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INTENSITY - DURATION-FREQUENCY RELATIONSHIP IN AN ARID AND A SEMI-ARID CASE STUDY WADI EL DOM-EL AIN EL SOKHNA, EGYPT

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ABSTRACT

Intensity–duration–frequency (IDF). They are curves describing the relationship between the intensity of precipitation, duration of precipitation. Ordinarily, intensity-duration-frequency (IDF) curves are widely used in hydrology and water resource systems to predict floods and their paths and to design protection structures and rain drainage networks. The intensity, duration, and frequency (IDF) curves are obtained by frequency analysis of rainfall intensity measurements available at meteorological stations. The Natural Resources Conservation Service (NRCS) method is can use for calculating direct runoff volume for a given rainfall event. Consequently, the main objective of this research is to illustrate the steps of the derivation of the IDF curve using rainfall measurements obtained from the meteorological Suez stations. The most popular and widely used distribution of probability functions methods has also been applied to determine the maximum precipitation depth in this study for varied return periods of 2, 5, 10, 25, 50, and 100 years using HyfranPlus. Accordingly, was demonstrated that the findings obtained using the Weibull approach were better than other distributions, the corresponding rain intensity was extracted for every 6 minutes over a 24-hour period for each of the previous years.

Keywords: Flood design; extreme rainfall intensity time series, Rainfall intensity.

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1. INTRODUCTION

Wadi El Dome, Ain Sokhna, Egypt, is one of the sites on the shore of the Red Sea. In recent years, the valley has been subjected to severe rainstorms, which led to severe flash floods in the region. The last storm to hit the area was on March 12, 2020, and the rainfall rate was 44.1 mm/day, causing sudden floods in the area, which damaged the tourist villages and stopped the Hurghada-Cairo road. Most water resources assessment studies require high-resolution rainfall data, but they are not available in many regions of the world, particularly in arid and semi-arid regions, due to the high cost of installing rain gauges. Daily or annual precipitation records are frequently available.

Hydrologists can solve this challenge by converting daily rainfall data into shorter-duration series. The development of intensity–duration–frequency curves (IDF Curves) is a graphic representation of the relationship between rainfall intensity and storm length over a certain return time. It is one of the most important hydrological analyses. [4]. since 1935, engineers in the United States have used IDF curves. David Yarnell developed the first "Intensity Frequency Maps" for the United States in 1935. Rainfall intensity assessments, particularly IDF curves for varied return periods, are required for most water resource planning and management projects [5]. The IDF curve, for example, was designed by Saudi Arabian hydrology and engineering academics (Al-Wagdany 2021[6]; Al-Amri and Subyani 2017 [7]; Elsebaie 2012[8]). Researchers have also offered several ways based on statistical data analysis for generating the IDF curve for arid and non-arid environments. For example, Bell (1969) [9] and Chen (1983) [10] developed IDF formulas for certain United States locations. The IDF curves can be calculated using frequency analysis of short-duration precipitation data or a variety of empirical formulae. Chowdhury et al. (2007) used the Indian Meteorological Department's empirical reduction formula to derive short-duration rainfall from daily rainfall in Sylhet city. Al-Wagdany et al. (2021) in Saudi Arabia created IDF curves using NRCS synthetic rainfall hyetographs and daily rainfall records. The most frequent method for separating total rainfall into shorter-duration segments is synthetic rainfall hyetographs (Bonta 2004). The four synthetic NRCS distributions (Types I, IA, II, and III; (SCS, 1986)) created by the National Resource Conservation Service are the most prevalent rainfall temporal distributions (NRCS). For the West Coast of the United States, Type I and IA hyetographs are recommended, Type III for the East Coast of the United States, the Gulf of Mexico area prone to severe tropical storms and a Type II hyetograph for the rest of the United States. Due to the lack of short-duration rainfall records, the temporal distribution of rainfall in Egypt has not been well researched. The only rainfall records available are daily data. The main objective of this research is the possibility of using the daily rainfall data available in the Suez station, coupled with NRCS temporal dimensionless rainfall distributions to generate short-duration rainfall data for the Wadi Al Dome, Ain Sokhna, a region in Egypt. The IDF curves are created using the generated short-duration rainfall series. IDF curves were created for durations ranging from 10 minutes to 1440 minutes, as well as five distinct return periods of 5, 10, 25, 50, and 100 years in this study. Using daily data from the Suez station.

