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Analysis of Temporal Trends and Variability of Rainfall Series in Northeastern Libya

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Abstract The main objective of this study was to analyze rainfall time series from a stretchered region in northeastern Libya focusing on the Mediterranean effective rainy period (Oct. - Mar.). The Mann-Kendall test (non-parametric) was used for detecting potential trends and assessing their significance. For this purpose, rainfall data recorded at four meteorological stations in northeastern Libya (Cyrenaica) are used over the period 1945 – 2010. All data were tested beforehand for homogeneity in order to be confident that the measurements were taken with the same instruments and at the same locations. Autocorrelation analysis was performed to meet the data randomness requirement for the Mann-Kendall test. For the wet period, statistically significant (at 95% confidence level) increasing and decreasing trends were found at the Ajdabiya and Shahat stations, respectively. Non-significant decreases were detected at the Benina Airport and Derna stations. A brief comparison has been made between the outcomes of this study and a previous relevant study showed an opposite direction of precipitation trend between northeastern and northwestern regions.

Keywords Rainfall; Homogeneity; Autocorrelation; Trend analysis; Mann-Kendall test; Sen's slope

1. Introduction

The investigation of climate changes can be achieved through the application of the very common process, which is known as Trend Detection, particularly in the fields of Climatology and Hydrology. One of the most important components of the hydrological cycle is precipitation, which has been considered along with temperature as the prime sectors to be directly affected by the climate change. Therefore, trend detection in precipitation time series is crucial for local and regional water resources management. Libya is situated in the southern Mediterranean where more than 95% of the country is arid to semi-arid climate. The coastal part of the country comprises two climatically distinctive western and eastern regions. In these regions, meteorological and hydrological data exhibit remarkable variability in both temporal and spatial domains.

The Mediterranean region is considered as a climate change hot-spot in the future due to the global warming in particular, as it has already undergone large climate change in the past [1-2]. In the Mediterranean region, several researchers have analyzed precipitation time series for the detection of possible trends. The southern areas of Italy have experienced significant negative trends in annual precipitation more than any other region in Italy [3-5].

Regarding the precipitation trends in the Southeastern Mediterranean region where major part of north Libya i.e. the northeastern region (the focus of this study) is influenced largely by the same climate, many studies have been conducted with clear different and contradicting results. Steinberger and Gazit-Yaari [6] analyzed precipitation data over the coastal line of Israel for the period 1960-1990 and detected a positive trend in southern stations whereas northern stations and mountainous stations of the coast revealed negative trends. In

Jordan and for a longer time-period (1953-2002), Dahamsheh and Aksoy [7] did not detect any trends using annual precipitations data from thirteen stations.

Zhang et al. [8] studied a wider region, the Middle East, and found that trends in the precipitation data are both weak and not significant. Törnros, [9] combined Jordanian and Israelis precipitation series from 37 stations for the period (1961-1990) as a one-region analysis, which afterwards tested, for possible trends. Non-significant negative precipitation trends were detected and when the time series period was lengthened to (1950-1997), the analysis results showed stronger negative precipitation trends.

Shaltout et al. [10] analyzed climate data from stations distributed along the Egyptian Mediterranean Coast and discussed their response to global changes. The results displayed clear significant negative trends in precipitation. Climatic data was investigated from the Sinai Peninsula, Egypt over the period 1970-2014 aiming to detect probable trends. Results have revealed significant decreasing trends in annual precipitation and it was argued that such negative trends have been the cause for the prolonged severe drought period in that region.

On the other hand, in the western side of the Mediterranean basin many attempts have been made in the same context of precipitation trend analysis with some interesting conclusions. The variability and trends of long term total annual and monthly precipitation data series (1900-2010) from large Mediterranean land region was investigated by Philandras et al [11]. The outcomes of the study showed positive trends although small and not statistically significant in southern and western parts of the Mediterranean i.e. Southern Italy, North Africa and Western Iberia Peninsula.

A detailed regional analysis on precipitation trends including Tunisia, Algeria, and Morocco over the period from 1970 to 2013 [12], pointed to a surprise increase in the precipitation since the early 2000s in Algeria and Tunisia and from 2008 with respect to Morocco. Those results, however contradicted the outputs of several climate models, which have predicted less precipitation and more aridity in the region.

