



Spatial and temporal rainfall changes in Egypt

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Abstract

During the twentieth century, the intensity and frequency of extreme events (e.g., storms and floods) have significantly altered globally due to human-induced climate change. Recently, it has been recognized that some regions in Egypt have exposed to extreme rainfall events which led in some cases to severe flash floods. In this work, the variability of rainfall characteristics in Egypt was investigated based on a detailed statistical analysis of historical rainfall records at 31 stations. Both parametric (Pearson) and non-parametric (Mann–Kendall and Spearman) tests were applied on annual and seasonal precipitation indices to examine temporal trends. A classification of significant trends was introduced to assess the degrees of their likelihood. The results detected significant trends in annual indices: maximum precipitation, total precipitation, simple daily intensity index, and number of rainy days at 29, 19, 19, and 13% of stations, respectively. Significant trends in seasonal indices were also found at a few stations. For all indices, 77% of the detected significant trends are negative concluding a decrease in the amount of precipitation in Egypt. Additionally, only 6% of the detected trends are classified as less likely, while the rest is likely and extremely likely, indicating a high probability of most detected trends. Generally, the detected trends do not form any spatial pattern in all cases. The results also provided a preliminary impression on the likely impacts of climate change on rainfall characteristics in Egypt.

Keywords Climate change · Extreme Rainfall · Mann–Kendall · Spearman · Pearson · Trend analysis · Egypt

Introduction

An accurate estimation of extreme rainfall events is important for water resources management. Therefore, detecting trends in rainfall data is extremely significant in practical engineering application because ignoring significant increasing (or decreasing) trends in the data may lead to unexpected floods (or droughts). The most important impacts of climate change relate to precipitation and temperature (Kousari et al. 2011). In addition to the increase in surface temperature, the change in precipitation characteristics is notable. The fifth assessment

report from the Intergovernmental Panel on Climate Change (IPCC 2014) indicated that the frequency of extreme rainfall events has increased over most land areas, consistent with growing temperatures and atmospheric water vapor. Consequently, studying changes in precipitation patterns could be the first step to understand the impact of climate change on water resources availability.

Recently, many studies have analyzed trends in rainfall data to assess the impacts of climate change on hydrologic time series around the world. Table 1 presents a summary of recent studies on rainfall trend analysis. For instance, Adamowski and Bougadis (2003) analyzed annual maximum observations for different durations in the province of Ontario (Canada). They found six out of eight regions had trends for 5- and 10-min rainfall durations. Trends of annual maximum rainfall were investigated over Canada by using the Mann–Kendall (MK) test (Burn and Taleghani 2013). The results revealed more increasing trends than decreasing ones in annual maximum precipitation. In Malaysia, Suhaila et al. (2010) used the MK test to study trends in daily rainfall for the period of 1975–2004. The results indicated decreasing trends in the total rainfall amount and frequency of wet days, as well as increasing trends in rainfall intensity during the southwest

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Table 1 Summary of recent studies on rainfall trend analysis

Study	Region	No. of stations	Observation period	Trend analysis	Rainfall duration	Rainfall index	Main finding
Crisci et al. (2002)	Tuscany, Italy	81	1946–1994	Pearson linear correlation and MK	1, 3, 6, 12, 24 h	Annual extreme rainfall	Only the Marinella station exhibited negative trends at all durations.
Adamowski and Bougadis (2003)	Ontario, Canada	44	1970–1990	MK	5, 10, 15 and 30 min and 1, 2, 6 and 12 h	Annual extreme rainfall	Significant trends were detected in six out of eight regions for 5- and 10-min rainfall durations, and only three regions showed significant trends for the remaining durations.
Bani-Domi (2005)	Jordan	26	1964–1999	MK	Daily	Annual total rainfall and seasonal rainfall	None of the precipitation series showed significant trends.
Suhaila et al. (2010)	Peninsular Malaysia	30	1975–2004	MK	Daily	TAR, FREQ, RI, XFREQ, XI*	Most of the stations exhibited decreasing trends regarding extreme rainfall indices which will reduce flood risk.
Tesemma et al. (2010)	Blue Nile Basin, (Ethiopia)	2	1964–2003	MK and Sen's slope	Daily	Annual and seasonal rainfall	No significant trend in annual basin-wide average, increasing significant trends during long rainy days.
Kousari et al. (2011)	Eastern and central area of Iran	26	1955–2005	MK	Daily	Annual precipitation	Most of the stations had decreasing trends in precipitation and no significant trend in temperature.
Zhang et al. (2012)	China	140	1960–2011	MK	Daily	1, 7, 30 days, 95th and 97.5th percentile	Increasing trends in extreme precipitation on the basis of historical rainfall data set over YRB.
Santos and Fragoso (2013)	Northern Portugal	39	1950–2000	MK	Daily	PRCPTOT, R30mm, Rx5day, and R95p	On a seasonal time scale, extreme precipitation indices had a decreasing significant trend.
Tramblay et al. (2013)	Maghreb countries	22		MK	Daily	PRCPTOT, R1mm, SDII, RX1day, Prec95p, and CDD	An increase of the dry duration and decrease of wet days and annual precipitation.
Zelenáková et al. (2014)	Libya	17	1971–2010	MK	Monthly	Monthly rainfall	Negative trends of monthly precipitation were found in gauging stations.
Khadr (2017)	Upper Blue Nile River	22	1960–2008	MK and Sen's slope	Daily	Annual and seasonal	Increasing and decreasing trends of annual and seasonal rainfall.

*TAR, total amount of rainfall; FREQ, frequency of wet days at least 1 mm of rain; RI, rainfall intensity; XFREQ, frequency of wet days exceeding 95th percentile; XI, rainfall intensity exceeding 95th percentile; PRCPTOT, the total precipitation; R30mm, number of days precipitation amount ≥ 30 mm; Rx5day, the maximum 5-day precipitation amount ≥ 95 th percentile; R1mm, the ratio of wet days; SDII, simple daily intensity index; RX1day, max 1-day precipitation; and CDD, consecutive dry days

monsoon. Amirabadizadeh et al. (2015) applied the MK test and Sen's slope method over the Langat River Basin (Malaysia). They showed increasing and decreasing trends in both annual and seasonal precipitation, and that the rate of increment in the annual precipitation was higher than that of the seasonal precipitation. The main characteristics of spatial and temporal variability of annual and seasonal precipitation were analyzed in China for the period (1956–2000) based on observation at 590 rain gauging stations (Zhang et al. 2012). It was concluded that the northern and northeastern parts of China had decreasing trends in annual and seasonal precipitation, while the northwest, east, and southeast of China showed increasing precipitation. Precipitation changes have been addressed in arid and semi-arid regions of Iran (e.g., Modarres and de Paulo Rodrigues da Silva 2007). For instance, Kousari et al. (2011) investigated monthly and annual trends at minimum, maximum, and mean precipitation in Iran using the MK test. They used 26 synoptic stations for 55 years and showed that most of the stations had significant decreasing trends. However, Kousari and Zarch (2011) did not detect any significant trends for precipitation when they analyzed annual precipitation by using the MK test over the arid and semi-arid regions of Iran.

In the Mediterranean region, Norrant and Douguédroit (2006) identified possible significant trends of daily, monthly, seasonal, and annual precipitation of 63 stations during the second half of the twentieth century. They concluded that non-significant trends were dominant for most regions at different time scales. However, in another study by Philandras et al. (2011), the trends of annual rainfall and rainy days at 40 stations over the Mediterranean region were analyzed and most stations exhibited significant negative trends during the period 1901–2009. Also, a significant decrease in precipitation patterns was observed in Greece (Karpouzou et al. 2010) and Spain (Valdes-Abellan et al. 2017). In Italy, several studies examined changes in annual and seasonal precipitation. Brunetti et al. (2001) found significant decreasing trends in the annual number of rainy days over Northeast Italy and concluded that significant trends were more evident in spring and autumn. Crisci et al. (2002) examined records from 81 rain gauges in Tuscany and showed that extreme events increased for different durations. Another study in Sicily (Italy), by Liuzzo and Freni (2015), concluded that increasing trends of extreme rainfall were accompanied by an increase in the number of the occurrences of floods.