2. STUDY AREA

The study area is located on the coast of the Gulf of Suez in the Red Sea and follows the Suez Governorate in Egypt between latitudes 29° 20'25.72"N and 29°28'0.56"N and longitudes 32°22'09"E and 32°31'33"E. The study area covers an area of approximately 74 km2 and is 55 km away from the city of Suez. It is one of the closest tourist areas to Cairo, as it is about 135 km away from Cairo. Figure 1 shows the site map of the study area and the boundary points of the study area are shown in Figure 2.

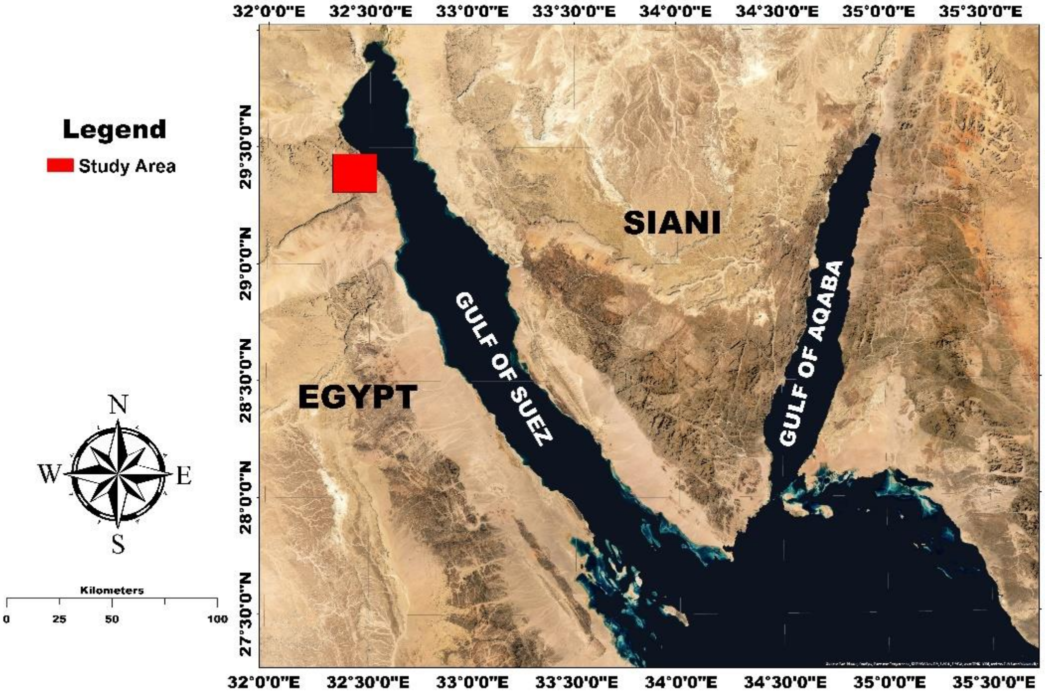

Figure 1 Location map of the study area

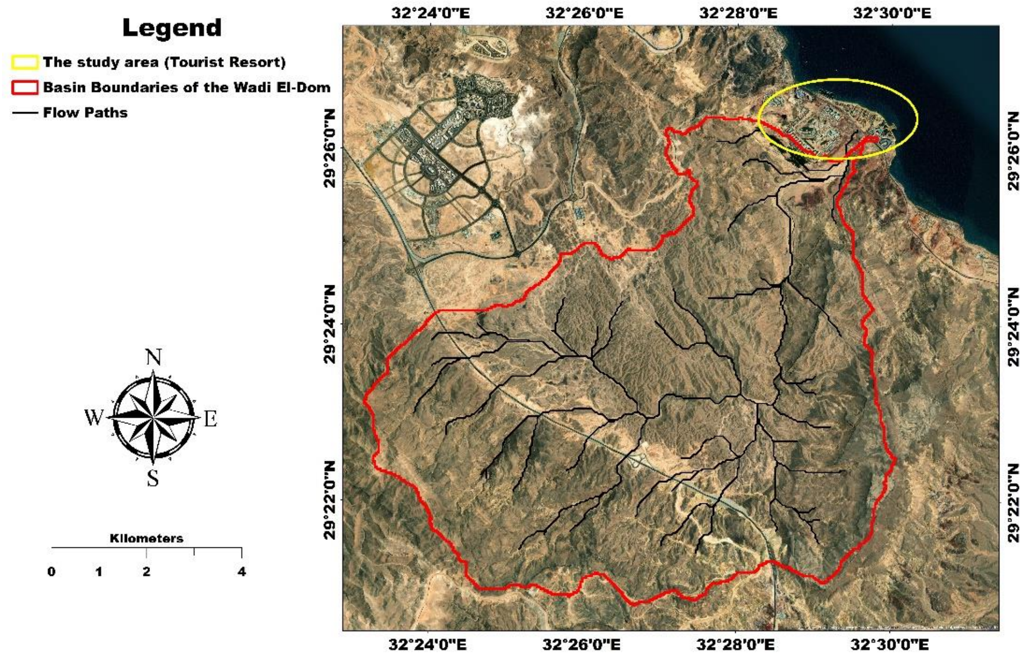

Figure 2 Basin Boundaries of the Wadi El-Dom

3. RAINFALL DATA AVAILABLE FROM GROUND METEOROLOGICAL STATION

In the procedure of estimating the Intensity Duration Frequency (IDF) curves for Wadi El Dom-El Ain El Sokhna, Egypt. Should available a lot of historical rainfall data with accurate values which can depend on it. Historical rainfall data for Wadi El Dom are available at the General Meteorological Authority (GMA). The closest ground Meteorological station with available daily rainfall data is the Suez station located at a distance of 55 km from the study area. The coordinates of this station are 29°57'49''N, 32°33'46''E are shown in Fig. 3. The design storm is generated based on an analysis of the measured data. The rainfall data are presented in time and in total rain record for 56 years, from 1965 to 2020 and the maximum data value of 49.6 mm/day recorded. And the most recent was in 2020 a rainstorm of data value 44.2 mm/day. Table 1 and Fig. 4 shows

