CLIMATE CHANGE EFFECTS ON ANNUAL RAINFALL CHARACTERISTICS IN EGYPT

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ABSTRACT

During the 20th century, the intensity and frequency of extreme events (*i.e.*, storms and floods)have significantly changed due to human-induced climate change. Recently, it has been recognized that regions in Egypthave become more vulnerable to extreme rainfall events which lead in some cases to severe flash floods.In this work, the variability of annual rainfall characteristics in Egypt was investigated based on a detailed statistical analysis of historical rainfall records of 31 stations. The parametric test(Pearson) and the non-parametric tests (Mann-Kendall and Spearman's Rho) were applied on four precipitation indices: Annual Maximum Precipitation (AMP), Annual Total Precipitation (ATP) andAnnual Number of Rainy Days (ANRD). The results showed that about 29% of the analyzed stations exhibited significant trends, where no special patterns of trends were found and most of them were decreasing trends.

Keywords: Climate change, Extreme Rainfall, Mann-Kendall, Spearman, Pearson, Egypt.

1 INTRODUCTION

An accurate estimation of extreme rainfall events is important for water resources management. Therefore, detecting rends 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 (CC) relate to precipitation and temperature (Kousari et al., 2011). In addition to the increase of surface temperature, the change in precipitation 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 CC on water resources availability. In the last decades, Egypt has been facing the climate change impacts on several aspects such as: human health, agriculture production, water quality, and extreme rainfall events.

Recently, a large number of studies have analyzed trends in rainfall data in order to assess the effects of climate change on hydrologic time series around the world. For instance, Adamowski and Bougadis (2003) analyzed annual maximum observations for different durations from the province of Ontario, (Canada). They found the six out of eight regions for 5 and 10 min rainfall durations had trends.Burn and Taleghani (2013) analyzed annual maximum rainfall trends by using the Mann-Kendall(MK) test over Canada. They showed that trend analysis has revealed more increasing trends than decreasing trends in annual maximum precipitation.In Malaysia, Suhaila et al. (2010) investigated trends in daily rainfall for the period of 1975-2004. The results of the MK test indicated decreasing trends in the total rainfall amount and frequency of wet days, in addition to increasing trends in rainfall intensity during the southwest monsoon. Amirabadizadehetal.(2015) applied the MK test and Sen's slope method over the Langat River Basin (Malaysia). The MK results showed increasing and decreasing trends in bothannual and seasonal precipitation. While the Sen’s slope results showed that the rate of increment in the seasonal precipitation was lower than that of the annual precipitation.

Several studies have addressed precipitation changes by identifying various precipitation indices. Modarres and Silva (2007) investigated annual rainfall, annual number of rainy days and monthly rainfall in arid and semi-arid regions in Iran. Their results showed increasing and decreasing trends inmonthly rainfallover the region,when monthly rainfall significant trends happened mostly in spring and winter.Kousari et al., (2011)investigated monthly and annual trends in minimum, maximum and mean temperature and precipitation in Iran using theMK test. They showed that most of stations had significant decreasing trends in precipitation. In contrast, Kousari and Zarch ,(2011) did not detect any significant trends for precipitation when analyzed annual precipitation by the MK test over the arid and semi-arid regions of Iran. Brunetti et al., (2001) examined changes of annual and seasonal precipitation and number of rainy days over the North-Eastern Italy. They found decreasing significant trends in annual number of rainy days and concluded that significant trends were more evident in spring and autumn. Crisci et al., (2002) examined records of 81 rain gauges in Tuscany (Italy) with the aim of detecting trends of historical extreme rainfall of different duration.They showed that extreme events increased for all durations. A recent study by Liuzzo and Freni (2015)analyzed trends in extreme rainfall series for durations 1,3,6,12 and 24 h for the period of 1950-2008 in Sicily (Italy), and they concluded that increasing trends of extreme rainfall led to an increase in the number of the occurrence of floods.

The comparison between the different methods of trend detection was the main subject of many studies. For example,Yue et al., (2002) compared the power of the Mann-Kendall (MK) and Spearman (SR) tests for detecting the monotonic trend in time series. They stated that the power of the test depends on the slope of trend, level of significance, sample size, and properties of the datasets, such as skewness and variation. The results confirmed that both tests provided the same consequences in the absence of autocorrelation.