In the Middle East and North Africa (MENA) region, few studies were conducted in order to study the characteristics of rainfall data. In Jordan, Bani-Domi (2005) applied the MK test and the log-one serial correlation to study the impact of climate change on extreme rainfall. He concluded that most of the stations had negative trends for total rainfall. Trambly et al. (2013) examined trends and variability of extreme precipitation observed at 33 stations located between Algeria, Morocco, and

Tunisia. They showed a strong tendency towards a decrease of precipitation total and wet days together with an increase in the duration of dry periods, mainly for Morocco and western Algeria. In Libya, Zeleňáková et al. (2014) investigated precipitation trends in climatic stations by using the MK test. Their results detected increasing and decreasing trends in the study area. In the Nile River Basin, rainfall trends at 39 stations were analyzed by Onyutha et al. (2016). They found that trends in annual rainfall were mainly positive in the equatorial region; contrastingly, trends were mostly negative in Sudan, Ethiopia, and Egypt. Also, some studies investigated spatial and temporal variability of rainfall in the Blue Nile Basin (e.g., Mengistu et al. 2014; Khadr 2017).

Egypt predominantly has an arid climate and recently experiences increases in rainfall extremes. In the last decade, several extreme rainfall events occurred in different regions in Egypt, in some cases, lead to severe flash floods. For instance, Luxor, a legendary historic city located in Upper Egypt, received a relatively huge amount of rainfall (1.2 in.) in only one day in March 2012, which is almost 30 times the average yearly rainfall (Nashwan et al. 2018). In two sequential years, 2015 and 2016, flash floods occurred in many regions of Egypt including the north coast, the Nile Delta, Red Sea and Upper Egypt governorates, and Sinai. These flash floods, which occur due to heavy rains exceeding 50 mm/day, caused dozens of deaths and hundreds of destroyed homes (Elnazer et al. 2017). More recently, in April 2018, heavy rainfall hit several parts in Cairo, Giza, and Ain Sokhna-Zafarana road resulting in property damage and several deaths due to road accidents (AhranOnline 2018).

Accordingly, studying the spatial and temporal changes in rainfall extremes in Egypt is vital for the assessment of possible impacts of climate change, and then, developing adaptation and mitigation measures. However, such research is very limited and most studies either used a small number of stations or gridded data. Lately, the statistical characteristics of extreme rainfall events were examined by using historical daily rainfall records at 30 stations throughout Egypt (Gado 2017). A great variation of rainfall characteristics was revealed over the whole country. Nashwan et al. (2018) investigated spatial trend patterns for annual and seasonal rainfall. They used the daily rainfall data of Princeton Global Meteorological Forcing for the period 1948–2010 having a spatial resolution of $0.25^\circ \times 0.25^\circ$. Additionally, the climate change impacts on several aspects in Egypt, such as human health, agriculture production, energy demand, water quality, and economic losses, have been recently investigated in some studies (e.g., Yates and Strzepek 1998; Conrad and Kotani 2014; Shourav et al. 2017; Egyptian Environmental Affairs Agency 2016; Shalby et al. 2018; and Barros et al. 2015).

In view of the previously mentioned issues, studying changes in meteorological variables such as rainfall in Egypt did not receive enough concern. Therefore, the main objective of the

present study is to evaluate the variability of rainfall characteristics over Egypt in order to assess the possible impacts of climate change. Both parametric (Pearson) and non-parametric (Mann–Kendall and Spearman) tests were applied on annual and seasonal precipitation indices, extracted from historical rainfall records at 31 stations, to examine temporal trends.

Methodology

Study area and data

Egypt is located in the northeastern corner of Africa. It lies between latitudes 22° and 31° N, and longitudes 24° and 36° E. It is bordered by the Mediterranean Sea to the north, the Red Sea to the east, Libya to the west, and Sudan to the south. Egypt has an area of 1,019,600 km², where its coastline extends for more than 3500 km² along the Mediterranean Sea and the Red Sea. Thus, the geography of Egypt is characterized by two different regions: North Africa and Southwest Asia. In general, Egypt's geological history has produced four major physical regions (Elmenoufy et al. 2017): the Nile Valley and the Nile Delta, the eastern desert, the western desert, and the Sinai Peninsula. Egypt's climate is semi-desert, characterized by two main seasons (Elmenoufy et al. 2017): a hot dry summer (from May to October) and a mild winter with little rainfalls (from November to April).

Daily precipitation data from 31 stations were analyzed. Precipitation data were obtained from multiple sources in order to get a long record over the available stations. The database was extracted from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC) (<https://www.ncdc.noaa.gov>), and Russia's Weather Server (<http://meteo.infospace.ru/main.htm>). Figure 1 shows the geographical location of the selected stations in the study area. Also, Table 2 shows some of the characteristics of the selected stations used in this study. A common period of record is favored for regional trend analysis (Burn and Taleghani 2013). However, in the case study, the gauged data are limited and recorded over different periods among the selected stations (Table 2). If a fixed period of record was considered, either many gauged stations would be excluded or the record length would be shortened. Accordingly, a common period of analysis was not practical for this study. After building the database, seven rainfall indices were established as shown in Table 3.

Data quality assessment

Rainfall records, as a part of climatic data, often contain inhomogeneities for many reasons such as changes in data collecting method, stations relocating, equipment changes, and drifts of equipment (Alexandersson and Moberg 1997).

Data inhomogeneity within the time series may cause wrong predictions (and/or interpretations) of extreme events, e.g., abrupt changes in the mean are usually false outcomes stem from inhomogeneity in the time series data (Santos and Fragoso 2013). Three homogeneity tests were used in this study: the Standard Normal Homogeneity Test (SNHT), Pettit's test, and the Von Neumann (VN). All time series data were checked at a 5% significance level.

The null hypothesis of the Mann–Kendall test states that the data are independent and randomly ordered, i.e., there is no trend or serial correlation structure among the observations. The existence of positive (negative) serial correlation will increase (decrease) the possibility of rejecting the null hypothesis of no trend (Yue and Wang 2004). Here, the serial correlation of the studied time series was checked by the Durbin–Watson statistic (Durbin and Watson 1951).

Trend analysis methods

For detecting significant trends in hydrologic data, two techniques are always used: parametric and non-parametric. The main assumption in all techniques is the independence of the data. Additionally, the parametric technique requires the selected random variable to follow some distributions (e.g., normal distribution). While the non-parametric technique does not assume the distribution function of the random variable to follow any theoretical distributions, and thus, it is the most widely used for trend analysis (Gado and Nguyen 2013). In this study, both techniques were used for trend detection in the different precipitation indices. For the non-parametric approach, two tests were used: Mann–Kendall's tau and the Spearman's Rho, while the Pearson's *r* was used as a parametric approach. In addition, the non-parametric Sen's slope method was used to estimate the magnitude of trends in rainfall time series data. Trend tests were conducted for all precipitation indices on both annual and seasonal time scales. Here, the null hypothesis (H_0) for all trend tests is no monotonic trend in the time series. The rejection of H_0 indicates a positive or negative trend in the tested data (Gotway et al. 2002). For each test, *p* values were calculated at two different significance levels: $\alpha = 5\%$ and 10%. The null hypothesis is rejected, and the time series is considered statistically significant when the *p* value is less than α .