Locally, relevant reviews of trends in previous studies on climatologic trend analysis are mostly seasonal (three months) and/or annual. El-Tantawi [13] identified positive and negative trends in annual and seasonal precipitation at different stations in Libya. Ageena [14] used climatic data from several meteorological and synoptic stations across Libya to detect temporal fluctuations and patterns of various climatic parameters such as temperature, rainfall, evapotranspiration, and relative humidity. Concerning the annual rainfall, the results of trend analysis have showed positive trends in the first half of study period and negative trends in the second half. The results have also detected with respect to the seasonal analysis positive trends in winter season and negative in spring season with no noticeable significant trends in other seasons. Negative trends of total annual rainfall were observed at most weather stations studied by El Fadli [15].

Very recently, Hafi [16] studied total annual rainfall variability and trend direction in northwestern Libya using data series with time length of more than 60 years from 11 stations. Surprising and interesting results have emerged from the trend detection analysis using the Mann-Kendall test. Except for one station (Tripoli Airport) which experienced a significant decline (negative trend) in its total annual rainfall, all the remaining stations showed positive trends although not all were statistically significant. Those results have been consistent with the findings of Philandras et al. [11] and Nouaceur and Murarescu [12] who pointed to prints of precipitation increase in the western Mediterranean region, particularly during the late two decades of the 20th century and the beginning of the current century.

The above studies however, have only focused on either the annual or the seasonal rainfall variability with no mention to the Mediterranean effective rainy period, which starts in October and ends in March as it was demonstrated by Xoplaki et al. [17] and confirmed afterwards, by Mehta and Yang [18]. The main purpose of this study is firstly, to carry out a precipitation trend detection in the northeastern region as a follow up to the study of Hafi [16] but with focus on six-month Mediterranean rainy period (October - March) and hence to gain a wider view of the possible precipitation variability over the whole north of Libya. Secondly, to briefly compare the outcomes of this study with the results of Hafi [16] in order to demonstrate if the direction of precipitation trend in the northeastern region is similar or opposite to that in the northwestern region given the fact that the two regions are noticeably remote from each other.

Data and Methods

Study Area and Data Sources

Meteorological data recorded by the Libyan National Meteorological Center (LNMC) at some meteorological stations placed at the part of Libya goes back to the middle of the last century or earlier. Taking into consideration the consistency of the duration length, geographical location, and reliability of data, observation length of sixty-five years is good enough for a valid mean statistic. Accordingly, this study focused on detecting rainfalls trends and their magnitudes at four stations in the northeast of Libya (Cyrenaica) as shown in Figure 1. Accordingly, the total monthly- rainfalls recorded at Ajdabiya, Benina Airport (Benghazi), Shahat, and Derna were chosen (Table 1).

