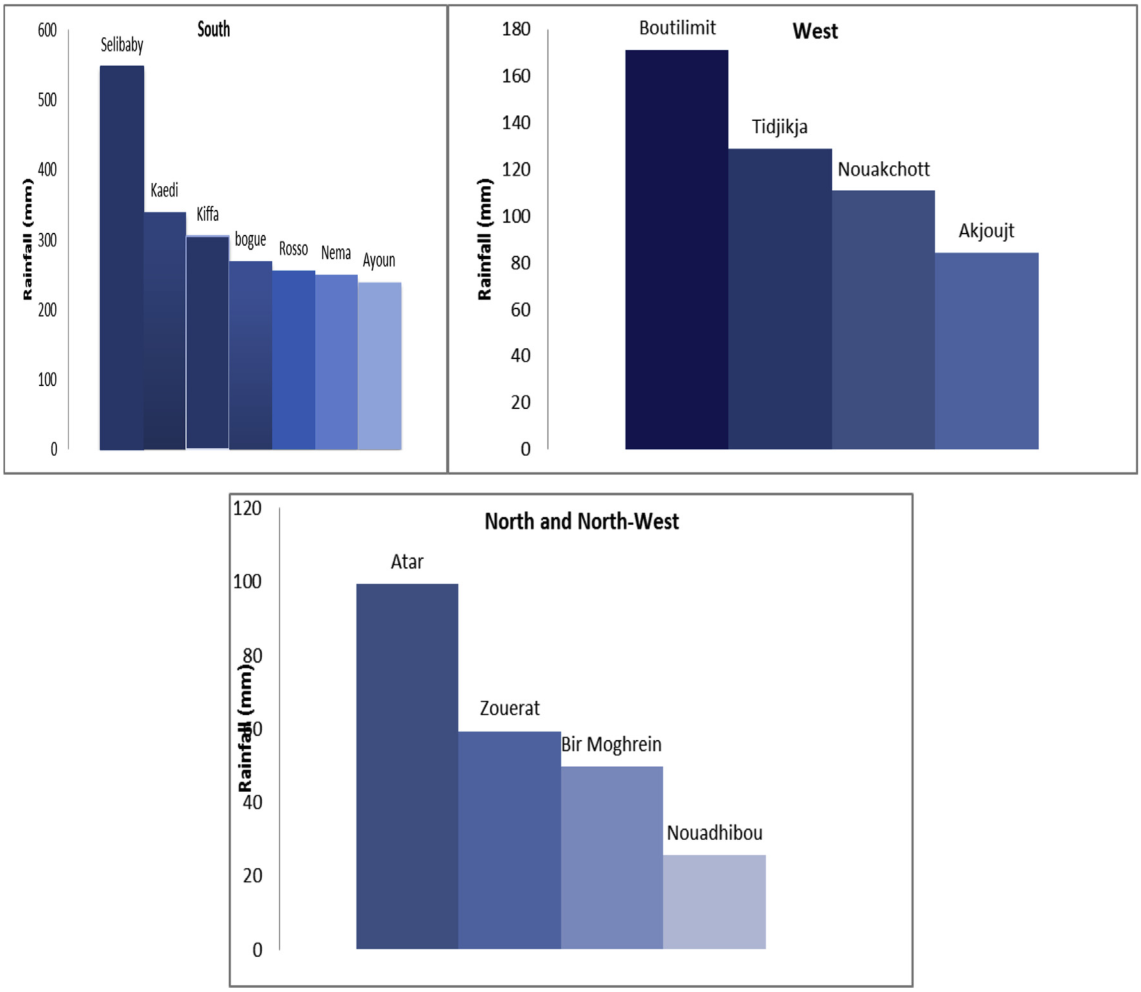

Fig. 2. Mean rainfall for the stations.

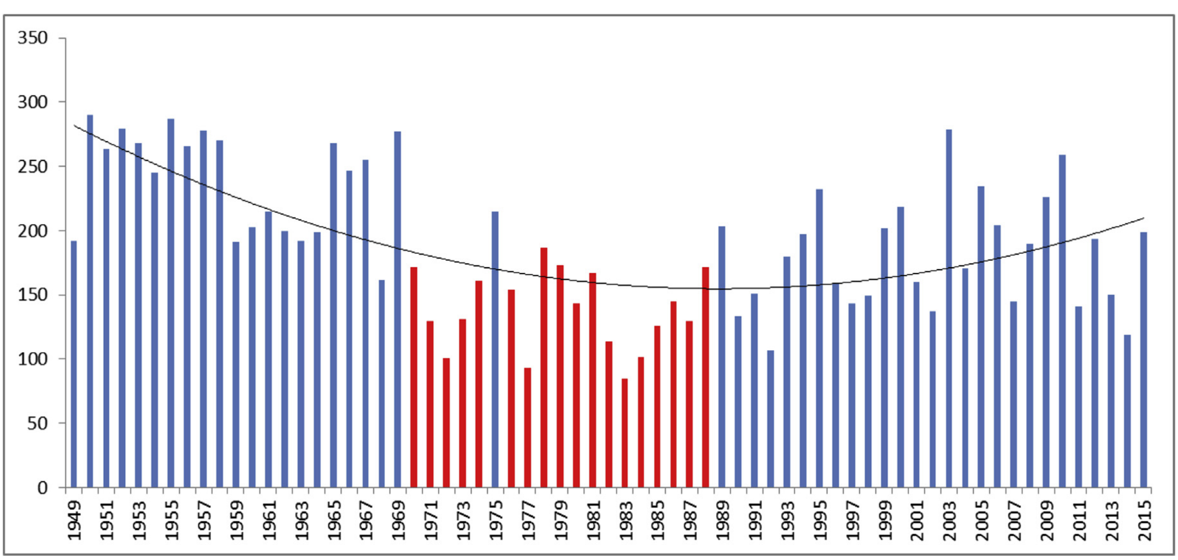

Fig. 3. Annual average rainfall (mm) for whole Mauritania from 1949 to 2015.

