STATISTICAL CHARACTERISTICS OF EXTREME RAINFALL EVENTS IN EGYPT

Tamer A. Gado[1]

[1] *Assistant Professor, Dept. of Irrigation and Hydraulics Engineering, Faculty of Engineering, Tanta Univ., Tanta, Egypt.*
E-mail: tamer.gado@f-eng.tanta.edu.eg; tamergado@hotmail.com

ABSTRACT

The occurrence of extreme rainfall events and their impacts on hydrologic systems and society are critical considerations in the design and management of numerous water resources projects. Recently, Egypt receives a significant amount of rainfall during specific storm events in particular regions (*e.g*., Sinai, North Coast, and Upper Egypt). These amounts of water lead to flash floods that cause damages to lives, property and livestock. This paper investigates therefore the statistical characteristics of rainfall extremes in Egypt based on historical annual maximum daily rainfall records for 30 stations throughout the country. Rainfall frequency analysis based on annual maximum series (AMS) was used in this study. In particular, the Generalized Extreme Value (GEV) distribution along with the L-moments parameter estimation method were applied to analyze the AMS. Results of the numerical application indicate a great variation over the whole country in all different aspects of rainfall.

Keywords: Rainfall Frequency analysis; rainfall extremes; Generalized Extreme Value; Egypt.

1 INTRODUCTION

An accurate estimation of extreme rainfall (magnitude, duration, and frequency) is fundamental for the planning and design of various hydraulic structures. Therefore, many studies have focused on the development of methods for improving the accuracy of extreme rainfall estimation. In this regard, rainfall frequency analysis (RFA) is commonly used to estimate the rainfall rate/volume for a given return period at a given site of interest.

In RFA, it is extremely important to find an accurate relationship between an extreme rainfall magnitude Q and the corresponding recurrence interval T. The commonly used extreme rainfall estimation models are based on annual maximum series (AMS). The AMS of rainfall data contains only the maximum peak rainfall in each year; therefore, for an n-year rainfall record, the AMS consists of n annual maximum rainfall values(Gado and Nguyen 2016).

Recently, some studies have analyzed extreme rainfall events in Sinai, Egypt (*e.g*., El-Sayed 2011; Cools *etal*. 2012; Moawad 2013; El-Afandi*etal*. 2013; Ibrahim and El-Afandi 2014; Fathy*et al*. 2014). Nonetheless, scanning the literature for statistical analysis of rainfall events in Egypt reveals that little has been done in regard to estimation of extreme rainfall events. Thus, in this paper, a thoroughly study of the statistical characteristics of rainfall in Egypt will be conductedin order to develop methods for extreme rainfall estimation in gauged and ungauged sites in Egypt.

2 STATISTICAL ANALYSIS

2.1 Data

In this study, data were compiled from multiple sources in order to get long record over the available stations. Then, data have been checked for consistency over the periods of overlap before being merged into a single record for each station. The database was extracted from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) https://www.ncdc.noaa.gov and the Russia's Weather Server http://meteo.infospace.ru/main.htm.

After building the database which consists of 30 stations throughout Egypt (Fig. 1),three types of rainfall data were established as follows:

1. The total annual rainfall data: the sum of daily rainfall data over each year;
2. The annual number of rainy days data: the sum of rainy days over each year; and
3. The annual maximum daily rainfall data.

Table 1 provides some of the characteristics of the selected stations used in this study. The periods of observation and the number of years observed for each station are also listed in Table 1. The length of the rainfall series varies from 14 to 81 years, with an average of 30 years. It can be noticed that the maximum record length is 81 years at MarsaMatrooh, while the minimum record length is 14 years at Nekhel.