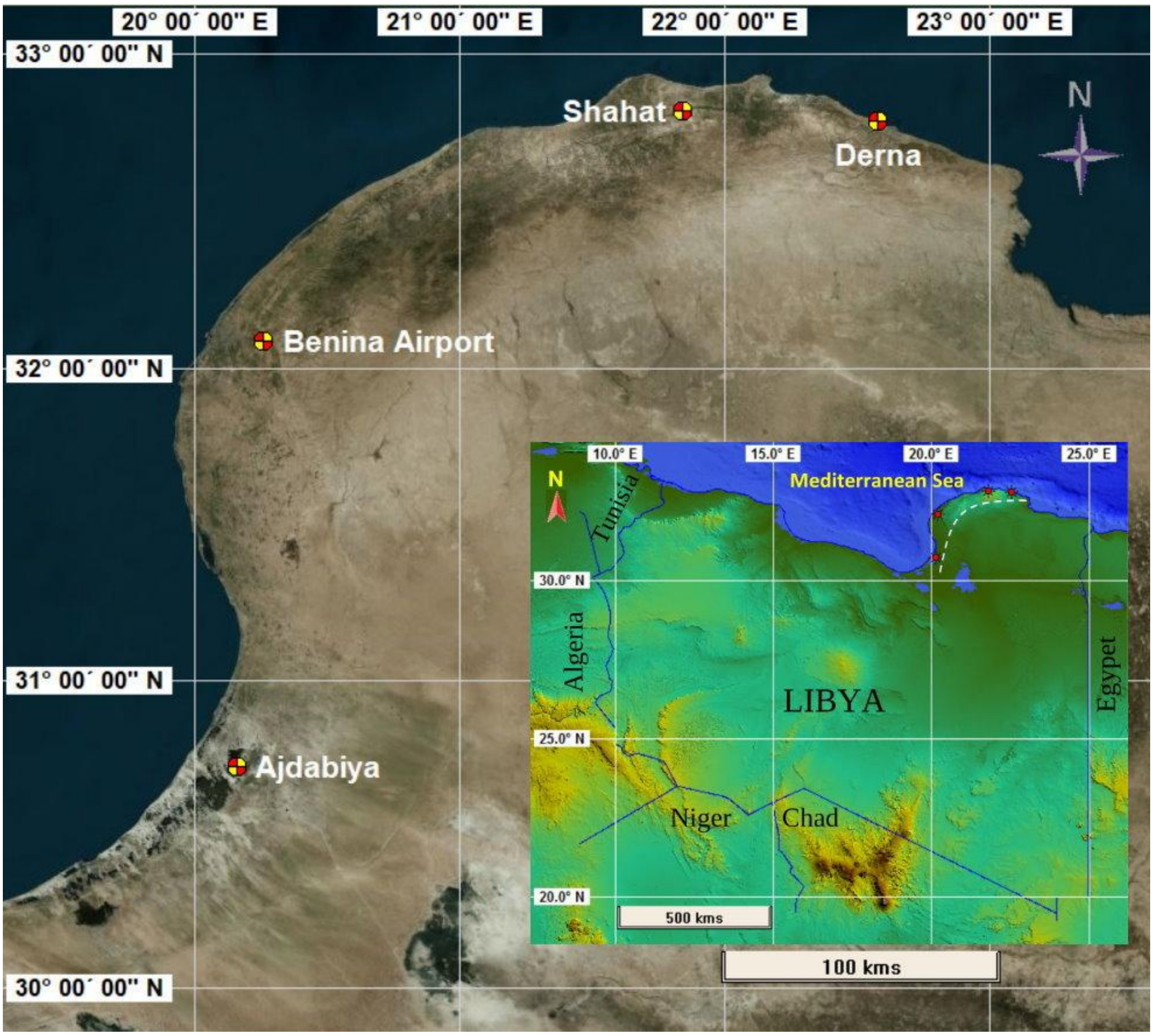

Figure 1: Locations of the meteorological stations under study

Table 1: Meteorological stations under study

Station	Time span (year)	Latitude (N)	Longitude (E)	Elevation a.m.s.l. (m)	Period of observation
Ajdabiya	64	30° 43.0′	20° 10.0′	-5.0	1946-2009
Benina Airport	65	32° 05.0′	20° 16.0′	122.0	1945-2009
Shahat	65	32° 49.0′	21° 51.0′	581.0	1945-2010
Derna	65	32° 47.0′	22° 35.0′	11.0	1945-2009

Elevation source: NASA SRTM 1 arc-sec resolution.

Method of Data Analysis

The rainfall data for each month of the objected rainy period (October – March) for every year were added to each other. The resultant value of the addition is therefore; represent the total rainfall amount in (mm) during the rainy period at that year. Each yearly rainfall amount (total) was treated as single data set. In order to perform trend analysis on each time series individually, using XLSTAT® version 2016 software, the following steps were conducted:

- Exploratory data analysis.
- Significance of randomness in data sets.
- Homogeneity tests.
- Mann–Kendall (MK) test.
- Magnitude of the trends.
- Percentage change in rainfall trends.

Exploratory Data Analysis

Exploratory data analysis often gives preliminary indications of the suitability of a data set for non-parametric statistical trend analysis. The common statistical parameters of rainfall time series for all meteorological stations under study were calculated. These included minimum (R_m), maximum (R_x), mean (R_e), standard deviation (*SD*), coefficient of skewness (C_s), coefficient of kurtosis (C_k), and coefficient of variation (C_v).