Mann–Kendall test

The Mann–Kendall statistic (*S*) is calculated as follows (Mann 1945; Kendall 1962):

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

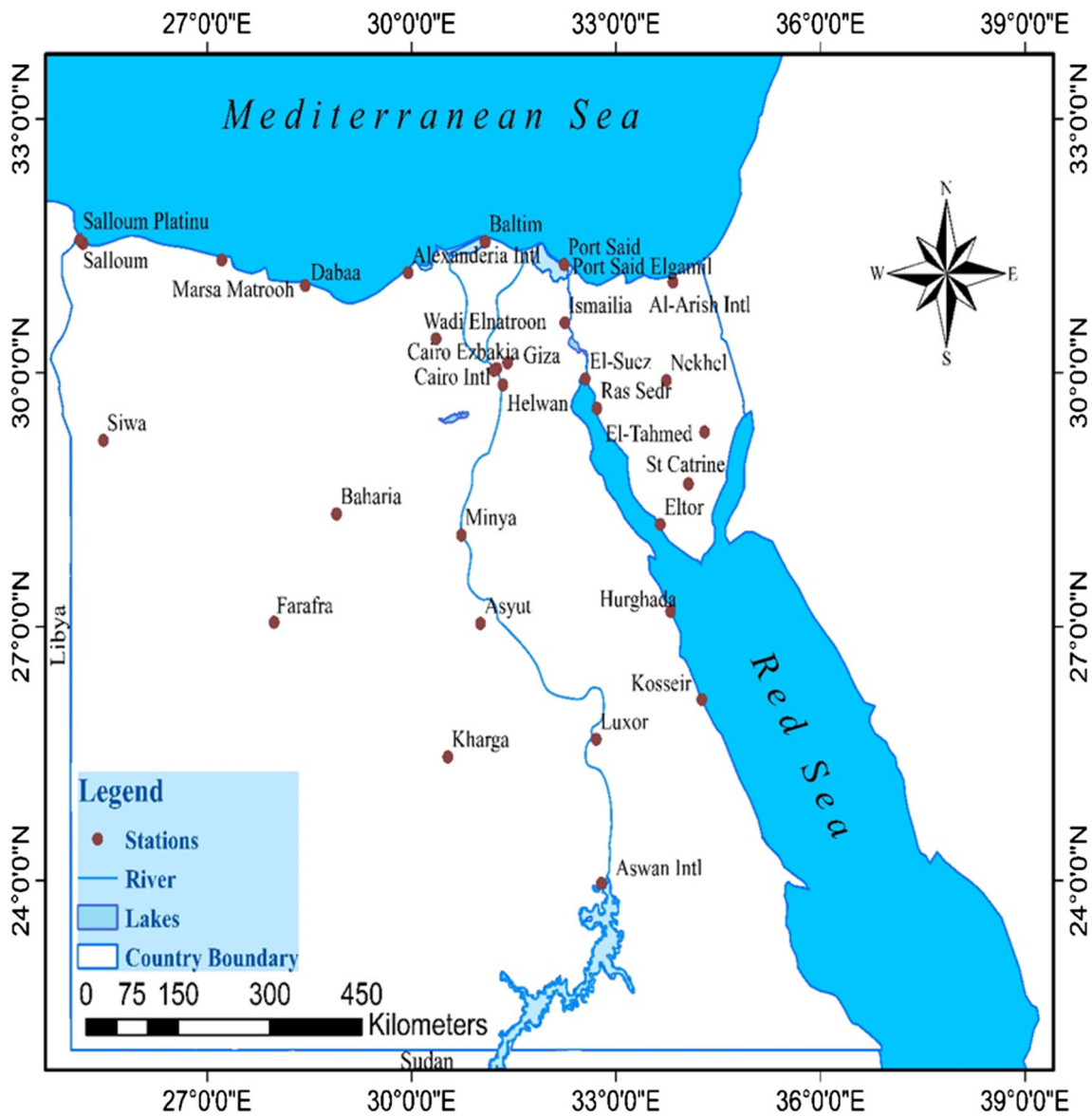


Fig. 1 Geographical locations of the selected gauging stations in Egypt

where n is the number of data points, x_i and x_j are the data values of time series i and j respectively ($j > i$), and $\text{sgn}(x_j - x_i)$ is defined as follows:

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

The variance of the Mann–Kendall statistic ($\text{var}(S)$) is computed as follows:

$$\text{var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(i)(i-1)(2t_i+5)}{18} \quad (3)$$

where m is the number of tied groups and t_i denotes the number of ties of extent i ; a tied group is a set of sample

data having the same value. For the sample size $n > 10$, the standard normal test statistic Z_{mk} can be computed as follows:

$$Z_{\text{mk}} = \begin{cases} \frac{s-1}{\sqrt{\text{var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{s+1}{\sqrt{\text{var}(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

The standardized Mann–Kendall statistics (Z_{mk}) follows the normal distribution with the mean of zero and variance of one. The p value of Z_{mk} is estimated by using the standard normal distribution function.

Table 2 Summary of the characteristics of the selected stations in Egypt (Modified after Gado 2017)

Station ID	Station	Latitude	Longitude	Elevation (m)	Period of record	Missing years	Record length (years)
62337	Al-Arish Intl	31.07	33.84	36.9	1985–2016	–	31
62318	Alexandria Intl	31.18	29.95	– 1.8	1957–2016	1967–1972	54
62414	Aswan Intl	23.97	32.78	200	1991–2015	1992, 2003, 2004, 2010, 2011	19
62393	Asyut	27.04	31.01	226	1979–2016	1986–1989, 1995–1999	30
62420	Baharia	28.33	28.90	130	1984–2016	1985, 1992	30
62325	Baltim	31.55	31.08	2	1994–2016	–	22
62374	Cairo Ezzbakia	30.05	31.25	20	1909–1957	–	48
62366	Cairo Intl	30.10	31.40	75	1957–2016	–	58
62309	Dabaa	31.03	28.44	18	1999–2015	–	16
62450	El-Suez	32.55	29.93	10	1907–1957	–	50
	El-Tamed	29.30	34.30	625	1922–1955	–	24
62459	El-Tor	28.12	33.65	35	1994–2016	1995, 1999, 2002, 2009, 2015	17
62423	Farafra	27.05	27.98	92	1957–2016	1967–1975, 1977–1992	36
62375	Giza Cairo	30.03	31.21	28	1924–1957	1941–1943	31
62378	Helwan	29.86	31.34	116	1904–1957	–	53
62463	Hurghada	27.18	33.80	14	1990–2016	1996, 1998, 1999, 2001, 2003, 2004	20
62440	Ismailia	30.59	32.25	13	1981–2013	1994	31
62435	Kharga	25.46	30.53	73	1961–2014	–	53
62465	Kossier	26.14	34.26	11	1960–2014	1967–1972	50
62405	Luxor	25.67	32.71	99	1990–2016	–	26
62306	Marsa Matrouh	31.33	27.22	30	1920–2016	1923, 1941–1944, 1967–1973, 1976	89
62387	Minya	28.08	30.73	31	1984–2015	1985, 1986, 1999, 2003, 2009, 2010	25
62452	Nekhel	29.91	33.74	402	2001–2014	–	13
62333	Port said	31.28	32.24	2	1901–2016	1967–1978, 2001–2012	93
62332	Port Said El Gamil	31.28	32.24	6	1987–2014	–	27
62455	Ras Seder	29.58	32.72	16	2000–2014	–	14
62300	Salloum	31.53	25.18	26	1919–1966	1941–1948	40
62305	Salloum Plateau	31.57	25.13	19	1996–2014	–	18
62417	Siwa	29.20	25.48	– 12	1982–2013	1984, 1986, 1993, 1994, 1995, 1998, 1999, 2002	23
623664	St. Catrine	28.69	34.06	1331	1980–2006	–	26
62357	Wadi El-Natron	30.40	30.36	1	1996–2016	1999, 2013, 2014	17

Spearman’s rho test

The Spearman’s rho (SR) rank correlation coefficient is a non-parametric rank statistic proposed to measure the association strength of two variables. The test statistic *D* is given as follows (Yue et al. 2002):

$$D = 1 - \frac{6 \sum_{i=1}^n [R(x_i) - i]^2}{n(n^2 - 1)} \tag{5}$$

where *R* (*x_i*) is the rank of *i*th observation *x_i* in the sample size *n*. The null hypothesis states that the distribution of *D* is asymptotically normal with the mean and variance as follows:

$$E(D) = 0 \tag{6}$$

$$V(D) = \frac{1}{n-1} \tag{7}$$

The *p* value of the SR statistic (*D*) of the observed sample data is estimated using the normal cumulative distribution function by using the following standardization:

$$Z_{SR} = \frac{D}{\sqrt{V(D)}} \tag{8}$$

The standardized statistic *Z_{SR}* follows the standard normal distribution *Z*–*N* (0, 1).