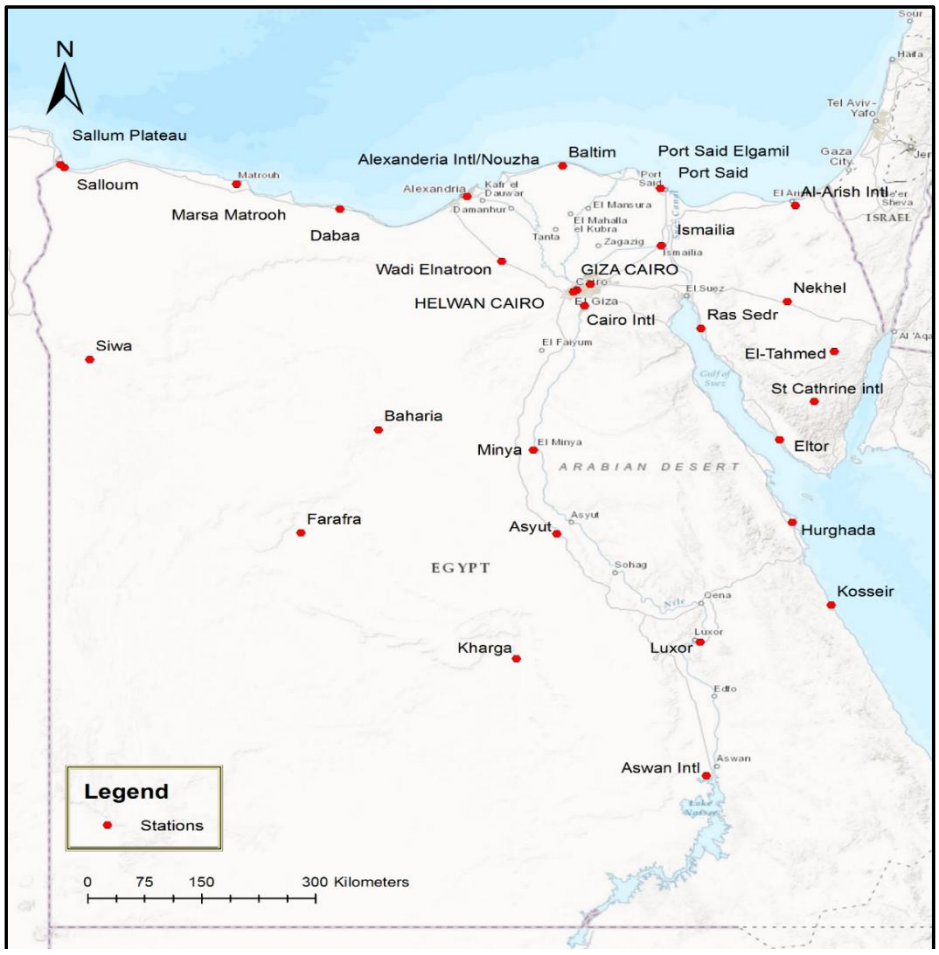

Figure 1. Geographical locations of the selected gauging stations in Egypt

Table 1. Summary of the characteristics of the selected stations in Egypt

Station ID	Station Name	Latitude	Longitude	Elevation (m)	Period of Record	Missing Years	Record Length (years)
62337	Al-Arish Intl	31.07	33.84	36.9	1985 - 2015	-	31
62318	Alexanderia Intl	31.18	29.95	-1.8	1957 - 2015	1967 - 1972	53
62414	Aswan Intl	23.97	32.78	200	1957 - 2015	1967 - 1972	21
62393	Asyut	27.04	31.01	226	1957 - 2014	1967 - 1972	19
62420	Baharia	28.33	28.90	130	1957 - 2015	1967 – 1982, 1992	24
62325	Baltim	31.55	31.08	2	1994 - 2015	-	22
62366	Cairo Intl	30.12	31.41	75	1944 - 2015	1947 - 1956, 1967 - 1972	51
147728	Cairo Ezbekiya	30.05	31.25	20	1909 - 1957	1941 - 1943	46
62309	Dabaa	31.03	28.44	18	1963 - 2015	1967 - 1998	21
	El-Tahmed	29.30	34.30	625	1922 - 1955	-	31
62459	Eltor	28.21	33.65	35	1960 - 2015	1967 - 1993	22
62423	Farafra	27.05	27.98	92	1957 - 2014	1967 - 1975, 1977 - 1992	16
62375	Giza Cairo	30.03	31.21	28	1924 - 1957	1941 - 1943	31
147730	Helwan Cairo	29.86	31.34	116	1904 - 1957	-	54
62463	Hurghada	27.18	33.80	14	1991 - 2015	2000, 2006, 2008, 2009, 2011, 2012	16
62440	Ismailia	30.59	32.25	13	1987 - 2013	-	26
62435	Kharga	25.46	30.53	73	1957 - 2014	1958 - 1959, 1967 - 1972, 1975 - 1981	15
62465	Kosseir	26.14	34.26	11	1960 - 2014	1967 - 1972	25
62405	Luxor	25.67	32.71	99	1944 - 2015	1946 - 1956, 1967 - 1972	32
62306	MarsaMatrooh	31.33	27.22	30	1920 - 2015	1923, 1941 - 1944, 1967 - 1973, 1975, 1976	81
62387	Minya	28.08	30.73	37	1957 - 2015	1967 - 1972, 1978	30
62452	Nekhel	29.91	33.74	403	2001 - 2014	-	14
62333	Port Said	31.28	32.24	2	1957 - 2015	1967 - 1972, 1974 - 1978, 1990	22
62332	Port Said Elgamil	31.28	32.24	6	1987 - 2014	-	27
62455	RasSedr	29.58	32.72	16	2000 - 2015	-	15
62300	Salloum	31.53	25.18	6	1957 - 1995	1967 - 1979	26
62305	Sallum Plateau	31.57	25.13	6	1996 - 2015	2013	19
62417	Siwa	29.20	25.48	-12	1920 - 2015	1923, 1941 - 1944, 1967 - 1978, 1984, 1986, 2014	59
623664	St Catherine Intl	28.69	34.06	1331	1934 - 2006	1938 - 1979	31
62357	WadiElnatroon	30.40	30.36	1	1996 - 2015	1999, 2013. 2014	17

3 RESULTS