Homogeneity Test

Accurate and reliable trend analysis requires homogenous data that are free of non-climatic factors such as relocation of station and change of instrument, which could influence the outcome of climatic and hydrological studies [19]. To locate the year where a break is likely to take place, various homogenization methods have been proposed in the literature. In this study, all rainfall series were subjected to three different homogeneity tests for detecting series inhomogeneity with the null hypothesis (H_0) of homogeneous data at 1% significance level. The applied tests were the Pettitt test [20], the standard normal homogeneity test (SNHT) [21], and the Buishand range test [22].

Test of Randomness

The autocorrelation function is used commonly for checking randomness and independence in data sets [23]. The Mann-Kendall test is applied to uncorrelated data because the presence of positive or negative autocorrelation could increase or decrease the probability of detecting significant trends [24-26]. For that reason, the autocorrelation test is an essential step for checking randomness and periodicity in time. For the current study, the autocorrelation coefficients of all series were computed for lag values $L = 1$ to k, where k is the maximum lag (i.e. $k = n/3$), and n is the length of the series.

Mann-Kendall Test (MK Test)

The complicating features of meteorological data make classical parametric methods such as regression, analysis of covariance, and traditional time series approaches difficult or impossible to implement appropriately. Consequently, such data often are analyzed with non-parametric methods [27-28].

Mann [29] presented a non-parametric test for randomness against time, which constitutes a particular application of Kendall's test that commonly is known as the 'Mann–Kendall test' [30]. One benefit of the MK test is that the data need not conform to any particular distribution because it compares the relative magnitudes of sample data rather than the data values themselves [31]. The null hypothesis (H_o) associated with this test assumes that the dataset under evaluation is free from trends. The alternative hypothesis, H_a, is that the data follow a monotonic trend [32]. The trend analysis framework that was adopted in this study is outlined in Fig. 2.

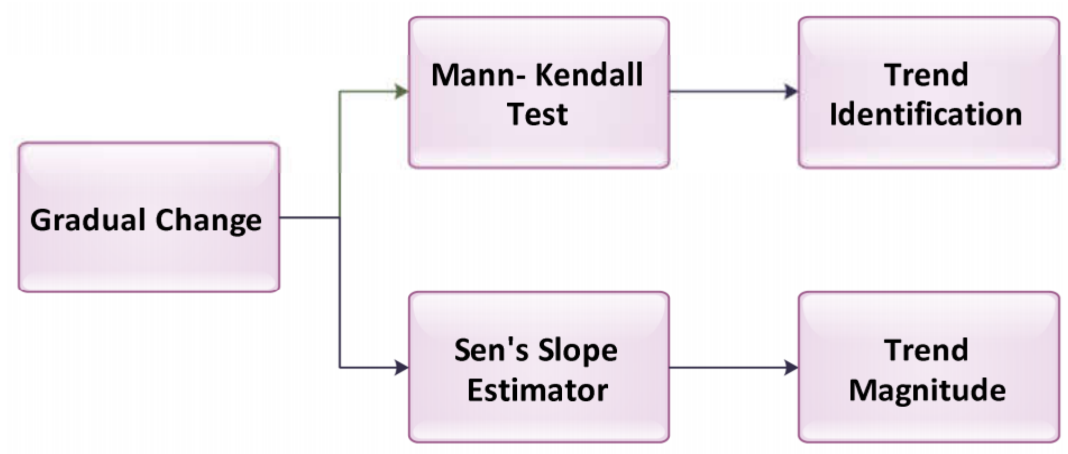

Figure 2: Trend analysis framework

The data values (only one value per time) are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 *(e.g.,* no trend). If a datum value from a later time period is larger than a value from an earlier time period, S is incremented by 1. On the other hand, if the datum value from a later time period is smaller than a data sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(y_j - y_i\right) \quad (1)$$

where y_i is the value of the i^{th} observation of the rainfall variable, n is the length of the time series, and the *sign* of the difference (sgn), is defined by:

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} 1 \;\; if \left(y_j - y_i\right) > 0 \\ 0 \;\; if \left(y_j - y_i\right) = 0 \\ -1 \;\; if \left(y_j - y_i\right) < 0 \end{cases} \quad (2)$$