Pearson’s *r* parametric test

Pearson’s *r*, also called the linear correlation coefficient, measures the linear association between two variables as follows (Gotway et al. 2002):

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \sqrt{\sum_i (y_i - \bar{y})^2}} \tag{9}$$

where

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}; \quad \bar{y} = \frac{\sum_{i=1}^n y_i}{n} \tag{10}$$

Here, the Pearson correlation coefficient does not fully capture the relationship between two variables if they do not follow the bivariate Gaussian distribution, which makes *r* not always suitable for describing the correlation between

Table 3 Definition of precipitation indices

Index	Index name	Definition	Unit
AMP	Annual maximum precipitation	The maximum daily precipitation over a year	mm
ATP	Annual total precipitation	The sum of daily precipitation over a year	mm
ANRD	Annual number of rainy days	The sum of rainy days over a year	Days
SDII	Simply daily intensity index	The sum of daily precipitation divided by the sum of rainy days	mm/day
SMP	Seasonal maximum precipitation	The maximum daily precipitation over a season	mm
STP	Seasonal total precipitation	The sum of daily precipitation over a season	mm
SNRD	Seasonal number of rainy days	The sum of rainy days over a season	Days

hydrological variables. The significance of r can be tested by estimating the p value from a table of the t distribution with $n-2$ degrees of freedom, according to the test statistic t_r , which is computed by the following equation:

$$t_r = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \tag{11}$$

Sen’s slope

In this study, the magnitude of a significant trend is estimated by using the well-known simple non-parametric procedure, Sen’s slope method (Sen 1968). This method assumes a linear trend in the time series with a slope (β) that is calculated by the following:

$$\beta = \text{median} \left[\frac{x_j - x_i}{j - i} \right] \text{ for all } i < j, i = 1, 2, \dots, n-1, \text{ and } j = 2, 3, \dots, n \tag{12}$$

Trend classification

In this study, we proposed a trend classification for rainfall data in order to assess the degree of its likelihood as follows (Table 4):

1. The “extremely likely” (EL) denotes that both parametric and non-parametric tests reject the null hypothesis of no trend with at least one of them has a significance level of 5%.
2. The “likely” (L) denotes that both tests reject the null hypothesis of no trend with a significance level of 10% or only one test rejects the null hypothesis with a significance level of 5%.
3. The “less likely” (LL) denotes that only one test rejects the null hypothesis of no trend with a significance level of 10%.

Results and discussions

Data quality assessment

The serial correlation of the time series was tested by the Durbin–Watson statistic. The results showed that the precipitation data had no serial correlation in the case study. For homogeneity, three tests were applied (SNHT, Pettit, and VN) on seven precipitation indices at the studied stations. All time series data were checked at a 5% significance level. The results indicated that all stations were homogeneous except the Cairo Intl station for only annual maximum precipitation (AMP) data. In this station, the data from 2012 to 2016 have been removed to make the AMP data homogeneous according to the three homogeneity tests (Fig. 2).

Temporal trends

The results of the temporal trends in the studied rainfall indices are presented in this section, for purposes of evaluating the possible impacts of climate change on rainfall patterns in Egypt. Analyses of these trends were performed by using non-parametric (Mann–Kendall and Spearman) and parametric (Pearson’s r) tests. Moreover, the magnitudes of significant

Table 4 Trend classification according to the parametric and non-parametric tests and the level of significance

Trend classification	Parametric test		Non-parametric test	
	5%	10%	5%	10%
Extremely likely	✓	✓	✓	✓
	✓	✓		✓
Likely		✓	✓	✓
	✓	✓		✓
Less likely			✓	✓
		✓		✓

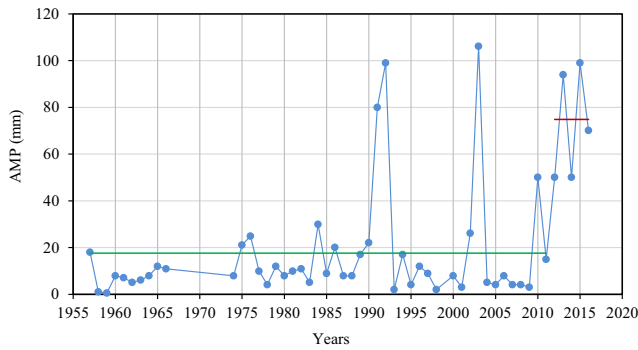


Fig. 2 Annual maximum precipitation of the Cairo Intl station

trends were obtained by Sen’s slope estimator. As mentioned earlier, seven annual and seasonal rainfall indices were investigated in 31 stations over Egypt. In this study, three seasons were considered when some stations experienced significant trends. These seasons are the following: autumn (23rd of September–20th of December), winter (21st of December–20th of March), and spring (21st of March–21st of June).

Annual maximum precipitation

The annual maximum precipitation (AMP) series was analyzed for each station to identify significant temporal trends.

Table 5 Summary of the significant trends for AMP, ATP, ANRD, and SDII

Station	Observation period	Trend tests			Sen’s slope	Classification
		MK	SR	r		
AMP						
					(mm/decade)	
Bahria	1984–2016			✓✓	− 1.45	Likely
Cairo Int	1957–2016	✓✓		✓	4.63	Extremely likely
El-Tamed	1922–1955	✓✓	✓✓		− 4.12	Likely
Farafra	1957–2016	✓✓	✓✓		− 6.35	Likely
Helwan	1907–1957		✓✓		− 3.32	Likely
Ismailia	1981–2013	✓✓	✓✓		− 2.69	Likely
Luxor	1990–2016	✓	✓		1.92	Less likely
Port Said	1901–2016	✓	✓	✓	− 1.37	Likely
St. Catrine	1980–2006			✓✓	− 2.27	Likely
ATP						
					(mm/decade)	
Cairo Intl	1957–2016	✓✓	✓✓	✓✓	4.63	Extremely likely
Farafra	1957–2016	✓✓	✓✓		− 6.96	Likely
Helwan	1904–1957	✓✓	✓✓		− 3.50	Likely
Ismailia	1981–2013	✓✓	✓✓		− 8.96	Likely
Luxor	1990–2016	✓	✓		3.12	Less likely
Port Said	1901–2016	✓	✓	✓	− 3.23	Likely
ANRD						
					(day/decade)	
Dabaa	1999–2015		✓✓	✓✓	2.00	Extremely likely
Marsa Matrouh	1920–2016	✓✓	✓✓	✓✓	1.67	Extremely likely
Ras Sedr	2000–2014	✓✓	✓✓	✓✓	− 2.50	Extremely likely
Wadi El-Natroun	1996–2016	✓		✓	− 5.00	Likely
SDII						
					(mm/[day×decade])	
Helwan	1904–1957	✓	✓	✓✓	− 0.39	Extremely likely
Luxor	1990–2016	✓	✓	✓	2.22	Likely
Marsa Matrouh	1920–2016	✓	✓	✓	− 0.29	Likely
Port Said	1901–2016	✓	✓	✓	− 0.45	likely
Salloum	1919–1966	✓	✓	✓	− 1.23	likely
Wadi El-Natroun	1996–2016			✓✓	1.77	Likely

Check marks (✓ and ✓✓) mean that the trend is significant at the 10% and 5% significance level, respectively

Table 5 shows the stations which exhibited statistically significant trends and their magnitudes and classifications. The results indicate that nine (29%) out of the 31 analyzed stations experience significant trends. Seven stations exhibit likely downward trends at Bahria, El-Tamed, Farafra, Helwan, Ismailia, Port Said, and St. Catrine. Only two stations have positive trends: Cairo Intl (extremely likely) and Luxor (less likely). The results detect opposed significant trends at two spatial closely stations: Helwan (downward) and Cairo Intl (upward). The reason for that may be attributed to the use of two different available observation periods: Helwan (1904–1957) and Cairo Intl (1957–2015). Figure 3 shows the time series of the AMP at the two stations along with their linear trends. It can be shown that the results of the non-parametric tests are almost the same, while the results of the parametric test are different from that of the other tests for all stations except one station (Port Said).