The independence, homogeneity and outlier of data on annual maximum daily rainfalls in the available stations were tested. The data is verified to be independent and homogeneous; and very few outliers were detected and then removed from the data base. Three types of rainfall data were investigated as mentioned before: total annual rainfall, annual number of rainy days, and annual maximum daily rainfall.

3.1 Analysis of Total Annual Rainfall Data

Basic statistical characteristics such as: the number of observations, the mean, the standard deviation, the coefficient of variation, the maximum, and the minimum were derived from the total annual precipitation data of the available rainfall stations in Egypt (Table 2). It can be concluded that the statistical characteristics of the total annual precipitation have high variations. Overall, the mean ranged from 5 to 153 mm; the standard deviation(6 to 85 mm);the coefficient of variation(0.46 to 2.81); the maximum (27 to 401 mm); and the minimum (0 to 9 mm).It can be shown that the mean of the total annual precipitation exceeded 100 mm at four stationslocated on the North Coast (Fig. 1): Alexanderia Intl (153 mm), Baltim (139 mm), MarsaMatrooh (122 mm), and Dabaa (108 mm). The maximum of the total annual precipitation in the case study was 401 mm occurred at MarsaMatrooh(Table 2) in 1994. On the other hand, the mean total annual precipitation did not exceed 10 mm at four stations located on the middle and the south of the country (Fig. 1): Baharia (5 mm), Aswan Intl (9 mm), Siwa (9 mm), and RasSedr (10 mm).

Table 2. Summary of the statistical characteristics of the total annual precipitation of the selected stations

Station	Mean (mm)	Standard deviation (mm)	Coefficient of variation	Maximum (mm)	Minimum (mm)
Al-Arish Intl	89	53	0.59	205	9
Alexanderia Intl	153	85	0.56	352	7
Aswan Intl	9	25	2.81	117	1
Asyut	30	76	2.56	316	1
Baharia	5	6	1.25	27	0
Baltim	139	64	0.46	236	4
Cairo Intl	38	32	0.84	129	1
Cairo Ezbekiya	24	19	0.76	92	1
Dabaa	108	63	0.58	257	5
Eltor	16	23	1.39	83	1
Farafra	13	18	1.39	70	1
Giza Cairo	22	16	0.74	61	3
Helwan Cairo	30	20	0.68	92	1
Hurghada	42	45	1.05	147	1
Ismailia	45	67	1.49	310	3
Kharga	14	25	1.80	73	1
Kosseir	14	15	1.10	53	1
Luxor	20	31	1.53	124	1
MarsaMatrooh	122	80	0.65	401	1
Minya	15	24	1.54	80	1
Nekhel	22	17	0.76	60	4