In the blue Nile basin, Mengistu et al., (2014)investigated spatial and temporal variability of rainfall at seasonal and annual time scales overthe upper Blue Nile Basin (Ethiopia). Their results showed that the annual total rainfall had statistically non-significantincreasing trends. Similarly, the seasonal rainfall had statistically non-significantincreasing trends for winter, spring, summer and autumn seasons.In the Middle East and North Africa (MENA) region, few studies were conducted in order to study the characteristics in rainfall data. For instance,Bani-Domi (2005)used the MK test and log-one serial correlation to study the climate change impact of extreme rainfall in Jordan. For the total rainfall, he concluded that most of the stations had negative trends in the case of total rainfall.Zeleňáková et al.,(2014)investigated precipitation trends in climatic stations in Libya using the MKtest.Their results showed that there were increasing and decreasing trends in the study area.Gado,(2017) examined the statistical characteristics of extreme rainfall events in Egypt and concluded that there was a great variation of rainfall characteristics over the whole country.

Studying changes in meteorological variables (*i.e.*, rainfall) in developing countries such as Egypt did not receive enough concern. Scanning the literature for climate change effects on rainfall characteristics in Egypt reveals that nothing has been done in regard to detection rainfall trends. Therefore, the main aim of this study is to detect trends of annual maximum precipitation, annual total precipitation, and annual number of rainy days over Egypt using non-parametric and parametric tests.

2 METHODOLGY

2.1 Study area and Data

Egypt is in the northeast corner of Africa located from 22˚ to 31˚ N in latitude and 24˚ to 36˚E in longitude. It is surrounded by the Mediterranean Sea in the north, the red seain the east, Libya in the west, andSudan in the south. Egypt hasan area of 1,019,600 km^2,where its coastline extends for more than 3,500km² along to the Mediterranean Sea and the red sea. Thus, the geography of Egypt characterized by two different regions: North Africa and southwest Asia. In general, Egypt's geological history has produced four major physical regions: Nile valley and Nile delta, eastern desert, western desert and Sinai Peninsula. Egypt's climate is semi desert, characterized by hot dry summers and moderate winters with little rainfall(Elmenoufy et al., 2017).

Daily precipitation datafrom 31 stations were analyzed. Precipitation data were obtained from multiple sources in order to get long record over the available stations. The database was extracted from the National Oceanic and Atmospheric Administration’s (NOAA) National Climatic Data Center (NCDC) https://www.ncdc.noaa.govand the 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 1shows some ofthe characteristics of the selected stations used in this study.