$$\Gamma(x) = \lim_{n\to\infty} \prod_{v=0}^{n-1} \frac{n! n^{y-1}}{y+v} \equiv \int_0^{\infty} y^{\alpha-1} e^{-y} dy \tag{2}$$

The maximum likelihood method is used to estimate the optimal values of the parameters α and β by Eqs (3) and (4) (Thom, 1958; Barua et al., 2010) as follows;

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3}$$

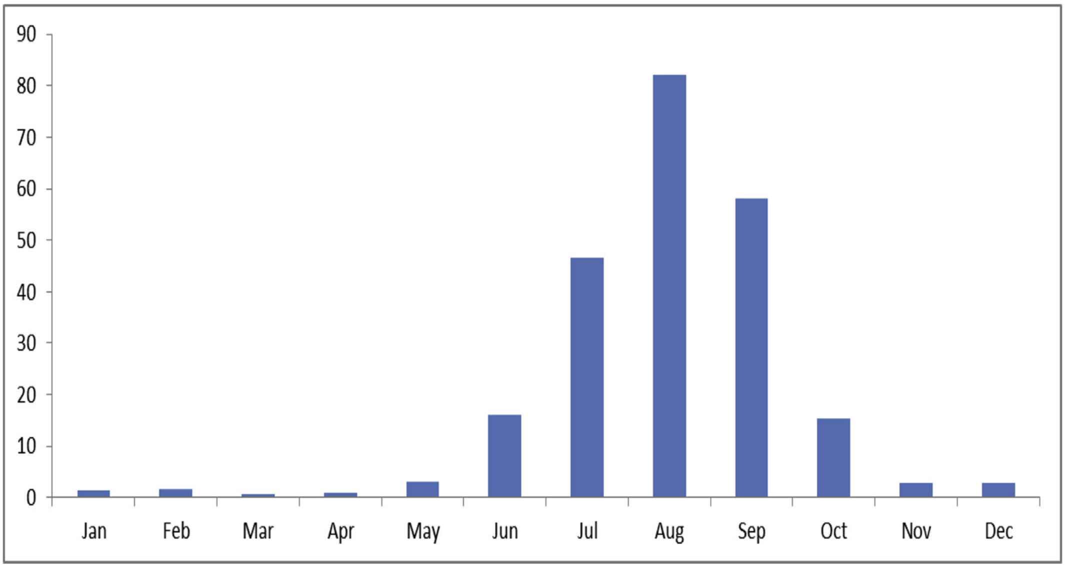

Fig. 4. Monthly mean rainfall (mm) from 1919 to 2017 for whole Mauritania.

Table 2
SPI drought classification (McKee et al., 1993; Lloyd-Hughes and Saunders, 2002; Barua et al., 2010).

SPI value(z-score)	Category
−**1.00 to -1.49**	Moderate drought
−**1.5 to -1.99**	Severe drought
−**2 or less**	Extreme drought

$$\hat{\beta} = \frac{\overline{x}}{\hat{\alpha}} \tag{4}$$

where

$$A = \ln(\overline{x}) - \frac{\sum ln(x)}{n} \tag{5}$$

where n is the number of observations. The resulting parameters $\hat{\alpha}$ and $\hat{\beta}$ are then used in Equ (6) to obtain the cumulative probability for nonzero rainfalls (Barua et al., 2010):

$$F(x) = \int_0^x f(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1}e^{-x/\hat{\beta}}dx \tag{6}$$

Equ.(6) can also be expressed as defined by Equ (7) (Barua et al., 2010):

$$F(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1}e^{-t}dx \tag{7}$$

where $t = x/\beta\hat{}$. Since the gamma function is undefined for $x = 0$ and precipitation may contain zeros, the cumulative probability of zero and non-zero is computed by Equ (8) as (Lloyd-Hughes and Saunders, 2002):

$$H(x) = q + (1 - q)F(x) \tag{8}$$

where, q is the probability of zero rainfall and it is estimated by m/n, when m is the number of zeros in a precipitation time series. The cumulative probability, H(x), is then transformed to the standard standardized normal distribution so that the SPI mean (z) and the variance become 0 and 1, respectively. The cumulative probability can be converted into the standard normal random variable, called z (Abramowitz and Stegun, 1965) as follows:

$$SPI = z = -\left(k - \frac{c_0 + c_1k + c_2k^2}{1 + d_1k + d_2k^2 + d_3k^3}\right) \quad \text{when } k = \sqrt{ln\left\{\frac{1}{[H(x)]^2}\right\}} \quad \text{for } 0 < H(x) \le 0.5 \tag{9}$$

$$SPI = z = +\left(k - \frac{c_0 + c_1k + c_2k^2}{1 + d_1k + d_2k^2 + d_3k^3}\right) \quad \text{when } k = \sqrt{ln\left\{\frac{1}{[1 - H(x)]^2}\right\}} \quad \text{for } 0.5 < H(x) \le 1 \tag{10}$$

where, $c_0 = 2.515517, c_1 = 0.802853$, $c_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, andd_3 = 0.001308$. The SPI threshold range that is used to define severity of the drought is presented in Table 2.