Annual total precipitation

The results of the trend analysis for annual total precipitation (ATP) series are shown in Table 5. Six (19%) out of the 31 stations show significant trends of different classifications. Four stations exhibit likely negative trends, Farafra, Helwan, Ismailia, and Port Said, while only two stations have positive trends: Cairo Intl (extremely likely) and Luxor (less likely). In this case, the results of the non-parametric tests are identical

and different from that of the parametric test except two stations (Cairo Intl and Port Said).

Annual number of rainy days

For each station, the annual number of rainy days (ANRD) series was analyzed to identify significant temporal trends, and the results are presented in Table 5. The results reveal that four stations (13%) experience significant increasing and decreasing trends. Increasing significant trends with extremely likely occur at two stations located on the north coast (Marsa Matrouh and Dabaa), while decreasing significant trends occur at Ras Sedr (extremely likely) and at Wadi El-Natroun (likely). Figure 4 presents the time series of the ANRD at Marsa Matrouh and Wadi El-Natroun stations, along with their linear trends, as examples of increasing and decreasing trends, respectively. In this case, the results of parametric and non-parametric tests are very close.

Simple daily intensity index

For simple daily intensity index (SDII) series, the results present that six stations (19%) experience significant trends in different regions in Egypt (Table 5). Four stations exhibit downward trends with extremely likely at Helwan and likely at Marsa Matrouh, Port Said, and Salloum. Only two stations have likely positive trends: Luxor and Wadi El-Natroun. Figure 5 presents the time series of the SDII at two stations (Marsa Matrouh and

Fig. 3 Annual maximum precipitation time series for **a** Cairo Intl and **b** Helwan

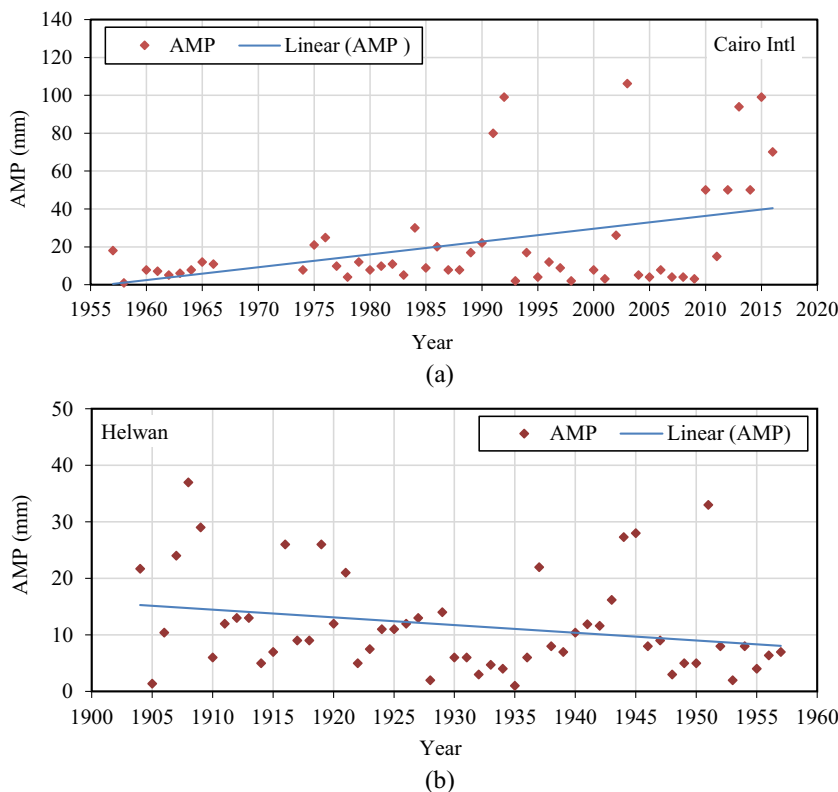
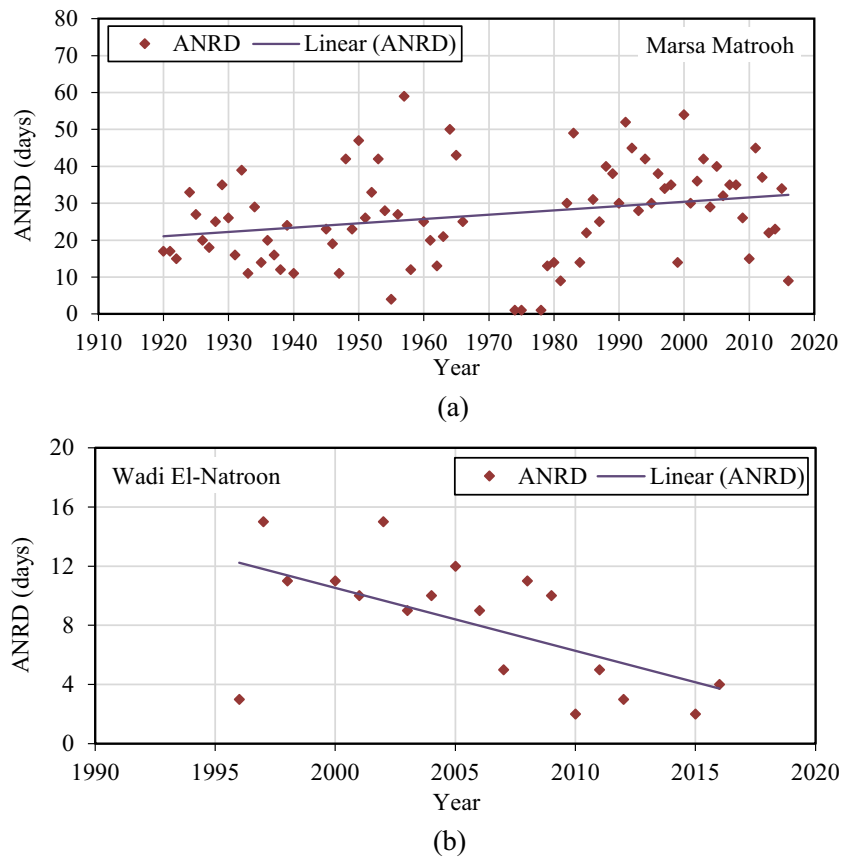


Fig. 4 Annual number of rainy day time series for **a** Marsa Matrouh and **b** Wadi El-Natroun



Wadi El-Natroun) along with their linear trends. Here, the results of parametric and non-parametric tests are almost the same for all detected stations except Wadi El-Natroun.

Seasonal maximum precipitation

The seasonal maximum precipitation (SMP) series was analyzed for each station to identify significant temporal trends for each season. The results indicate that four stations (13%) exhibit significant trends in three seasons: winter, autumn, and spring (Table 6). All detected seasonal trends are negative and their classifications are likely except that of the trend of Ismailia station which is less likely. It can be concluded that the Port Said station exhibits likely significant decreasing trends in the three detected seasons. In this case, the results of all tests are identical at one station (Port Said), while for the other stations, the results of the parametric test are completely different from that of the non-parametric tests.

Seasonal total precipitation

The results of trend analysis for seasonal total precipitation (STP) are shown in Table 6, where five stations (16%) experience significant trends in the three mentioned seasons. The classification of all detected trends is likely except the extremely likely trend at Al-Arish in winter. All detected trends

are negative except one positive trend at Marsa Matrouh in winter. Again, Port Said station exhibits likely significant decreasing trends in the three seasons. In this case, the results of all tests are comparable.