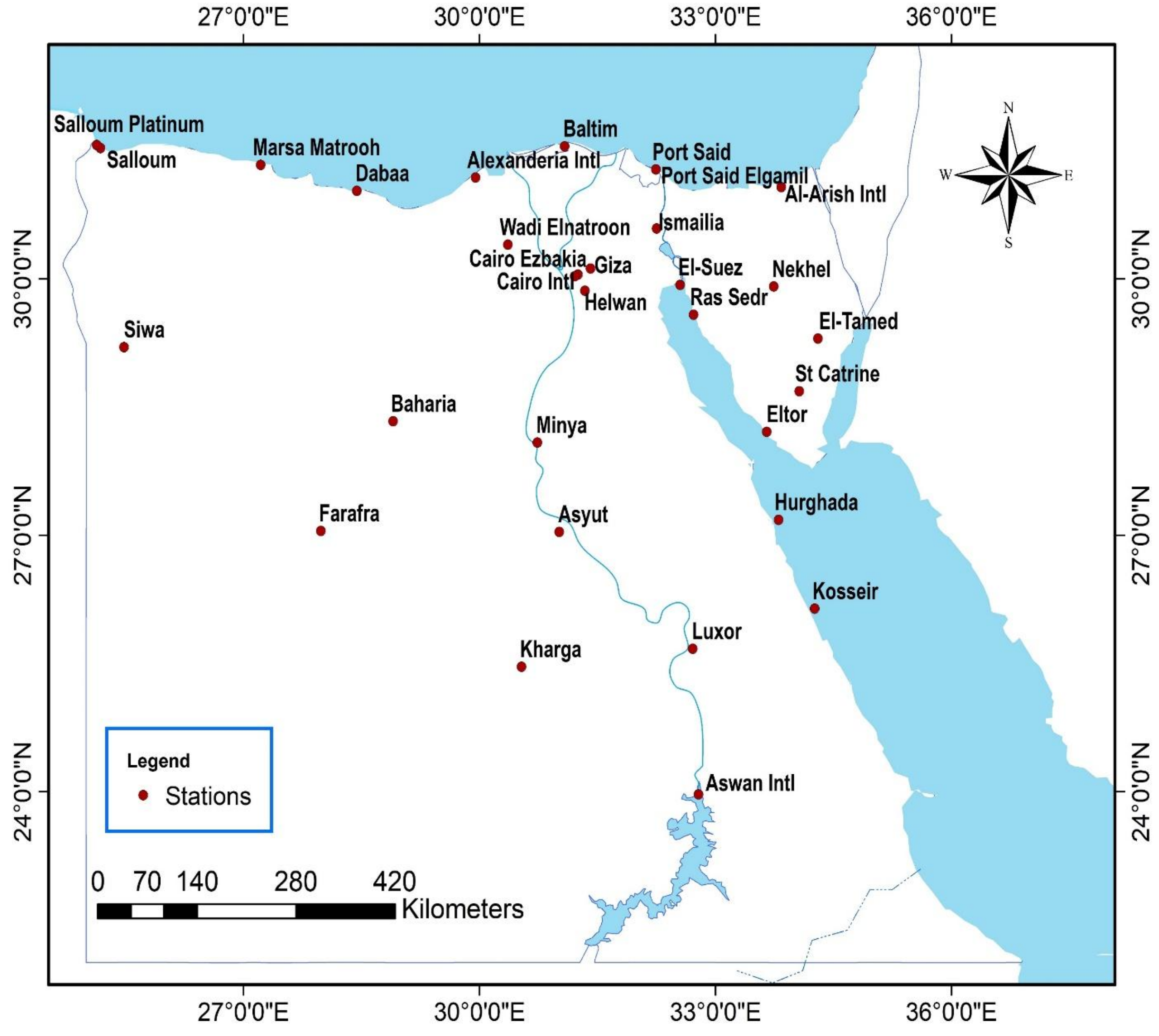

Figure 1.Geographical locations of the selected gauging stations in Egypt

2.2 Data quality assessment

Rainfall records, as a part of climatic data, often contain inhomogeneities for many reasons such as:changes in data collecting method, relocating the stations, equipment changes, drifts of equipment(Alexandersson and Moberg, 1997). Data inhomogeneity within the time series may cause wrong predictions and wrong interpretations of extreme events. Abrupt changes in the mean are one of the normal outcomes from inhomogeneity in the time series data(Santos and Fragoso, 2013). In this study, three homogeneity tests were used: The Standard Normal Homogeneity Test (SNHT), Pettit's test, and Von Neumann (VN). All-time series data were checked at 5% significance level.

Table 1. 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-ArishIntl	31.07	33.84	36.9	1985-2016	-	31
62318	Alexandria Intl	31.18	29.95	-1.8	1957-2016	1967–1972	53
62414	Aswan Intl	23.97	32.78	200	1991-2015	1992,2003,2004, 2010,2011	24
62393	Asyut	27.04	31.01	226	1979-2016	1986-1989,1995-1999	37
62420	Baharia	28.33	28.90	130	1984-2016	1985,1992	32
62325	Baltim	31.55	31.08	2	1994-2016	-	22
62374	Cairo Ezzbakia	30.05	31.25	20	1909-1957	-	48
62366	Cairo Intl	31.12	41.41	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	22
62423	Farafra	27.05	27.98	92	1957–2016	1967-1975,1977–1992	59
62375	Giza Cairo	30.03	31.21	28	1924–1957	1941-1943	33
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	26
62440	Ismailia	30.59	32.25	13	1981–2013	1994	32
62435	Kharga	25.46	30.53	73	1961–2014	-	53
62465	Kossier	26.14	34.26	11	1960–2014	1967-1972	54
62405	Luxor	25.67	32.71	99	1990–2016	-	26
62306	MarsaMatrooh	31.33	27.22	30	1920–2016	1923,1941 – 1944, 1967-1973,1976	96
62387	Minya	28.08	30.73	31	1984–2015	1985,1986,1999, 2003,2009,2010	31
62452	Nekhel	29.91	33.74	402	2001–2014	-	13
62333	Port said	31.28	32.24	2	1901–2016	1967 – 1978, 2001-2012	115
62332	Port Said Elgamil	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	46
62305	SalloumPlateau	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	31
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	20

2.3 Trend tests

Two techniques are usually used for detecting a trend in hydrologic data: parametric and non-parametric. The non-parametric approachis the most widely used for the analysis of extremes(Gado and Nguyen, 2013),as no assumption regarding the distribution function of the selected random variable is required. However, the results of this technique can be affected by the presence of serial correlations. In contrast, the parametric techniques require the selected random variable to follow some distributions (*e.g.*, normal distribution).