The standardized Mann-Kendall test statistic, Z, is estimated as follows:

$$Z_{MK} = \begin{cases} \dfrac{\text{S-1}}{\sqrt{\text{VAR(S)}}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{\text{S+1}}{\sqrt{\text{VAR(S)}}} & if\ S < 0 \end{cases} \quad (3)$$

where VAR(S) is the variance of Mann-Kendall statistic, S. The standardized MK test statistic (Z_{MK}) follows the standard normal distribution with a mean of zero and a standard deviation of one. A positive value of Z_{MK} indicates an *increasing* trend (upward trend) while a negative Z_{MK} value signifies a *decreasing* trend (downward trend). When the p-value is less than the level of significance (a), the null hypothesis (H_o) is rejected and a statistically significant trend exists in the rainfall time series. If the p-value is greater than (a), the null hypothesis (H_o) is accepted. Failing to reject the null hypothesis does not mean that there is no trend. Rather, it is a statement that the available evidence is not sufficient to conclude that there is a trend [28].

Estimating the Magnitude of the Trend

If a linear trend is present in a time series, the magnitude of the trend can be estimated with Sen's slope method, developed by Theil [33] and Sen [3]4. This means that the linear model, *f (t)*, can be described as:

$$f(t) = Qt + B \quad (4)$$

where Q is the slope and B is the intercept of the trend line.
To get the slope estimate, Q, in Eqn. 4, above, the slopes of all data value pairs are calculated as:

$$Q_i = \frac{y_j - y_i}{x_j - x_i} \qquad i = 1, 2, \ldots\ldots N, \; j > i, \quad (5)$$

where, x_i is the time of the i^{th} observation, and y_i is the value of the i^{th} observation of the rainfall variable. The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is:

$$Q_{med} = \begin{cases} Q_{\frac{N+1}{2}} & if \quad N \; is \; odd \\ \frac{1}{2}\left(Q_{\frac{N+1}{2}} + Q_{\frac{N+2}{2}}\right) & if \quad N \; is \; even \end{cases} \quad (6)$$

A positive value of Q_{med} indicates an 'upward trend' (increasing trend over time), and a negative value of Q_{med} gives a 'downward trend' or decreasing trend in the time series.

Change Magnitude as Percentage of Mean

The percentage change over the length of the observation period was estimated by following the assumption of a linear trend, estimating the magnitude by Theil-Sen's median slope, and assessing the mean over the period.

$$\%\; change = \left\{ \frac{median \text{ slope x } period \;\; lenght}{mean} \right\} \text{x } 100 \quad (7)$$

Preliminary Analysis

The maximum six-month total rainfall of 824.20 mm was recorded at Shahat in 1989, and the minimum of 30.90 mm was recorded at Derna in 1951, see (Tab. 2). The season mean rainfall of the study region was moderately low and ranged from 140.13 mm, south of N 31° Parallel in the coastal lowland part of the study area (Ajdabiya), to 512.21 mm close to N 33° Parallel in the mountainous area north of Al Jabel Al Akhdar (Shahat). In general, the standard deviation was high, ranging from 54.63 mm at Ajdabiya to 119.67 mm at Shahat.

Table 2: Summary of six-month total rainfall statistics

Station	R_m (mm)	R_x (mm)	R_e (mm)	SD (mm)	C_s	C_k	C_v
Ajdabiya	42.10	293.50	140.13	54.63	0.649	0.286	0.387
Benina Airport	110.20	482.70	250.20	76.17	0.725	0.491	0.302
Shahat	272.00	824.20	512.21	119.67	0.493	0.200	0.232
Derna	30.90	457.70	243.39	81.47	0.312	0.397	0.332

The skewness varied between 0.725 and 0.312, predominantly positive, indicating that six-month total rainfall during the period of observation was asymmetric and was to the right of the mean for all stations. The coefficient of kurtosis varied between 0.200 and 0.491 for all stations. To analyze the spatial variability of rainfall, the coefficient of variation (C_V) is a statistical measure of how the individual data points vary about the mean value. The C_V varied between 38.70% south of N 31° Parallel (Ajdabiya station) and 23.2% in the mountainous area north of Al Jabel Al Akhdar (Shahat station). The greater the value of C_V, the greater the variability, and vice versa. Preliminary analysis of the rainfall showed that the zones of usually moderate rainfall were the zones of smaller variability and the zones of less rainfall were the zones of greater variability.