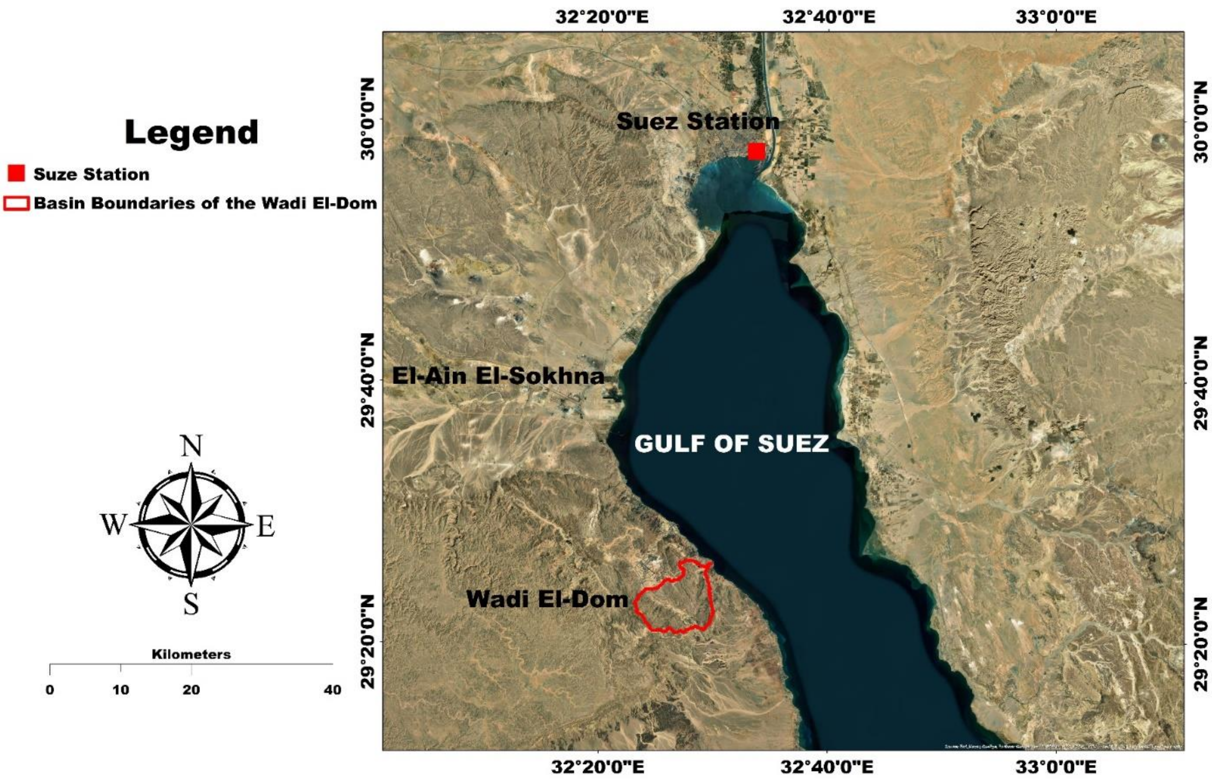

Figure 3 Ground Meteorological Suez Station Location

Table 1 Available Rainfall Data

Ground Meteorological Suez Station daily data							
Year	**Rainfall (mm)**	**Year**	**Rainfall (mm)**	**Year**	**Rainfall (mm)**	**Year**	**Rainfall (mm)**
1965	49.6	1980	5.2	1995	0	2010	4
1966	3.6	1981	6.7	1996	2.6	2011	10.2
1967	22	1982	7.7	1997	8.5	2012	0.1
1968	2.8	1983	6.3	1998	2.8	2013	6.6
1969	2.7	1984	9.7	1999	2.6	2014	6.2