The non-parametric tests used here were the Mann Kendall and the Spearman's Rho. For the parametric test, the Pearson's *r* was used. Moreover, the Sen's non-parametric method was used to estimate the magnitude of trends in the rainfall time series data.

2.3.1. 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 2):

1. The "extremely likely" denotes that both parametric and non-parametric tests accept the null hypothesis of a trend with at least one of them has a significant level of 5%.
2. The "likely" denotes that both tests accept the null hypothesis of a trend with a significant level of 10% or only one test accepts the null hypothesis with a significant level of 5%.
3. The "less likely" denotes that only one test accept the null hypothesis of a trend with a significant level of 10%.

Table 2. Trend classification according to the parametric and non-parametric tests and the level of significant

Parameteric Test		Non-Parametric Test		Trend Classification
5%	10%	5%	10%	
✓	✓	✓	✓	extremely likely
✓	✓		✓	
	✓	✓	✓	
	✓		✓	Likely
✓	✓			
		✓	✓	
	✓			less likely
			✓	

3 RESULTS AND DISCUSSIONS

3.1 Data quality assessment

Three homogeneity tests were applied on three precipitation indices in the available stations. The results showed that all stations are homogeneous except CairoIntlstation for only annual maximum precipitation data.To make the annual maximum precipitation data homogeneous in Cairo Intl station, the data from 2012 to 2016 were removed,and then it became homogeneous according to the three homogeneity tests. Figure 2 illustratesthe annual maximum precipitationbefore and after homogenization for this station.

3.2 Temporal trends

3.2.1 Annual Maximum precipitation (AMP)

The annual maximum precipitation (AMP) series were analyzed for each station by the non-parametric tests (Mann-Kendall and Spearman) and the parametric test (Pearson), and the magnitudes of the significant trends were obtained by the Sen's slope estimator. Table 3 shows the results of the significant trends of the AMP. It can be shown that the results of both non-parametric tests are almost the same. In contrast, the results of the parametric test are different from the other two tests. Figure 3 shows the spatial distribution of the significant trends for the AMP. The results indicated that nine out of 31 stations had significant trends of AMP. All the detected trends were negative except two stations (Cairo Intl and Luxor) which had positive trends.