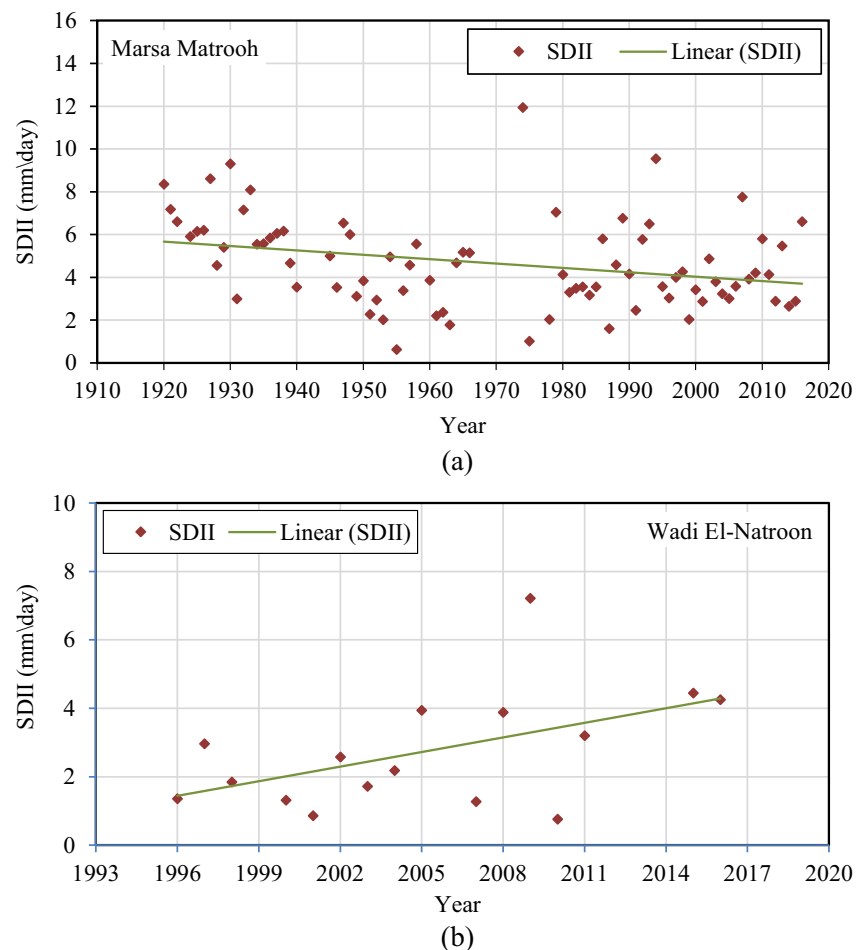
Seasonal number of rainy days

For each station, the seasonal number of rainy days (SNRD) series was analyzed to identify significant temporal trends, and the results are presented in Table 6. Here, five stations (16%) experience significant trends in the three seasons. The classification of all detected trends is extremely likely except the likely trends at Port Said in the three seasons and Marsa Matrouh in autumn. All detected trends are negative except two positive trends at Marsa Matrouh in winter and autumn. The results of all tests are similar in this case.

Spatial distribution of annual trends

For regional trend analysis, it is preferred that all considered stations shall have the same period of record. Thus, in this section, a recent common period of record (1990–2016) was selected and 19 stations were included in order to investigate the spatial distribution of annual trends in the case study. The spatial distribution of trends in annual rainfall indices (AMP, ATP, ANRD, and SDII) is depicted on a map of Egypt (Fig. 6), where there is

Fig. 5 Simple daily intensity index time series for **a** Marsa Matrouh and **b** Wadi El-Natroun



no particular pattern in the spatial distribution of the stations with significant trends across the country. In this study, the inverse distance weighting method (IDW) was used to interpolate rainfall trends of the available stations in order to produce continued raster surfaces for Egypt's boundaries as shown in Fig. 6.

Discussions

In this study, the results reveal that 36 (77%) out of the 47 detected significant trends for all indices are decreasing (Table 7). One can argue that Egypt is generally characterized by a decrease in rainfall. Only three detected significant trends (6%) are classified as less likely, concluding high confidence of most of the detected trends which categorized as likely and extremely likely. For all rainfall indices, the results show that there is no particular pattern in the spatial distribution of the stations with significant trends across the country (Fig. 6).

In the case of annual precipitation, the results reveal that a considerable proportion of stations (29%) in Egypt experiences significant trends for annual maximum precipitation (AMP). Most of these detected trends are negative and likely. For annual total precipitation (ATP), 19% of stations show

significant trends, most of them are negative as well. Only two stations experience increasing trends for both AMP and ATP: Cairo Intl and Luxor. Concerning the annual number of rainy days (ANRD), 13% of stations experience significant increasing and decreasing trends, most of them are extremely likely. Two stations located on the north coast (Marsa Matrouh and Dabaa) have increasing significant trends with extremely likely for the ANRD. The results show that the percentage of stations that experience significant trends in the case of simply daily intensity index (SDII) is 19%.

For seasonal analysis, the considered stations exhibit significant trends in three seasons: winter, autumn, and spring. The highest number of stations with significant trends occurred in winter. In the case of seasonal maximum precipitation (SMP), significant trends are detected in 13% of all stations, and all these trends are downward. Regarding the seasonal total precipitation (STP) and seasonal number of rainy days (SNRD), 16% of stations exhibit significant trends, most of them are decreasing. The results indicate that Port Said station exhibits likely significant decreasing trends in the three detected seasons for both SMP and STP. While Marsa Matrouh station has increasing trends for STP in winter and for SNRD in winter and autumn.

Table 6 Summary of the significant trends for SMP, STP, and SNRD

Season	Station	Observation period	Trend tests			Sen's slope	Classification
			MK	SR	<i>r</i>		
SMP							
						(mm/decade)	
Autumn	Ismailia	1981–2013	✓✓	✓✓		– 51.6	Likely
	Port Said	1901–2016	✓	✓	✓	– 0.5	Likely
Winter	Al-Arish	1985–2016	✓✓			– 3.4	Likely
	Ismailia	1981–2013	✓	✓		– 0.8	Less likely
Spring	Port Said	1901–2016	✓	✓	✓	– 1.4	Likely
	Helwan	1904–1957	✓✓	✓✓		– 2.3	Likely
	Port Said	1901–2016	✓	✓	✓	– 0.3	Likely
STP							
						(mm/decade)	
Autumn	Ismailia	1981–2013	✓✓	✓✓		– 2.9	Likely
	Port Said	1901–2016	✓	✓	✓	– 0.8	Likely
Winter	Al-Arish	1985–2016	✓✓	✓✓	✓✓	– 22.3	Extremely likely
	Marsa Matrouh	1920–2016		✓✓		0.6	Likely
Spring	Port Said	1901–2016	✓	✓	✓	– 4.4	Likely
	Helwan	1904–1957	✓✓	✓✓		– 2.5	Likely
	Port Said	1901–2016	✓	✓	✓	– 0.5	Likely
SNRD							
						(day/decade)	
Autumn	Marsa Matrouh	1920–2016	✓	✓		0.5	Likely
	Port Said	1901–2016	✓✓	✓✓	✓✓	– 0.2	Likely
Winter	Al-Arish	1985–2016	✓✓	✓✓	✓✓	– 3.3	Extremely likely
	Ismailia	1981–2013	✓		✓	– 1.8	Extremely likely
Spring	Marsa Matrouh	1920–2016		✓	✓	0.8	Extremely likely
	Port Said	1901–2016	✓✓	✓✓	✓✓	– 0.8	Likely
	Port Said El Gamil	1987–2014	✓	✓	✓	– 3.2	Extremely likely
	Port Said	1901–2016	✓✓	✓✓	✓✓	– 0.2	Likely

Check marks (✓ and ✓✓) mean that the trend is significant at the 10% and 5% significance level, respectively

Regarding the trend tests used in this study, the results of the non-parametric tests (Mann–Kendall and Spearman) are almost the same in all studied cases. This is in agreement with the results of a study by Yue et al. (2002) who compared between the different methods of trend detection. However, the results of the parametric test (Pearson's *r*) are not parallel with those of the non-parametric tests in some cases including AMP, ATP, and SMP, indicating that the distributions of these rainfall indices, in the case study, maybe far from the normal distribution. In contrast, the results of all tests are comparable in the other cases (ANRD, SDII, STP, and SNRD), owing to the rainfall indices may fairly follow the normal distribution. Further studies should be carried out to identify the best approach for trend detection in rainfall indices in Egypt.