Port Said	45	45	0.99	168	1
Port Said Elgamil	89	76	0.86	397	7
RasSedr	10	7	0.69	32	1
Salloum	63	52	0.84	189	1
Sallum Plateau	51	41	0.80	173	3
Siwa	9	10	1.09	42	1
WadiElnatroon	34	33	0.98	111	2

3.2 Analysis of Annual Number of RainyDays Data

Table 3 presents some basic statistical characteristics of the annual number of rainy days of the selected stations in Egypt. The characteristics include the mean (1 to 31 days), the standard deviation (0.63 to 13.31 days), the coefficient of variation (0.36 to 1.03), the maximum (3 to 64 days), and the minimum (1 to 6 days).The mean of the annual number of rainy daysexceeded 20 days at six stations located on the North Coast: Baltim (31 days), Alexanderia Intl (30 days), Dabaa (30 days), MarsaMatrooh (28 days), Port Said Elgamil (23 days), and Al-Arish Intl (20 days). The maximum of the annual number of rainy days in the case study was 64 days occurred at Dabaa in 2000. In contrast, it can be shown that the mean annual number of rainy days did not exceed 5 days at 12 stations: Farafra, Aswan Intl, Asyut, Baharia, Hurghada, Kharga, Kosseir, Luxor, Eltor, Minya, Siwa, and RasSedr.

Table 3. Summary of the statistical characteristics of the annual number of rainy days of the selected stations

Station	Mean (day)	Standard deviation (day)	Coefficient of variation	Maximum (day)	Minimum (day)
Al-Arish Intl	20	9.12	0.45	37	3
Alexanderia Intl	30	13.24	0.45	56	2
Aswan Intl	2	1.03	0.65	4	1
Asyut	2	1.79	0.87	8	1
Baharia	2	1.46	0.71	6	1
Baltim	31	11.56	0.37	48	4
Cairo Intl	10	5.58	0.55	30	1
Cairo Ezbekiya	7	3.74	0.51	15	1
Dabaa	30	13.31	0.45	64	6
Eltor	3	1.93	0.66	8	1
Farafra	1	0.63	0.44	3	1
Giza Cairo	7	4.51	0.67	23	1
Helwan Cairo	9	4.47	0.50	22	1
Hurghada	2	0.80	0.41	3	1
Ismailia	12	5.19	0.44	20	3
Kharga	2	0.74	0.48	3	1
Kosseir	2	1.54	0.67	7	1
Luxor	2	1.91	0.86	10	1
MarsaMatrooh	28	13.31	0.47	54	1
Minya	3	1.46	0.58	6	1
Nekhel	6	2.58	0.45	10	2
Port Said	16	9.92	0.61	35	1

Port Said Elgamil	23	8.52	0.36	47	4
RasSedr	5	2.90	0.54	13	1
Salloum	17	10.71	0.61	37	1
Sallum Plateau	14	8.31	0.58	32	3
Siwa	3	3.37	1.03	19	1
WadiElnatroon	8	4.27	0.51	15	2

3.3 Analysis of Annual Maximum Daily Rainfall Data

One of the aims of this study is to determine the annual maximum daily precipitation in different regions in Egypt for several established return periods. For this purpose, the annual maximum daily rainfall series from 30 stations in Egypt have been analyzed.