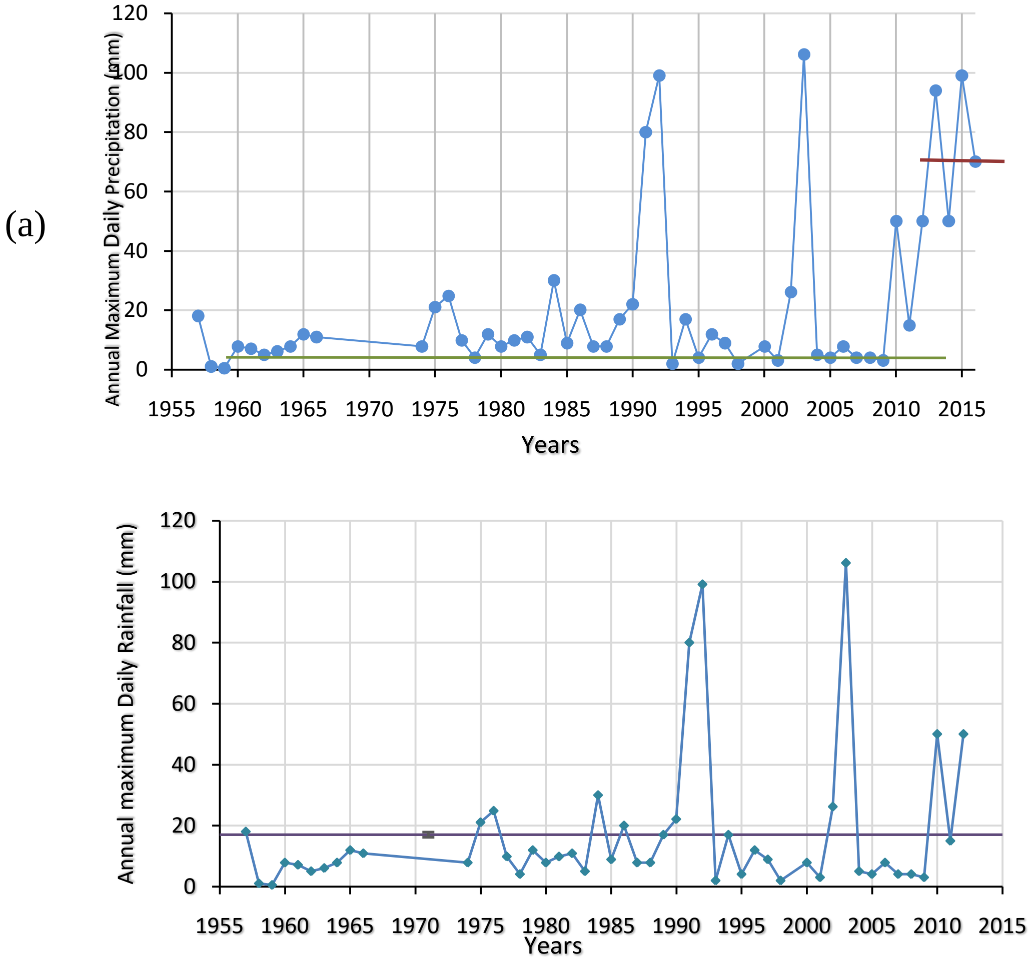

Figure 2.Annual maximum daily rainfall for Cairo Intl station; (a) before homogenization, (b) afterhomogenization.

Table 3. Results of thesignificant trends of the annual maximum precipitation

Station	Period years	MK	SR	Pearson	Sen's slope (mm/day)	Classification
Bahria	1984-2016			✓*	-0.145	Likely
Cairo Intl	1957-2015	✓*		✓**	0.463	Extremely likely
El-Tamed	1982-2006	✓*	✓*		-0.412	Likely
Farafra	1957-2016	✓*	✓*		-0.635	Likely
Helwan	1904- 1957		✓*		-0.332	Likely
Ismailia	1981-2013	✓*	✓*		-0.269	Likely
Luxor	1990-2016	✓**	✓**		0.192	Less Likely
Port Said	1901-2016	✓**	✓**	✓**	-0.137	Extremely Likely
St Catrine	1980-2006			✓*	-0.227	Likely