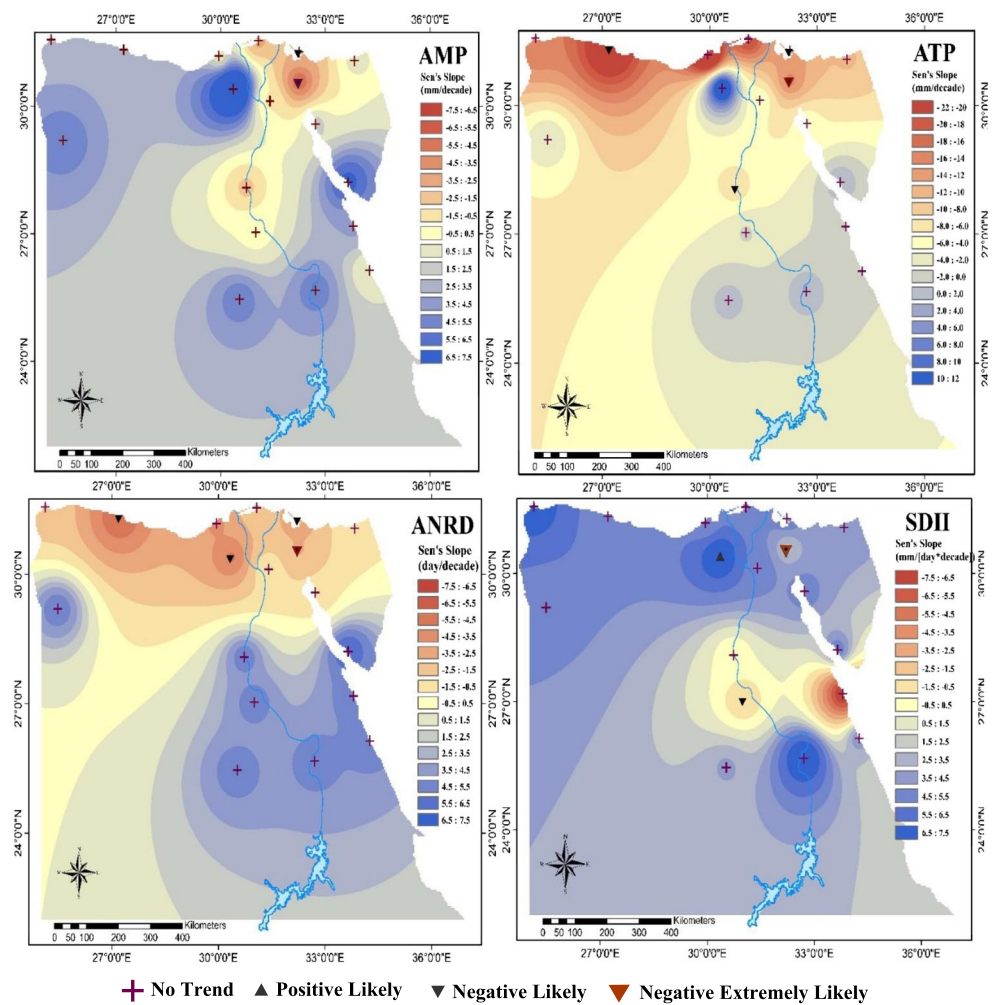
Only some studies have investigated trends in rainfall in Egypt. These studies used either limited station's data or gridded data. In this study, however, gauged data of 31 stations

were analyzed. Thus, a thorough comparison between the spatial pattern in trends resulted from this study and the previous studies was not feasible. Yet, the current results, regarding annual precipitation, are consistent with those obtained from a previous trend study (Nashwan et al. 2018), which analyzed gridded data in Egypt. These results reveal that increasing trends occur in central and Upper Egypt while decreasing trends occur in the northern and western parts of the country where agriculture activities depend on rainfall (Fig. 6).

Conclusions

This study investigated the possible changes in rainfall patterns over Egypt, based on a detailed statistical analysis of historical daily rainfall records available at 31 stations. Both parametric (Pearson) and non-parametric (MK and SR) tests

Fig. 6 Spatial distribution of trends by Sen’s slope method in annual rainfall indices: AMP (mm/decade), ATP (mm/decade), ANRD (day/decade), and SDII (mm/(day × decade)), for the period (1990–2016)



were used to examine the temporal trends in annual and seasonal precipitation indices. The magnitudes of detected significant trends in rainfall time series data were estimated by the non-parametric Sen’s slope method. Furthermore, a trend classification was proposed in order to evaluate the probability of

detected trends. The results brought some new evidence on recent changes of precipitation in Egypt.

Table 7 Number of significant trends of each classification and direction for all indices

Index	Classification			Direction		Total
	EL	L	LL	Upward	Downward	
AMP	1	7	1	2	7	9
ATP	1	4	1	2	4	6
ANRD	3	1	0	2	2	4
SDII	1	5	0	2	4	6
SMP	0	6	1	0	7	7
STP	1	6	0	1	6	7
SNRD	4	4	0	2	6	8
Total	11	33	3	11	36	47

In general, the detected trends do not form any systematic spatial pattern. Nevertheless, most of the detected trends are negative indicating a decrease in the amount of precipitation in Egypt. These spatial and temporal changes in rainfall in Egypt could be due to anthropogenic climate change or multi-decadal timescale natural variability. However, these results rather contradict the frequently observed extreme rainfall events recently occurred in Egypt. Keeping in mind that the historical rainfall records used in the study ended in 2016 or earlier, the analysis might not detect these expected increasing trends. Thus, it is recommended to locate more meteorological stations, with a recent common period of record, in order to determine the possible climate change signature in rainfall data in Egypt. Additional studies on the expected correlation between hydrological and climatic variables will be valuable in this regard.

Due to the shortness of the available rainfall records considered in this study, our analyses did not account for the possible change point or the possibility of long-term

persistence. Accordingly, we could not predict the long-term behavior of the detected trends of these rainfall series far into the future. Rather, it can be concluded that these trends deserve more investigation in order to identify their impact on extreme rainfall estimation. In the same line, it is essential to develop improved methods of extreme rainfall estimation to account for this nonstationary behavior of rainfall data since the traditional assumption of stationarity in current procedures is no longer suitable in such cases. Consequently, the design of related hydraulic structures should be adapted to consider the changes in rainfall characteristics that might occur during the whole life span of the structures.