Basic statistical characteristics such as: the number of observations, the mean, the standard deviation, the coefficient of variation, the maximum, and the minimum were derived from the annual maximum daily rainfall data of the 30 available rainfall stations in Egypt (Table 4). Overall, the mean ranged from 3 to 35 mm; the standard deviation(2 to 38 mm); the coefficient of variation (0.5 to 2.5); the maximum (8 to 142 mm); and the minimum (0 to 6 mm). It can be shown that the mean of the annual maximum daily rainfall exceeded 25 mm at only four stations: Hurghada (35 mm), Al-Arish Intl (29 mm), Alexanderia Intl (29 mm), and MarsaMatrooh (26 mm). The maximum of the annual maximum daily rainfall in the case study was 142 mm occurred at El-Tahmed in 1925 (Table 4). On the other hand, the mean of the annual maximum daily rainfall did not exceed 5 mm at two stations: Baharia (3 mm) and RasSedr (4 mm).

Table 4. Summary of the statistical characteristics of the annual maximum daily precipitation of the selected stations

Station	Mean (mm)	Standard deviation (mm)	Coefficient of variation	Maximum (mm)	Minimum (mm)
Al-Arish Intl	29	27	0.94	99	4
Alexanderia Intl	29	20	0.71	102	6
Aswan Intl	5	13	2.45	62	1
Asyut	8	13	1.53	52	1
Baharia	3	3	0.98	12	0
Baltim	24	21	0.87	102	2
Cairo Intl	21	28	1.33	106	1
Cairo Ezbekiya	10	9	0.87	43	1
Dabaa	24	20	0.83	99	2
El-Tahmed	18	28	1.50	142	0
Eltor	13	20	1.52	70	1
Farafra	12	18	1.50	70	1
Giza Cairo	10	11	1.07	53	2
Helwan Cairo	12	9	0.75	37	1
Hurghada	35	38	1.08	121	1
Ismailia	19	29	1.53	102	1
Kharga	8	13	1.57	40	1
Kosseir	9	10	1.09	32	1
Luxor	15	25	1.61	100	1

MarsaMatrooh	26	20	0.77	99	1
Minya	11	18	1.69	76	1
Nekhel	12	11	0.95	34	2
Port Said	13	11	0.86	44	1
Port Said Elgamil	24	28	1.19	103	1
RasSedr	4	2	0.53	8	1
Salloum	17	16	0.96	70	1
Sallum Plateau	20	20	1.03	92	2
Siwa	5	6	1.10	28	0
St Catherine Intl	12	16	1.29	76	1
WadiElnatroon	23	32	1.40	99	1

GEV distributions were fitted to each of the 30 annual maximum series of daily precipitation depths using the method of L-moments. The values of the parameters in the GEV functions fitted to every series are shown in Table 5. The averages over all stations and the dispersion characteristics (minimum and maximum values and standard deviations) of the three parameters of the GEV distribution are shown in Table 6. The most important parameter is the shape parameter (κ) because it determines the shape of the distribution and consequently the behavior of its tail. However, the estimation of the shape parameter involves a great deal of uncertainty because it depends on the skewness whose value cannot be determined accurately (Koutsoyiannis, 2004). The estimated values of the shape parameter range from -0.75 to 0.11 as shown in Table 6. It can be noticed that the estimated κ is negative for all stations except only one station (RasSedr) whose κ = 0.11 (Table 5).

Furthermore, the maximum daily precipitation for each station corresponding to return periods between 5 and 1000 years, have been estimated by using the GEV distribution with L-moments (Table 5). For the return period of 100 year as an example, the daily extreme rainfall estimation ranges from 11 mm at RasSedr to 203 mm at Hurghada. It can be shown that the 100-year daily extreme rainfall (P_{100}) exceeded 150 mm at six stations: Hurghada (203 mm), WadiElnatroon (185 mm), Ismailia (167 mm), Al-Arish Intl (159 mm), Port Said Elgamil (158 mm), and Cairo Intl (157 mm). In contrast, the P_{100} did not exceed 50 mm at six stations: RasSedr (11 mm), Baharia (17 mm), Siwa (33 mm), Helwan (47 mm), Cairo Ezbekiya (48 mm), and Aswan Intl (50 mm).