* Significance level at 5%
** Significance level at 10%

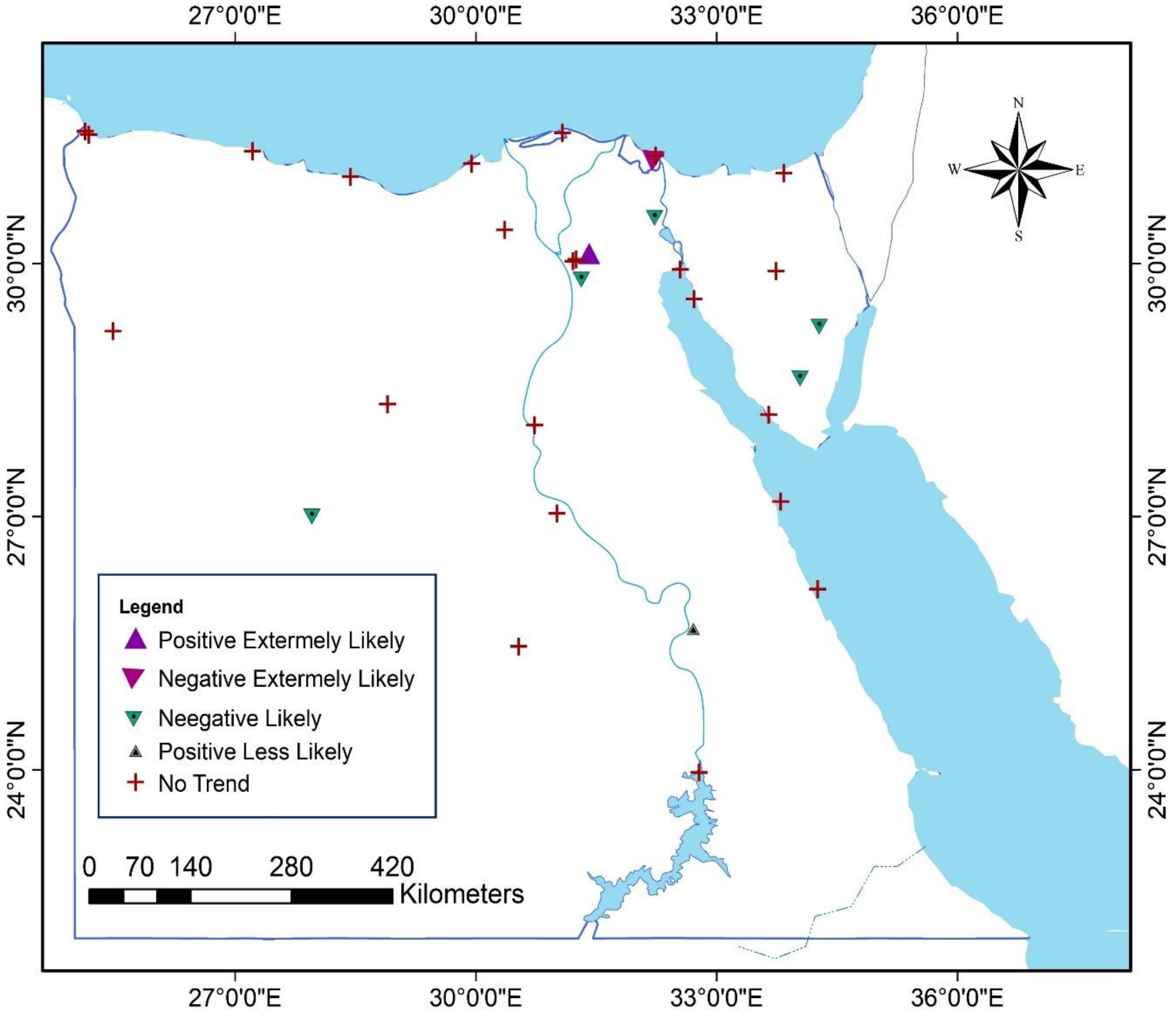

Figure 3. Annual Maximum Daily Rainfall Trends in the selected stations

3.2.2 Total Annual Precipitation (TAP)

The non-parametric tests and the parametric test were also applied to detect trends of total annual precipitation (TAP) for all selected stations. The results of the significant trends of the TAP are shown in Table 4. It can be shown that the results of both non-parametric tests are the same but different from the parametric test. Figure 4 shows the spatial distribution of the significant trends for the TAP. The results indicated that six out of 31 stations had significant trends of TAP. All the detected trends were negative except twostations (Cairo Intl and Luxor) which had positive trends.

Table 4.Results of the significant trends of the total annual precipitation

Station	Period years	MK	SR	Pearson	Sen's slope (mm/day)	Classification
Cairo Intl	1957-2015	✓*	✓*	✓*	0.463	Extremely likely
Farafra	1957-2016	✓*	✓*		-0.696	Likely
Helwan	1904- 1957	✓*	✓*		-0.350	Likely
Ismailia	1981-2013	✓*	✓*		-0.896	Likely
Luxor	1990-2016	✓**	✓**		0.312	Less likely
Port Said	1980-2006	✓**	✓**	✓**	-0.323	Extremely Likely