3.2. Mann-Kendall Test (MK test)

The MK test (Mann, 1945; Kendall, 1975) is used for the trend identification for a given time series data. The main purpose of MK test is to statistically investigate if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward trend means that the variable consistently increases in time. Similarly, a monotonic downward trend means that the variable consistently decreases in time. In this test, the null hypothesis H_0 and the alternative hypothesis $H_{a,}$ respectively, refer to non-existence and existence of trend. The MK test is calculated as (Mann, 1945; Kendall, 1975; Guclu, 2018):

$$sgn(x_i - x_j) = \begin{cases} 1; & \text{IF } x_j > x_i \\ 0; & \text{IF } x_j = xi \\ -1; & \text{IF } x_j < xi \end{cases} \tag{11}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_i - x_j) \tag{12}$$

where; x_i and x_j respectively indicate the data values at times i and j, and n is the length of the data set. If S value is positive it means the variable consistently increases through time, while negative value S indicates a decreasing trend. Equation (13) is used in cases where n is larger than 0.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18} \tag{13}$$

where,p indicates the number of tied groups, t_i is the number of data points in the pth group. When the variance of time series is provided in

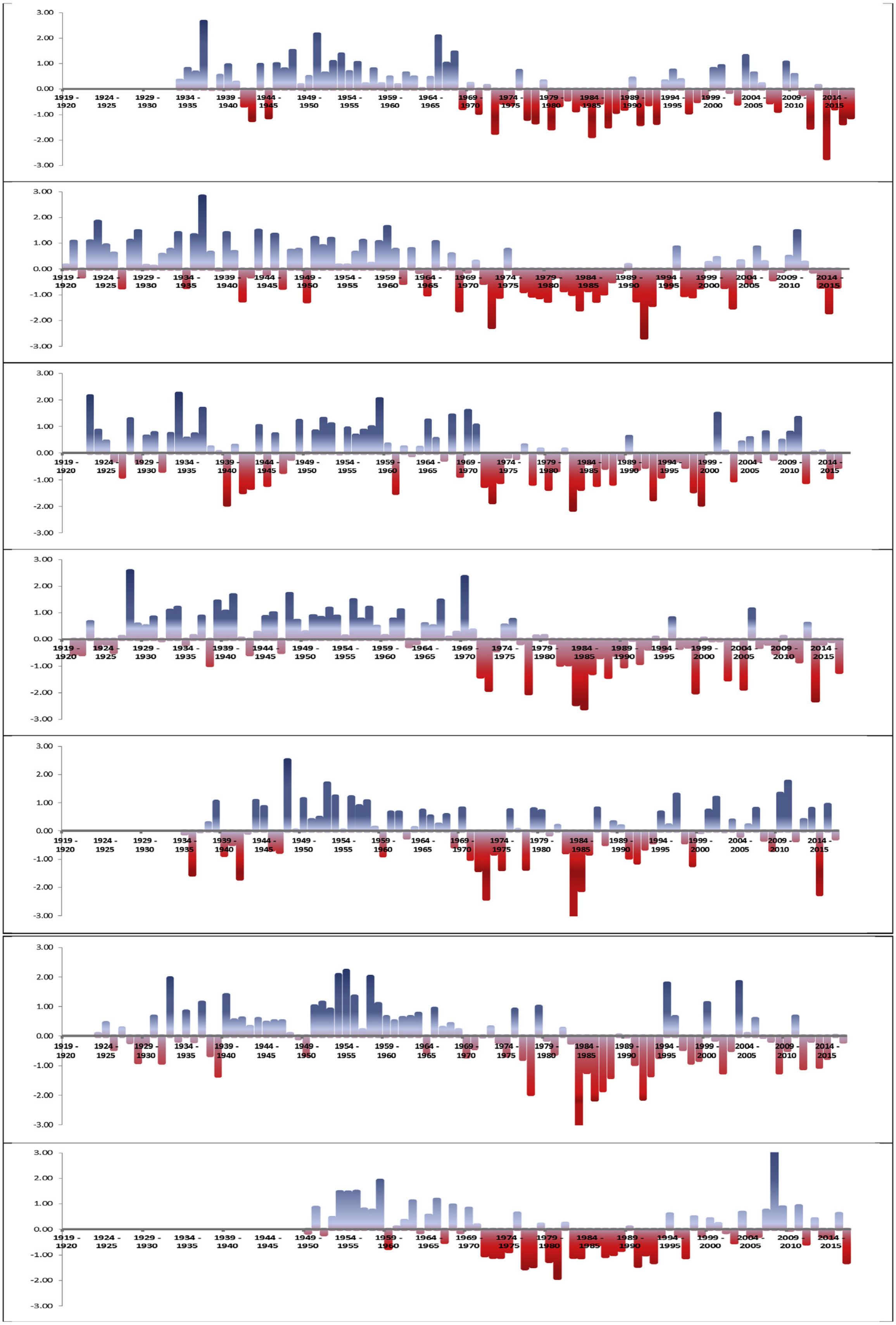

Fig. 5. Annual gamma-SPI results in southern region of Mauritania at stations: from top the bottom, respectively; Selibaby, Kaedi, Kiffa, Bougue, Ross, Nema and Ayoun.