Table 5. Values of the parameters of the GEV distribution and daily extreme rainfall estimation of different return periods (PT) of the selected stations

Station	GEV parameters			P_T (mm)						
	Location (ξ)	Scale (α)	Shape (κ)	P_5	P_{10}	P_{25}	P_{50}	P_{100}	P_{200}	P_{1000}
Al-Arish Intl	15.66	11.86	-0.37	39	57	88	119	159	210	394
Alexanderia Intl	19.25	10.37	-0.25	38	51	70	88	109	134	212
Aswan Intl	1.25	1.21	-0.75	5	8	17	30	50	84	282
Asyut	2.51	3.51	-0.52	11	18	32	47	70	103	244
Baharia	1.49	1.44	-0.32	4	6	10	13	17	21	38
Baltim	14.44	8.89	-0.35	32	45	67	89	116	152	275
Cairo Intl	7.93	8.39	-0.50	27	43	74	108	157	225	511
Cairo Ezbekiya	5.80	4.29	-0.30	14	20	29	37	48	61	104
Dabaa	15.21	9.66	-0.24	33	44	61	77	95	117	183

El-Tahmed	7.06	6.14	-0.57	22	35	63	95	144	215	543
Eltor	4.16	5.20	-0.53	16	27	48	72	107	157	376
Farafra	3.57	5.46	-0.50	16	26	47	69	101	147	337
Giza Cairo	5.16	4.14	-0.39	14	20	32	44	59	79	155
Helwan Cairo	7.31	5.41	-0.19	17	22	31	38	47	56	84
Hurghada	15.55	22.64	-0.23	56	83	123	160	203	253	407
Ismailia	5.76	7.31	-0.56	23	39	72	110	167	250	632
Kharga	2.40	3.20	-0.57	10	17	32	49	74	112	284
Kosseir	4.12	5.17	-0.31	14	21	32	43	57	74	129
Luxor	4.01	6.28	-0.56	19	32	60	92	138	207	518
MarsaMatrooh	16.19	11.36	-0.22	36	49	69	87	108	132	204
Minya	2.65	4.03	-0.59	12	22	41	65	100	153	406
Nekhel	6.24	5.15	-0.36	17	24	37	50	67	89	165
Port Said	7.48	5.74	-0.29	18	26	38	49	64	81	137
Port Said Elgamil	10.91	9.08	-0.47	31	47	78	111	158	221	479
RasSedr	3.36	2.12	0.11	6	8	9	10	11	12	14
Salloum	8.81	8.16	-0.27	24	34	50	66	84	106	176
Sallum Plateau	10.37	8.01	-0.38	27	39	60	82	110	146	278
Siwa	2.53	2.51	-0.37	8	11	18	25	33	44	84
St Catherine Intl	5.27	5.07	-0.46	16	25	43	61	87	122	263
WadiElnatroon	7.25	10.23	-0.49	30	49	86	128	185	266	603

Table 6. Summary of the statistical characteristics of the parameters of the GEV distribution of the selected stations

	GEV parameters		
	Location (ξ)	Scale (α)	Shape (κ)
Mean	7.46	6.73	-0.39
Standard deviation	5.03	4.18	0.17
Coefficient of variation	0.67	0.62	-0.42
Maximum	19.25	22.64	0.11
Minimum	1.25	1.21	-0.75

4 CONCLUSIONS

The statistical characteristics of rainfall extremes in Egypt have been investigated based on historical annual maximum daily rainfall records for 30 stations throughout the country. Furthermore, this research seeks to derive the design rainfalls through the GEV distribution along with the L-moments using annual maximum daily rainfall in 30 Egyptian stations. It can be concluded that there is a great variation over the whole country in all different aspects of rainfall.

Although the case study is based on rainfall data from only 30 stations in Egypt, the inferences made in this paper represent a starting point with respect to the analysis of extreme rainfall events in the country. Thus, a recommendation for future studies is directly related to the use of more stations to have better understanding of the statistical characteristics of extreme rainfall events in Egypt. Moreover, different

probability distributions along with different parameter estimation methods should be usedin order to identify the best method that could provide the most accurate extreme rainfall estimation in Egypt.

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