Analysis of Randomness

In the examination of the autocorrelograms (Fig. 3), rainfall time series for both seasons have two positive significant autocorrelation coefficients (0.382 and 0.302) at lag 3 (Ajdabiya station) and one negative (-0.279) at lag 6 (Shahat station). One might suggest that these time series are not completely random and the MK test cannot be employed. However, no other significant autocorrelation coefficients at other lags exceeded the 95% confidence limit (plotted as horizontal dotted lines on the autocorrelograms). Clear randomness at all stations met the independently identical distribution criteria, and the Mann–Kendall test can be applied with certainty to all series.

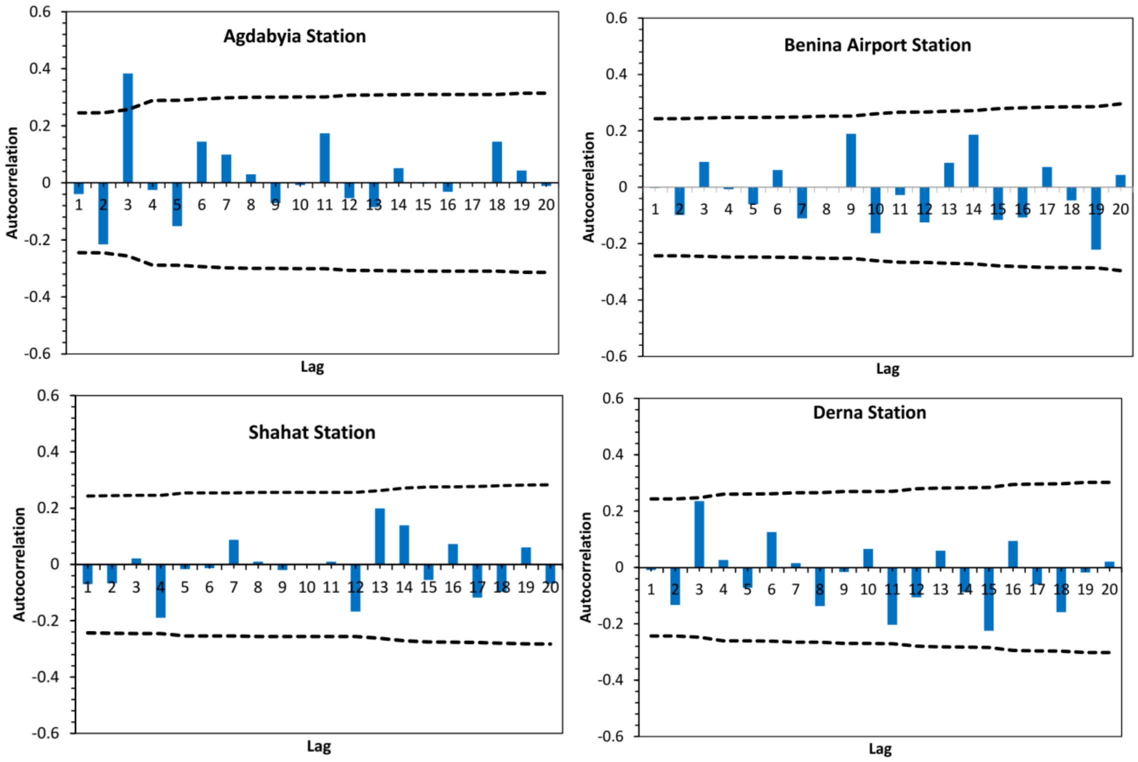

Figure 3: Autocorrelation plots for six-month total rainfall; upper and lower dashed lines are 95% confidence bands

Analysis of Homogeneity Tests

Results of the homogeneity tests at 1% significance level showed that the null hypothesis of homogeneity for all data series was accepted because the critical values for all tests to reject the H_o hypothesis were far from fulfilled (Tab. 3). Following the categories presented by Wijngaard et al., [35], the test results were classified as Class 1: 'useful'. Under this class, the series are sufficiently homogeneous and undoubtedly can be used for trend analysis.

Table 3: Results of the homogeneity tests for all rainfall time series (six-month total rainfall).