1970	1.4	1985	16.3	2000	3.8	2015	18.9
1971	9.3	1986	4.4	2001	2	2016	16
1972	5.2	1987	9.7	2002	3.4	2017	1
1973	3.8	1988	16.5	2003	6	2018	2.8
1974	0	1989	0.3	2004	4.3	2019	11.4
1975	0	1990	22	2005	7.9	2020	44.1
1976	0	1991	10.5	2006	3		
1977	9.2	1992	5.6	2007	0.8		
1978	4.8	1993	0.4	2008	1.6		
1979	6.8	1994	7.7	2009	3.9		

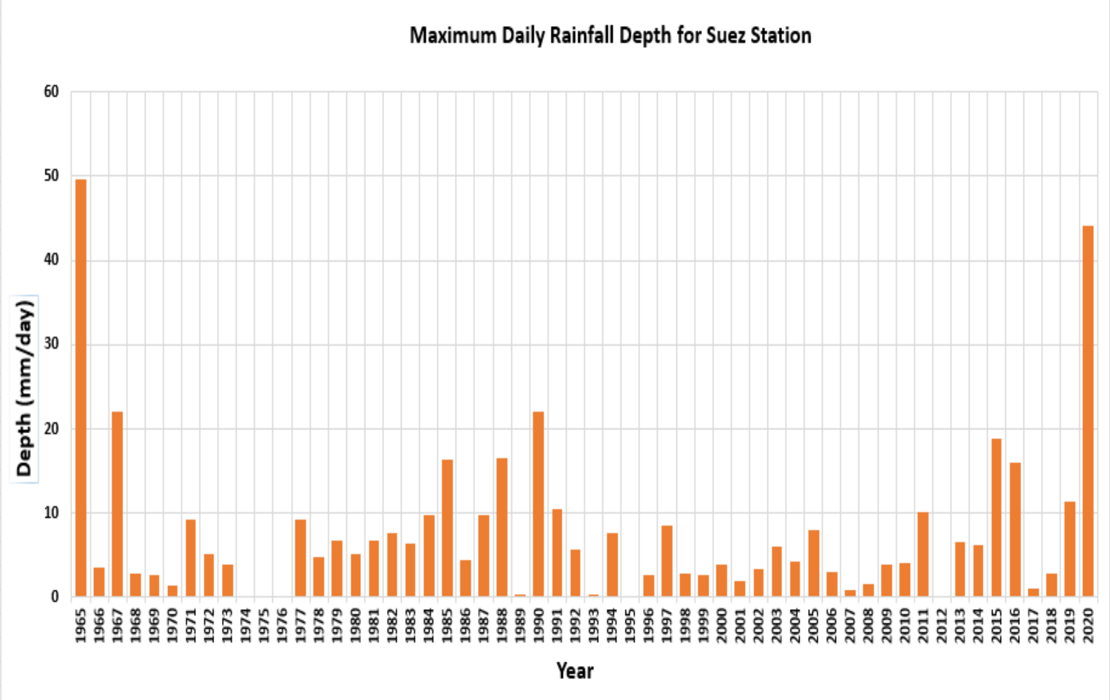

Figure 4 The maximum daily rainfall depth during 56 years (1965-2020)