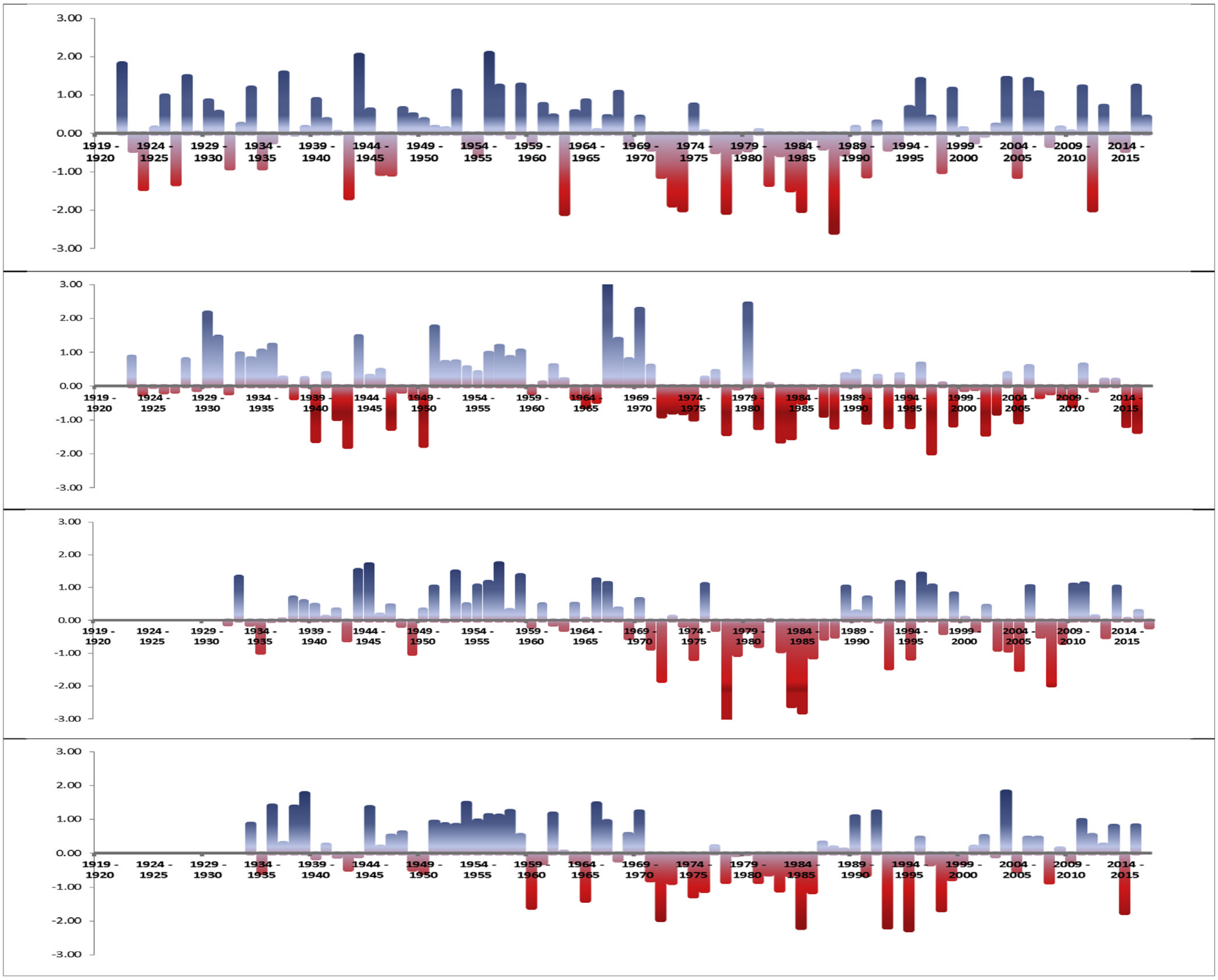

Fig. 6. Annual gamma-SPI results in west region of Mauritania in the stations:in order from top to bottom respectively; Boutilimit, Tidjikja, Nouakchott, and Akjoujit.

Eq (13), the standard Z can be expressed by Eq. (14) as follows (Mann, 1945; Kendall, 1975; Mohorji et al., 2017):

$$Z=\begin{cases}\frac{S-1}{\sqrt{Var(S)}} & \text{IF } S>0\\ 0; & \text{IF } S=0\\ \frac{S+1}{\sqrt{Var(S)}}; & \text{IF } S<0\end{cases} \quad (14)$$

The calculated Z value is compared to the Standard Normal Distribution Table with two tailed confidence levels. When $|Z| > Z_{1-\alpha/2}$ then H_o is rejected and H_a is accepted, meaning that there is a significant trend. Otherwise, H_0 is accepted and H_a is rejected, meaning that the trend is not statistically significant. 5% significant level which refers to $Z_{1-\alpha/2} = 1.96$ (from the Standard Normal Distribution Table) is used for the MK method in this study.

3.3. Thiel-Sen (TS) approach

TS method (Thiel, 1950; Sen, 1968) is used to calculate the magnitude of the slope of the trend obtained by the MK test. The TS approach can be expressed by Eq. (15) (Sen, 1968; Shadmani et al., 2012):

$$\beta = \text{Median}\left(\frac{X_j - X_i}{j-i}\right) \quad (15)$$

where; X_i and X_j indicate the sequential data values of the time series in years i and j. The calculated β is the estimated magnitude of the trend slope.

4. Drought and trend analysis results

Employing the gamma-SPI, drought analysis is carried out for the annual precipitation time series data at 15 stations. Figs. 5–7 and Tables 3, 5 and 7 present the drought analysis results. The trend analysis results are summarized in Tables 4, 6 and 8.

4.1. Southern region (Stations located along the southern region)

Fig. 5 shows the drought results for seven stations (Selibaby, Kaedi, Kiffa, Bougue, Ross, Nema, and Ayoun) located in the southern part of the country (see Fig. 1). As seen, all the stations experienced some sort of drought in early 1940s, 1970s, much of the 1980s, early and late 1990s and early 2010s. Severe drought and extreme drought years are specifically summarized in Table 3. As seen in Fig. 5 and Table 3, the moderate drought conditions have often been seen since 1969. The severe and extreme drought conditions, on the other hand, were intensified in 1970s and 1980s. It seems from the recent data that these drought conditions reemerged in early 2010s. As summarized in Table 3, it is interesting to see that no extreme drought conditions were