* Significance level at 5%
** Significance level at 10%

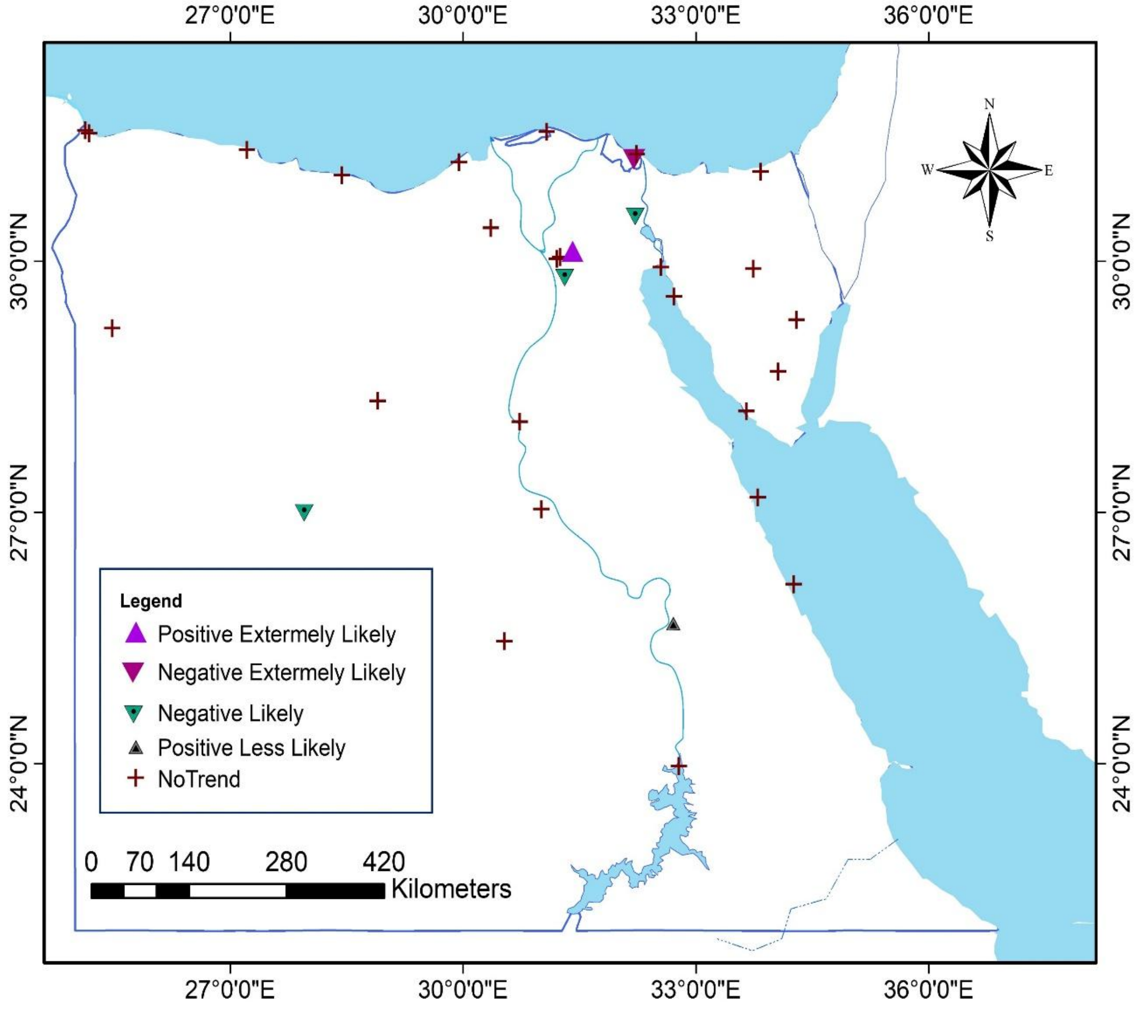

Figure 4. Total annual rainfall trends in the selected stations

3.2.3Annual Number of Rainy days (ANRD)

The results of the significant trends of the annual number of rainy days (ANRD) are shown in Table 5 and Figure 5. Only four stations had significant trends according to the three tests, which gave almost the same results in this case. Two stations (Dabaa and MarsaMatrooh) exhibited positive extremely likely trends, one station (RasSedr) exhibited a negative extremely likely trend, and one station (Wadi El-Natron) exhibited a negative likely trend.

Table 5.Results of the significant trends of the annual number of rainy days

Station	Period years	MK	SR	Pearson	Sen's slope (days)	Classification
Dabaa	1999-2015		✓*	✓*	0.200	Extremely likely
MarsaMatrooh	1920-2016	✓*	*✓	✓*	0.167	Extremely likely
RasSedr	2000-2014	✓*	*✓	✓*	-0.250	Extremely likely
Wadi El-Natron	1996-2016	✓**		✓**	-0.500	Likely