Station	Pettitt's test	SNHT	Buishand's (BR) test		Classification
	(X_E)	(T_0)	$Q/\sqrt{n}$	$R/\sqrt{n}$	
Ajdabiya	309	4.776	1.143	1.467	Class 1
Benina Airport	214	4.894	0.670	1.079	Class 1
Shahat	371	4.111	0.994	0.994	Class 1
Derna	222	1.529	0.558	1.106	Class 1

Note: for homogenous series, $X_E < 655$, $T_0 < 12.03$, $Q/\sqrt{n} < 1.55$ *and* $R/\sqrt{n} < 1.81$.

Results and Discussion

Trend Analysis

Results of precipitation variability and trend direction (MK test statistics and Theil and Sen's slope) for all stations are presented in Figure 4 and Table 4. Symmetries and asymmetries in the precipitation variability can clearly be seen between the four stations throughout the period of study. It is evident from Figure 4 that, the noticeable decline in (Oct-Mar) precipitation since the beginning of the first decade of the 21st century has been consistent between all stations. Also, the similarity in the year to year precipitation variability behavior can clearly be noticed in those northeastern stations, particularly between further northeastern stations i.e. (Benina Airport, Shahat, Derna). In addition, apart from Ajdabiya, which lies at the southwestern corner of the study area, the remaining stations showed downward trend directions, which reflect a decline in their (Oct-Mar) precipitation (Fig.4). It is interesting to note from Table 4, that the significant precipitation increase and significant precipitation decrease were obtained at the lowest site (Ajdabiya) and highest site (Shahat), respectively. A highly significant decreasing trend was detected for the Shahat station, with almost 30% change, whereas Ajdabiya station showed a significant increase, with 44% change (Table 4). Non-significant negative trends were evident at the Benina Airport and Derna stations, with -18.69% and -8.87% changes, respectively. The results of this study are consistent with the findings of previous studies on precipitation trend analysis in northeastern Mediterranean, southeastern Mediterranean and central Mediterranean regions. Among those studies: Greece [36], Italy [37-38], Jordan and Israel and Egypt [10].

As it has been presented in the introduction, Hafi [16] analyzed precipitation variability in the northwestern region of Libya (not shown) and that all stations except one have showed positive precipitation trends with some of them were close to the statistical significance. A comparison between one or two stations from both studies i.e. the outcomes from this study and those from Hafi [16], can clearly show the differences between both regions. In the northwestern region, the coastal station of Sirt has been subject to a remarkable significant increase (positive trend) with a percentage change valued (+ 37%). Again, in the same region, the mountainous station of Az Zintan (714 m above m.s.l.) showed an upward trend (very close to statistical significance) associated with percentage increase of (24 %). In contrast, within the study area of the northeastern (current study) region, the coastal station of Benina Airport has experienced a noticeable decline in its precipitation (negative trend) as the percentage change has recorded (- 19 %). The mountainous station of Shahat (581 m above m.s.l.), situated to the east of Benina Airport and usually receives the largest amount of precipitation in Libya has also suffered a significant precipitation decrease with high negative percentage of (- 30 %) from its seasonal mean.

Therefore, the fact that the two regions have showed opposite signs of precipitation trends presented as an increase in the northwest and decrease in the northeast could raise an important question about the precipitation variability in Libya. Have the northeast and northwest of Libya responded differently or more precisely, oppositely to the global change era since the late seventies and early eighties? Or do both regions indeed experience different climates in first place and as a result of that, their precipitation temporal viabilities could not be similar?