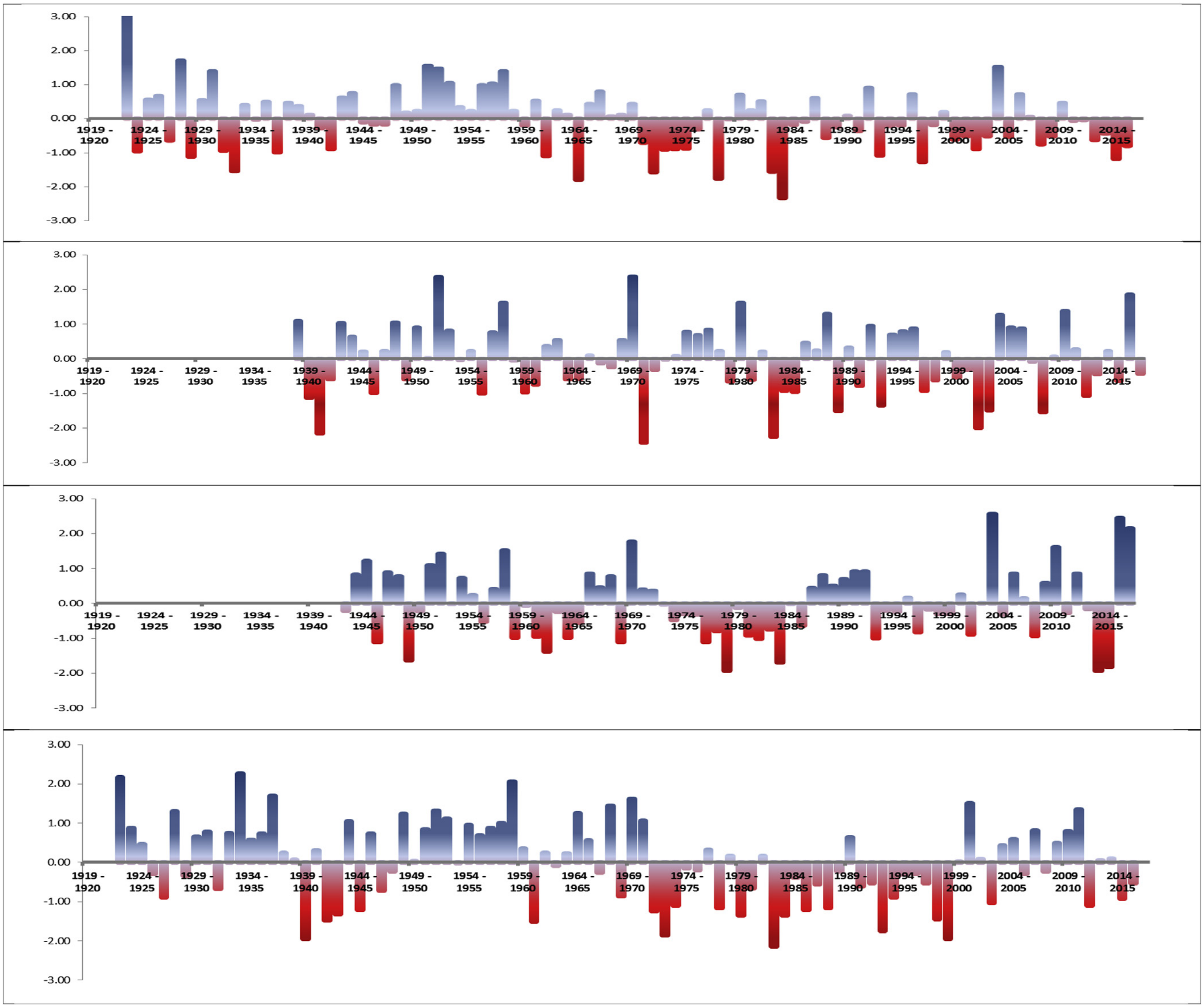

Fig. 7. Annual gamma-SPI results in north and north-west regions of Mauritania in the stations: in order from top to bottom, respectively; Atar, Zouerat, Bir Moghrein and Nouadhibou.

observed in stations of Ayoun and Kiffa which are neighboring stations. Similarly, Selibaby and Kaedi neighboring stations showed fewer severe and extreme conditions. The last column in Table 3 contains more comments on the drought results.

The trend analysis results revealed that there is significant decrease in precipitation time series at all the stations, particularly in Kaedi, Boughe, Kiffa, Nema and Selibaby. Table 4 presents the rate of the decrease in these stations. The precipitation decrease in these stations are computed as at a rate of 1.855, 1.389, 1.150, 0.978 and 2.854 mm per year, respectively (see Table 4). As such, the decrease is more pronounced at stations Kaedi and Selibaby. The decrease, on the other hand, is softer at Rosso and Ayoun stations (see Table 4).

4.2. Western region (Stations located along the western region)

Fig. 6 shows the drought results for four stations (from top to bottom, respectively; Boutilimit, Tidjikja, Nouakchott, and Akjoujit) located in the western part of the country (see Fig. 1). As seen, all the stations experienced some sort of drought in early 1940s, late 1950s, late 1960s, much of 1970s and 1980s, mid 1990s, early 2000s and 2010s. Severe drought and extreme drought years are specifically summarized in Table 5. As seen in Fig. 6 and Table 5, the moderate drought conditions have often been seen since 1970s. The severe and extreme drought conditions, on the other hand, were intensified in 1970s and 1980s. As summarized in Table 5, these stations often experienced severe and extreme drought conditions, especially station Boutilimit, followed by Akjoujit station that are further inside the inland. Table 5 contains more comments on the drought conditions observed at these stations. The trend analysis results revealed that the decrease in the precipitation is less than 1 mm per year for all the stations in this region (Table 6).

4.3. North and north-west region stations

Fig. 7 shows the drought results for four stations (from top to bottom, respectively; Atar, Zouerat, Bir Moghrein and Nouadhibou) located in the north and north-west part of the country (see Fig. 1). As seen, all the stations experienced some sort of drought in early, mid, and late periods of almost each decade. Nouadhibou station seems to have experienced more severe drought conditions than the others. The elevation of this station is about 12 m but others are at 220 m (Atar), 360 m (Zouerat) and 370 m (Bir Moghrein). The behavior of station

Table 3
Severe and extreme drought years for the southern stations.