* Significance level at 5%
** Significance level at 10%

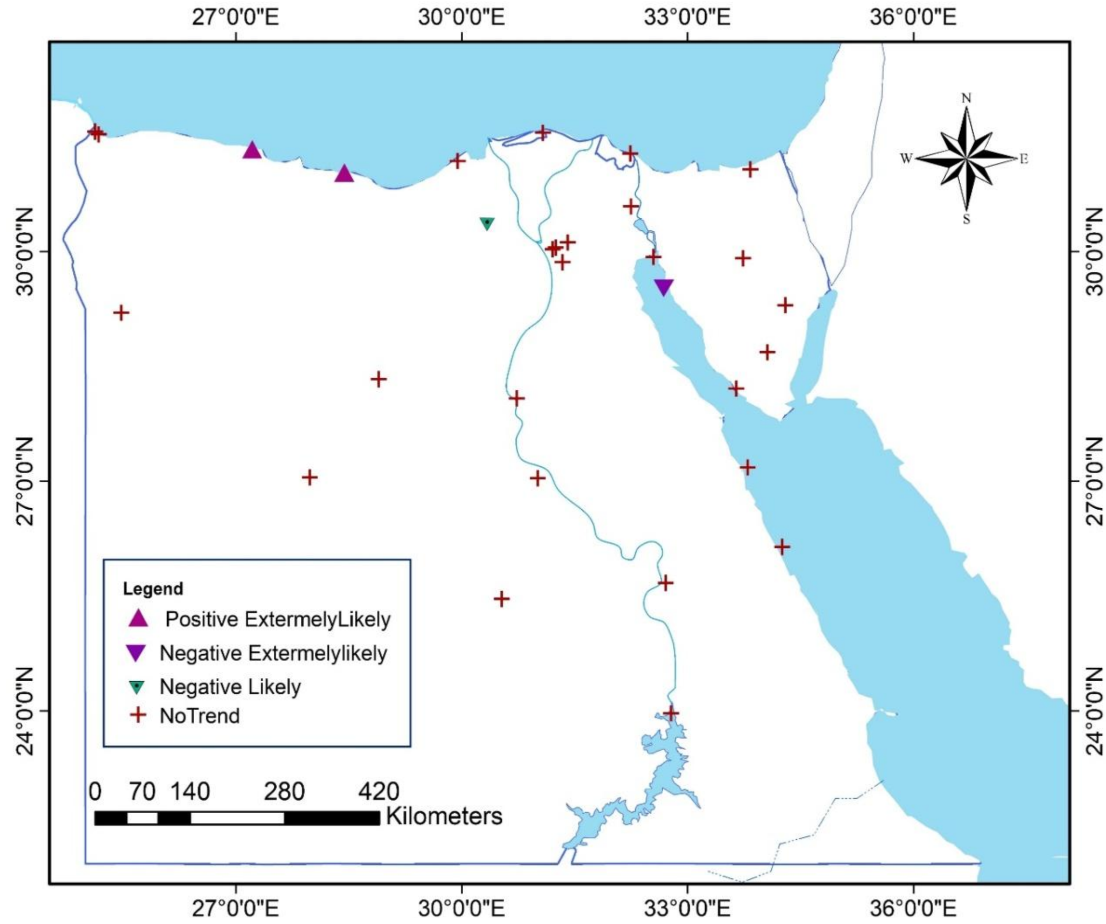

Figure 5. Annual number of rainy days trends in the selected stations

4 CONCLUSIONS

This study investigates the possible change in rainfall patterns based on a detailed statistical analysis of the historical daily rainfall records available at 31 stations in Egypt. Both non-parametric tests (MK and SR) and parametric test (Pearson) were used to examine temporal trends in the annual maximum daily precipitation (AMP), total annual precipitation (TAP) and annual number of rainy days (ANRD). The main findings of this paper can be summarized as follows:

1. Significant trends in the AMP were detected for a high proportion (29%) of the stations. All these trends were decreasing except two stations (Cairo Intl and Luxor).
2. Significant trends in the TAP were detected for a proportion (19%) of the stations. All these trends were decreasing except two stations (Cairo Intl and Luxor).
3. Significant trends in the ANRD were detected for a small proportion (13%) of the stations. Two stations exhibited decreasing trends (RasSedr and Wadi El-Natron), while other two stations exhibited increasing trends (Dabaa and MarsaMatrooh).

In general, the detected trends did not form any systematic spatial pattern. Nevertheless, most of the detected trends were negative indicating a decrease in the amount of precipitation in these regions. 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. Consequently, it is recommended to locate more meteorological stations in order to determine the climate change signature (if any) in rainfall data in Egypt.

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