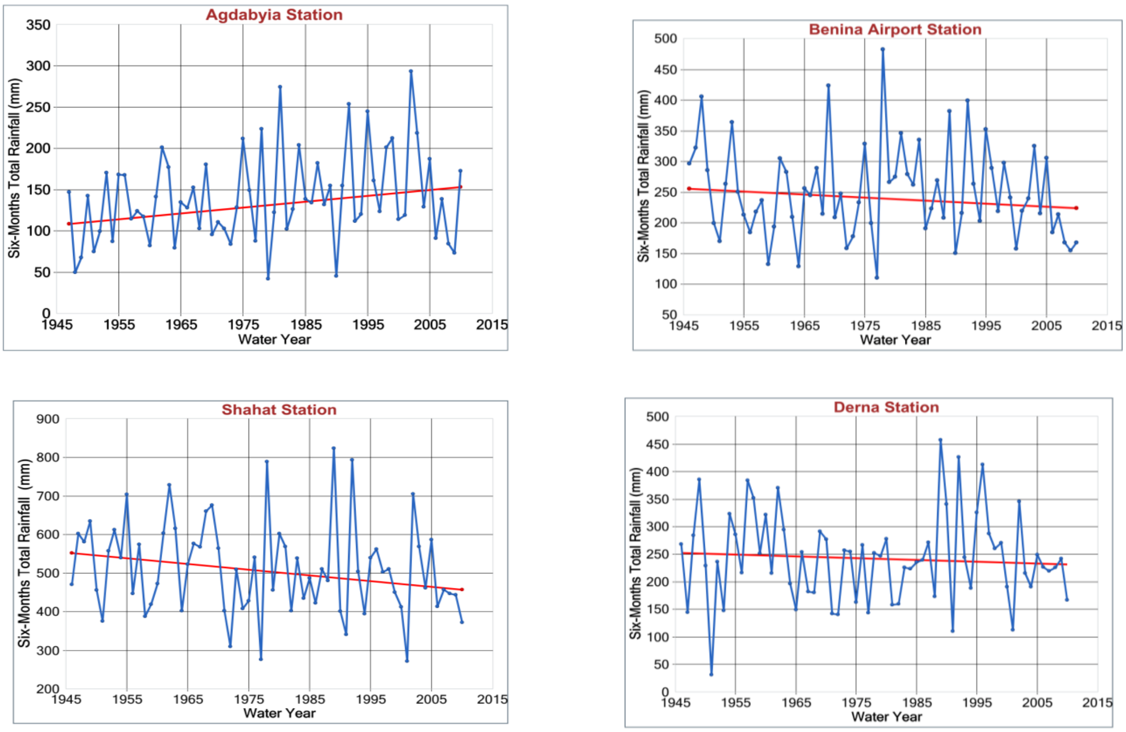

Figure 4: Six-month total rainfall time series and the corresponding Theil-Sen trend line

Table 4: Results of Mann–Kendall trend test at 5% (a=0.05), Sen's slope, and percentage change (six-month total rainfall)

Station	*p-Value*	*S*	Z_{MK}	Significance	Theil-Sen's Slope	Change %
Ajdabiya	0.036	311	1.796	significant increase	0.709	44.24
Benina Airport	0.177	-164	-0.923	non-significant decrease	-0.493	-18.69
Shahat	0.031	-329	-1.857	significant decrease	-1.487	-29.70
Derna	0.267	-110	-0.617	non-significant decrease	-0.332	-8.87

S = Kendall test statistics; Z_{mk} *= standardized MK test statistics; statistically significant trends and Sen's slope are highlighted in bold at the 5% level of significance.*

Conclusions

The different tests showed that all analyzed time series were homogeneous at 1% significance level. The rainfall time-series autocorrelograms showed that the autocorrelation coefficients for all stations fell within the 95% confidence limits and were strongly random. The results of the Mann–Kendall test for the six-month total rainfall series showed that except for Ajdabiya which lies in further southwest of the study area, all other northeastern stations showed a downward (negative) trend. The results of this paper are consistent with many studies considering precipitation variability, particularly those made in eastern, south eastern and central Mediterranean regions. Highly significant decreasing trend was detected for the Shahat station, with almost -30% change, whereas Ajdabiya station showed a significant increase, with +44% change. Non-significant decreasing trends were detected for the Benina Airport and Derna stations. When the outcomes of this study were briefly, compared to the findings of Hafi [16] about the type of precipitation trends in northwestern Libya, opposite trend directions (signs) have been revealed between northeast and northwest of Libya. Negative precipitation trends in the northeast against positive precipitation trends in the northwest. It is argued however, that both regions might have responded oppositely to the well-documented global climate change or because of their different geographical positions, they face different climates and therefore the precipitation temporal variability would probably differ from region to region. The Z_{MK} value as well as the statistical significance of the trend were markedly, related to rainfall variability in both temporal and spatial domains (CV). Overall, the results indicate that the rainfall trends and variability in rainfall patterns in most of the region can be attributed to local changes in the rainfall regime rather than changes in large-scale patterns of atmospheric circulation.

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