Station	Severe drought years	Extreme drought years	Comment
Nema	1937–1938 1976–1977 1985–1986 1990–1991	1982–1983 1991–1992	From 1982 to 1986 for about 5 years in row experienced severe and extreme drought conditions.
Ayoun	1978–1979	–	Although it is close to Nema Station, it did not experience the same drought conditions.
Kiffa	1937–1938 1972–1973 1990–1991 1997–1998	–	It is located in the middle section, showing somewhat similar behavior as the nearby Ayoun Station.
Selibaby	1972–1973 1983–1984	2011–2012	It is interesting to see that it experienced the extreme drought 7 years ago.
Kaedi	1972–1973	1990–1991	Although it experienced moderate droughts, the number of extreme and severe drought cases are few.
Bougue	1972–1973 1976–1977 1997–1998 2002–2003	1982–1984 2011–2012	Although the dates show some variance, it experienced the same number of severe and extreme droughts as Nema Station.
Rosso	1934–1935 1939–1940 1973–1974 1976–1977	1972–1973 1982–1984 2011–2012	This station located at the south-west tip of the country. It experienced prolonged extreme drought conditions in the first half of 1970s and 1980s.

Table 4
Trend analysis results for the southern stations.

Stations	First year	Last year	Number of years	test Z	β
Kaedi	1919	2015	97	−4.20	−1.855
Ayoun	1949	2016	68	−1.34	−0.797
Boughe	1920	2016	97	−4.10	−1.389
Kiffa	1922	2015	94	−2.28	−1.150
Nema	1923	2016	94	−3.00	−0.978
Selibaby	1933	2016	84	−3.70	−2.854
Rosso	1934	2016	83	−0.46	−0.237

Table 5
Severe and extreme drought years for the western stations.

Station	Severe drought years	Extreme drought years	Comment
Tidjikja	1970–1971 1990–1991 2003–2004 2005–2006	1976–1977 1982–1984	This station did not experience severe or extreme drought conditions before 1970.
Akjoujit	1958–1959 1962–1963 1971–1972 1995–1996 2013–2014	1982–1983 1990–1991 1992–1993	This station from 1996 to 2013, for about two decades, did not experience severe or extreme drought conditions.
Nouakchott	1970–1971 1990–1991 2003–2004 2005–2006	1976–1977 1982–1984	This station did not experience severe or extreme drought conditions before 1970 and after 2006.
Boutilimit	1921–1922 1924–1925 1940–1941 1979–1980 1982–1983	1940–1941 1960–1961 1971–1973 1982–1983 1984–1985 2009–2010	This is the station that, almost at every decade, experienced severe and/or extreme drought conditions. This is the station that had experienced the extreme drought conditions often.

Nouadhibou is similar to the other stations located at the west and south regions that have low elevations as well. This may imply that the stations at low elevations may experience more drought conditions. We may see this result in Table 7summarizing specifically the severe and extreme drought years for the stations located in the north and north-west region of Mauritania. The last column in Table 7 summarizes more commentary information on the drought conditions of the stations. The trend analysis results revealed that the decrease in the precipitation is insignificant for all these stations (Table 8).

Table 6
Trend analysis results for the western stations.

Station	First year	Last Year	Number of years	test Z	β
Akjoujit	1933	2015	83	−1.93	−0.510
Boutilimit	1921	2016	96	−0.94	−0.296
Nouakchott	1931	2016	86	−1.94	−0.500
Tidjikja	1922	2015	94	−3.04	−0.714

Table 7
Severe and extreme drought years for the western stations.

Station	Severe drought years	Extreme drought years	Comment
Atar	1930–1931 1962–1963 1969–1970 1975–1976 1980–1981	1981–1982	This station did not experience many extreme drought conditions. In the last century, the only extreme drought condition was observed in 1981–1982. It is interesting that since 1982 this station has not experienced severe or extreme drought.
Zouerat	1938–1939 1987–1988 1991–1992 2000–2002 2006–2007	1939–1940 1969–1970 1981–1982	This station from 1940 to 1969, for about three decades, did not experience severe or extreme drought conditions.
Bir Moghrein	1947–1948 1959–1960 1976–1977 1981–1982 2012–2013	–	This station did not experience any extreme drought conditions. Also, severe drought conditions have been observed once in two decades.
Nouadhibou	1942–1943 1959–1960 1969–1970 1971–1972 1975–1976 1978–1979 1982–1983 1984–1985 2001–2002 2010–2011	1937–1938 1970–1971 1981–1982 1991–1992 1996–1998	This is the station that, almost at every decade, experienced severe and/or extreme drought conditions. This is the station that had experienced the extreme drought conditions often especially in 1970s, 1980s and 1990s.

Table 8
Trend analysis results for the western stations.

Time series	First year	Last Year	Number of years	test Z	β
Atar	1922	2015	94	−2.72	−0.590
Bir-Mogherien	1942	2016	75	−0.04	−0.007
Nouadhibou	1922	2015	94	−0.01	0.000
Zouerat	1938	2016	79	−0.50	−0.082

5. Discussion of results

The results summarized in Tables 3–8 and Figs. 5–7 reveal that Mauritania has experienced moderate drought conditions all over the country every decade since 1920s. This has intensified for the last 50 years. The severe and extreme drought conditions had often been seen in the western and southern region stations, especially in 1970s, 1980s and 1990s. In the northern region, the station Noudhibou had experienced extreme and severe conditions, behaving like the stations in the