References

- Adamowski K, Bougadis J (2003) Detection of trends in annual extreme rainfall. *Hydrol Process* 17(18):3547–3560. <https://doi.org/10.1002/hyp.1353>
- AhramOnline (2018) ‘Egypt’s top prosecutor orders report into ‘failure to manage’ heavy rain in New Cairo’, (Saturday 28 Apr 2018)
- Alexandersson H, Moberg A (1997) Homogenization of Swedish Temperature Data. Part I: homogeneity test for linear trends. *Int J Climatol* 17(1):25–34. [https://doi.org/10.1002/\(SICI\)1097-0088\(199701\)17:1<25::AID-JOC103>3.0.CO;2-J](https://doi.org/10.1002/(SICI)1097-0088(199701)17:1<25::AID-JOC103>3.0.CO;2-J)
- Amirabadzadeh M, Huang YF, Lee TS (2015) Recent trends in temperature and precipitation in the Langat River Basin, Malaysia. *Adv Meteorol* 2015:1–16. <https://doi.org/10.1155/2015/579437>
- Bani-Domi M (2005) ‘Trend analysis of temperatures and precipitation in Jordan’, Umm Al-Qura University Journal of Educational. Soc Sci Humanit 17(1):13–36
- Barros VR, Boninsegna JA, Camilloni IA, Chidiak M, Magrín GO, Rusticucci M (2015) Climate change in Argentina: trends, projections, impacts and adaptation. *Wiley Interdiscip Rev Clim Chang* 6: 151–169. <https://doi.org/10.1002/wcc.316>
- Brunetti M, Maugeri M, Nanni T (2001) Changes in total precipitation, rainy days and extreme events in Northeastern Italy. *Int J Climatol* 21(7):861–871. <https://doi.org/10.1002/joc.660>
- Burn DH, Taleghani A (2013) Estimates of changes in design rainfall values for Canada. *Hydrol Process* 27(11):1590–1599. <https://doi.org/10.1002/hyp.9238>
- Conrad JM, Kotani K (2014) Adapting to climate change. <https://doi.org/10.1007/978-94-017-8631-7>
- Crisci A, Gozzini B, Meneguzzo F, Pagliara S, Maracchi G (2002) Extreme rainfall in a changing climate: regional analysis and hydrological implications in Tuscany. *Hydrol Process* 16(6):1261–1274. <https://doi.org/10.1002/hyp.1061>
- Durbin J, Watson GS (1951) Testing for serial correlation in least squares regression. *Biometrika* 30:159–178
- Egyptian Environmental Affairs Agency (2016) ‘Egypt Third National Communication’. Available at: https://unfccc.int/files/nationalreports/non-annex_i_parties/biennial_update_reports/application/pdf/tnc_report.pdf
- Elmenoufy HM, Morsy M, Eid MM, El Ganzoury A, Wahab MMA (2017) Towards enhancing rainfall projection using bias correction method: case study Egypt Towards enhancing rainfall projection using bias correction method: case study Egypt, (September).
- Elnazer AA, Salman SA, Asmoay AS (2017) Flash flood hazard affected Ras Gharib City, Red Sea, Egypt: a proposed flash flood channel. *Nat Hazards* 89:1389–1400. <https://doi.org/10.1007/s11069-017-3030-0>
- Gado TA (2017) Statistical characteristics of extreme rainfall events in Egypt. Twentieth International Water Technology Conference, IWTC20, (May), pp. 18–20. Available at: <http://iwtc.info/wp-content/uploads/2017/05/44.pdf>.
- Gado TA, Nguyen V (2013) Effect of climate change on annual flood peaks in Quebec. *EIC Clim Change Technol Conf* 2013(1569696769):1–11
- Gotway C a, Helsel DR, Hirsch RM (2002) Statistical methods in water resources. *Hydrol Anal Interpret* 4(3):1–524. <https://doi.org/10.2307/1269385>
- IPCC (2014) Climate change 2014: synthesis report, Core Writing Team. R.K. Pachauri and L.A. Meyer. <https://doi.org/10.1017/CBO9781107415324.004>
- Karpouzou DK, Kavalieratou S, Babajimopoulos C (2010) Trend analysis of precipitation data in Pieria Region (Greece). *Eur Water* 30:31–40
- Kendall MG (1962) ‘Rank correlation methods’ Hafner, 3rd edn. Publishing Company, New York
- Khadr M (2017) Recent trends and fluctuations of rainfall in the Upper Blue Nile River Basin, pp 451–466. https://doi.org/10.1007/698_2017_1.
- Kousari MR, Zarch MAA (2011) Minimum, maximum, and mean annual temperatures, relative humidity, and precipitation trends in arid and semi-arid regions of Iran. *Arab J Geosci* 4(5):907–914. <https://doi.org/10.1007/s12517-009-0113-6>
- Kousari MR, Ekhtesasi MR, Tazeh M, Naeini MAS, Zarch MAA (2011) An investigation of the Iranian climatic changes by considering the precipitation, temperature, and relative humidity parameters. *Theor Appl Climatol* 103(3–4):321–335. <https://doi.org/10.1007/s00704-010-0304-9>
- Liuzzo L, Freni G (2015) Analysis of extreme rainfall trends in Sicily for the evaluation of depth-duration-frequency curves in climate change scenarios. *J Hydrol Eng* 20(12):04015036. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0001230](https://doi.org/10.1061/(ASCE)HE.1943-5584.0001230)
- Mann HB (1945) Nonparametric tests against trend. *Econometrica* 13: 245–259
- Mengistu D, Bewket W, Lal R (2014) Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. *Int J Climatol* 34(7):2278–2292. <https://doi.org/10.1002/joc.3837>
- Modarres R, de Paulo Rodrigues da Silva V (2007) Rainfall trends in arid and semi-arid regions of Iran. *J Arid Environ* 70(2):344–355. <https://doi.org/10.1016/j.jaridenv.2006.12.024>
- Nashwan MS, Shahid S, Rahim NA (2018) Unidirectional trends in annual and seasonal climate and extremes in Egypt. *Theor Appl Climatol*. <https://doi.org/10.1007/s00704-018-2498-1>
- National Oceanic and Atmospheric Administration | U.S. Department of Commerce. Available at: <http://www.noaa.gov/>. Accessed: 1 November 2016
- Norran C, Douguédroit A (2006) Monthly and daily precipitation trends in the Mediterranean (1950–2000). *Theor Appl Climatol* 83(1–4): 89–106
- Onyutha C, Tabari H, Taye MT, Nyandwaro GN, Willems P (2016) Analyses of rainfall trends in the Nile River Basin. *J Hydro Environ Res* 13:36–51
- Philandras CM, Nastos PT, Kapsomenakis J, Douvis KC, Tselioudis G, Zerefos CS (2011) Long term precipitation trends and variability within the Mediterranean region. *Nat Hazards Earth Syst Sci* 11(12):3235–3250
- Russia’s Weather - forecast, weather conditions, weather archive. Available at: <http://meteo.infospace.ru/main.htm>. Accessed: 1 November 2016
- Santos M, Fragoso M (2013) Precipitation variability in Northern Portugal: data homogeneity assessment and trends in extreme

- precipitation indices. *Atmos Res* 131:34–45. <https://doi.org/10.1016/j.atmosres.2013.04.008>
- Sen PK (1968) Estimates of the regression coefficient based on Kendall's Tau. *J Am Stat Assoc* 63(324):1379–1389. <https://doi.org/10.1080/01621459.1968.10480934>
- Shalby A, Elshemy M, Zeidan BA (2018) Climate change impacts on the hydrodynamic characteristics of Lake Burullus, Coastal Lagoon (Egypt). In: Sixth International Conference on Estuaries and Coasts" (ICEC-2018)At: Caen, France
- Shourav MSA, Shahid S, Singh B, Mohsenipour M, Chung E-S, Wang X-J (2017) Potential impact of climate change on residential energy consumption in Dhaka City. *Environ Model Assess* 23:131–140. <https://doi.org/10.1007/s10666-017-9571-5>
- Suhaila J, Deni SM, Zawiah Zin WAN, Jemain AA (2010) Trends in Peninsular Malaysia rainfall data during the southwest monsoon and northeast monsoon seasons: 1975-2004. *Sains Malays* 39(4): 533–542. <https://doi.org/10.1007/s00703-010-0108-6>
- Tesemma ZK, Mohamed YA, Steenhuis TS (2010) Trends in rainfall and runoff in the Blue Nile Basin: 1964-2003. *Hydrol Process* 24(25): 3747–3758. <https://doi.org/10.1002/hyp.7893>
- Tramblay Y, El Adlouni S, Servat E (2013) Trends and variability in extreme precipitation indices over Maghreb countries. *Nat Hazards Earth Syst Sci* 13(12):3235–3248. <https://doi.org/10.5194/nhess-13-3235-2013>
- Valdes-Abellan J, Pardo MA, Tenza-Abril AJ (2017) Observed precipitation trend changes in the western Mediterranean region. *Int J Climatol* 37:1285–1296
- Yates DN, Strzepek KM (1998) An assessment of integrated climate change impacts on the agricultural economy of Egypt. *Clim Chang* 38(3):261–287. <https://doi.org/10.1023/A:1005364515266>
- Yue S, Wang CY (2004) The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resour Manag* 18(3):201–218. <https://doi.org/10.1023/B:WARM.0000043140.61082.60>
- Yue S, Pilon P, Cavadias G (2002) Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *J Hydrol* 259(1–4):254–271. [https://doi.org/10.1016/S0022-1694\(01\)00594-7](https://doi.org/10.1016/S0022-1694(01)00594-7)
- Zelenáková M, Purcz P, Hlavatá H, Gargar I, Portela MM (2014) Statistical trends of precipitation in chosen climatic station in Slovakia and Libya. *WSEAS Trans Environ Dev* 10(1):298–305
- Zhang Q, Singh VP, Peng J, Chen YD, Li J (2012) Spatial-temporal changes of precipitation structure across the Pearl River basin, China. *J Hydrol* 440–441:113–122. <https://doi.org/10.1016/j.jhydrol.2012.03.037>

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