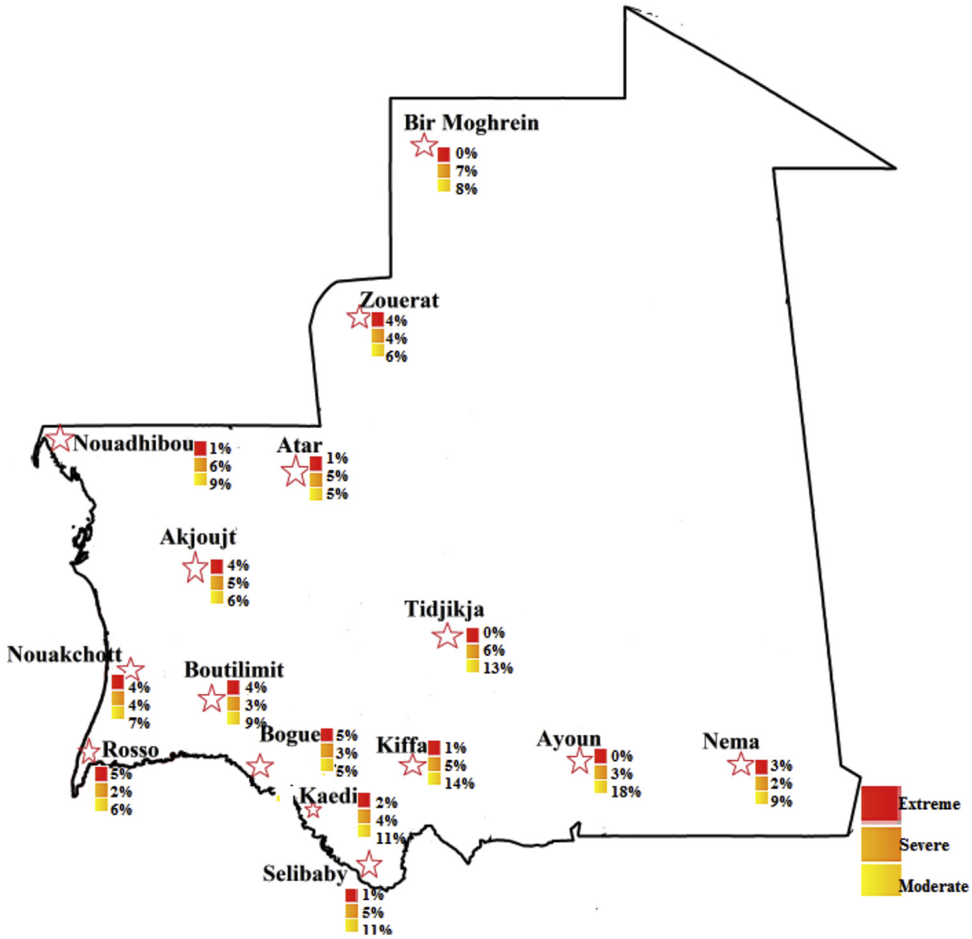

Fig. 8. Frequency of droughts.

Table 9
Total number of droughts for whole the stations.

Drought type	1948–1970	1971–1991	1992–2012	2013–2016
Moderate	9	51	27	9
Severe	7	23	13	4
Extreme	2	20	3	3
Total	**18**	**94**	**43**	**16**

south and west.

Fig. 8 shows the frequency of droughts observed at all stations. The frequency is computed as the ratio of the total number of droughts in a category to the whole number of observations. For example; the ratio of the total number of moderate droughts cases to the total number of observations would result in the observed frequency (percentage) of the moderate droughts. As seen, the southern stations, namely Ayoun, Kiffa, Selibaby and Kaedi, had experienced severe and extreme drought conditions more frequently. The frequency of the extreme drought conditions at these stations is more than 15% and reaching 21% at

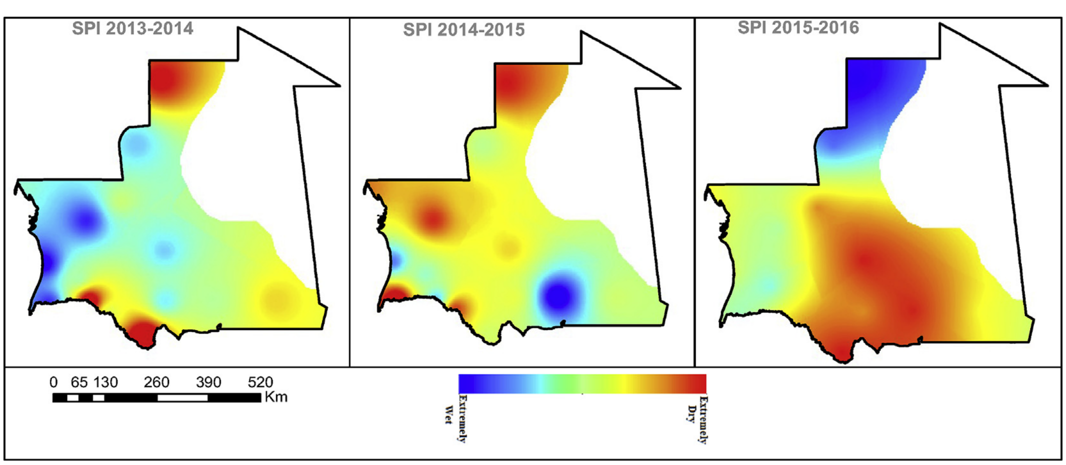

Fig. 9. Drought maps, from left to right, respectively; for recent years of 2013,2014 and 2015.

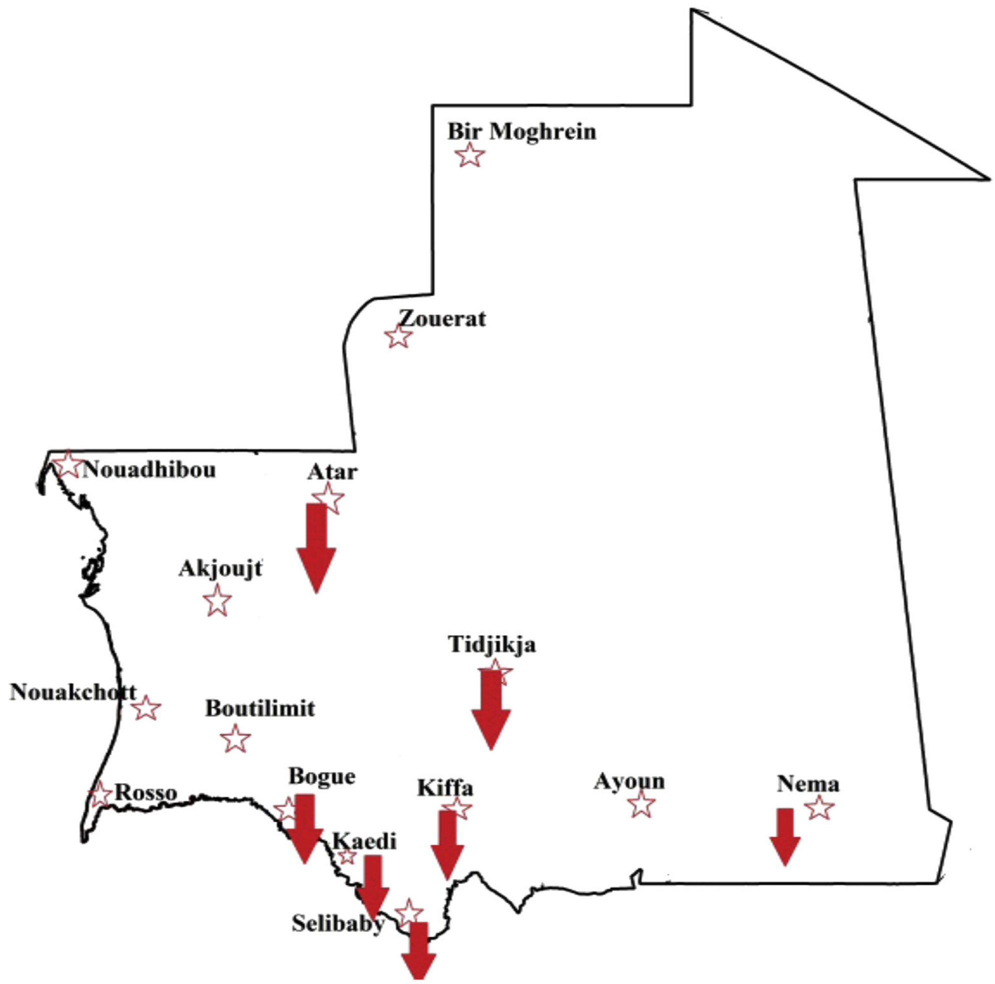

Fig. 10. Representation of precipitation trend decrease at stations.

Ayoun station. In a similar fashion, Tidjikja station, which is in the central part, experienced frequent drought conditions (19%), same as the station of Nouadhibou (16%) located on the north-west tip of the country. It is interesting to see that, when one adds all the frequency of moderate, severe and extreme droughts at each station; the lowest frequency is observed in Atar (11%), followed by Rosso and Bogue with 13%, The highest frequency is observed at station Ayoun, followed by Kiffa, both of which are located in the southern region. The average frequency for the southern stations is 17%, followed by the western stations (16%) and northern stations (15%) (see Fig. 8).

Table 9 summarizes the predicted number of years of drought for all the stations. As summarized in Table 9, the frequency of droughts is visibly increased from 1971 to 1991 (20 years), decreased in the following two decades (1992–2012) then it had started increasing since 2010s. The average number of droughts for 1948–1970 period is less than 1 per year. This ratio is almost 5 for the period 1971–1991, followed by 2 per year from 1992 to 2012. The ratio for the recent years is back to 5 per year, which may indicate prolonged and frequent drought years ahead, similar to the period of 1970–1990.

Fig. 9 shows the drought maps for the country for the years 2013–2014, 2014–2015 and 2015–2016. As seen, while the western region was wet in 2013, it is getting moderately wet in recent years. The northern region was dry in 2013–2015, yet it is quite wet in 2016. What is interesting to see that the central and southern region is getting drier, receiving less precipitation.

Fig. 10 summarizes pronounced decrease in precipitation at the stations. As seen, southern ones, especially Bogue, Kaedi, Selibaby, Kiffa and Nema, is experiencing decreasing trend in precipitation. Tidjikja at the central part and Atar at the northern region are also experiencing decreasing trend in precipitation. These results are compatible with drought map given for 2015 in Fig. 9, indicating that the central and southern regions may experience more drought conditions presently and in near future.

6. Conclusions

This study, employing the gamma-SPI, carried out drought analysis for whole Mauritania using long period of (67–96 years) precipitation data. Also, trend analysis of the same precipitation data was carried out by employing the MK and TS approaches. The following conclusions are drawn from this study.

1. The frequency of droughts is visibly increased from 1971 to 1991. Although it showed a decrease in the following two decades, it has started picking up again in the current decade. This is maybe a worry for the future. From 1948 to 1970, there had been seen a total of 18 drought cases at all the stations. This number reached to 94 in between 1971 and 1991 and then decreased to 43 in 1992–1012. However, in the last 4 years (2012–2016), a total of 16 drought cases had been observed at all the stations. This is an alarming outcome, indicating that over the next decades, Mauritania may experience the severe drought conditions of 1970 and 1980s that had affected millions of people.
2. The decreasing trend in precipitation is more pronounced at the central and southern regions, where there are more cities. The most populated city is Nouakchott (660,000 people), followed by

Nouadhibou (72,000 people) where they located on the western part. On the other hand there are 11 cities located in the central and southern regions. The decrease in precipitation can cause serious water shortage problems for these cities.
3. The southern stations which are the main agricultural production areas of Mauritania, (Ayoun, Kiffa, Selibaby and Kaedi), had experienced severe and extreme drought conditions more frequently.
4. The drought behavior of Nouadhibou station seems similar to the ones located at the western and southern regions. This station had experienced more severe and extreme droughts than the ones located on the northern region.
5. Among the western stations, Boutilimit had often experienced severe and extreme drought conditions, followed by Akjouijit station.
6. The trend analysis results reveal that the decrease in precipitation is less than 100 mm in almost a century at the western stations while no decrease can generally be observed at the stations on the north. However, the decrease can reach to 300 mm in nearly a 100-year period at the southern stations, conforming to the incoming drought years for the southern region of the country.

The recording periods at 15 stations vary from 96 years to 67 years. Since these periods can be considered long; for a detailed trend analysis, it would be also possible to carry out the trend analysis partially using the innovative multi-duration trend analysis (Mohorji et al., 2017; Guclu, 2018) and/or partial trend identification by the change-point successive averaging methodology (Sen, 2019).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafrearsci.2020.103761.

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