4. METHODOLOGY

The depths of future precipitation in dry and semi-arid regions cannot be predicted with the required accuracy. As a result, using the concepts of probability, the amount and frequency of precipitation must be explored and evaluated. Precipitation data is usually short or absent in locations where there is no reliable measurement, making it impossible to estimate intensity – time duration – frequency. The Generation of an IDF curve requires the implementation of the following steps:

Step 1: Analysis of the daily precipitation data taken Suez station of the rainfall data record for 56 years, from 1965 to 2020 and using the appropriate statistical distribution, estimate the maximum depth of precipitation for 2 years, 5 years, 10 years, 25 years, 50 years, 100 years.

Step 2: generate short-duration rainfall data using typical National Resources Conversion Service (NRCS).

Step 3: Calculating the daily rainfall depth in (mm/hr) from the maximum daily rainfall for the duration of time (0:1440) minutes for the different return periods; 2, 5, 10, 25, 50, and 100. For the same Ground Meteorological Station, the generated data is utilized to create IDF curves.

5. FREQUENCY ANALYSIS OF THE MAXIMUM DAILY RAINFALL

5.1. Candidate Models and Distribution Selection Criteria

The main objective of frequency analysis is to use statistical probability distributions to calculate the amount and frequency of rainfall and Distribution Selection Criteria. The most commonly used probability distribution functions in hydrology this methodology in HYFRAN-PLUS software to perform frequency analysis in this study are shown in Fig. 5. The fitting of the ground meteorological Suez station data to Weibull, Log-Pearson Type 3, Gamma, 3-Parameter Lognormal, and Generalized Gamma, Gumbel, Pearson Type 3 and Pareto distributions are shown in Figures 6 to 13. Zero data (4 values out of 56) were neglected to be on the safe side and to allow for log transformations.

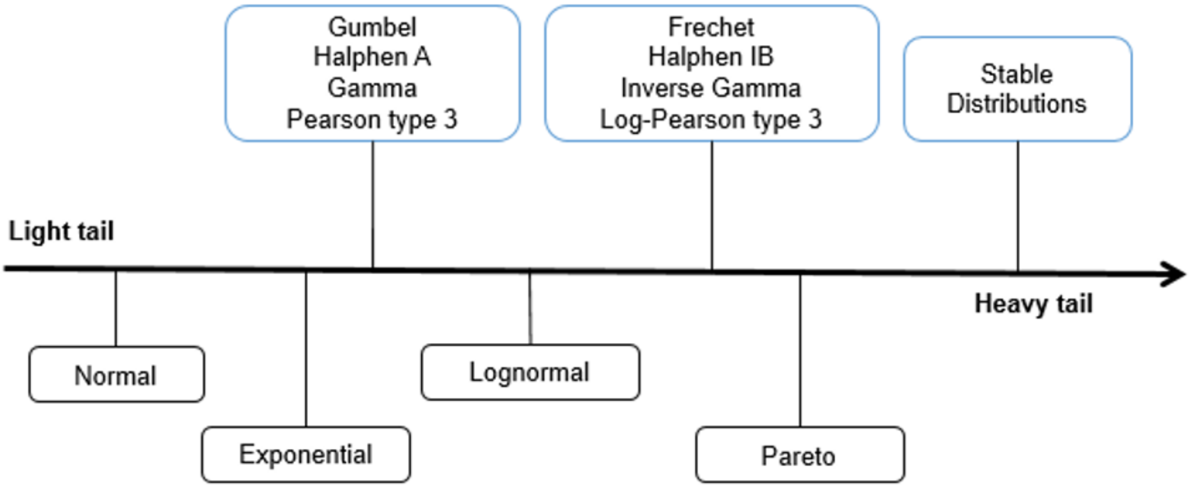

Figure 5 Distributions commonly used in hydrology

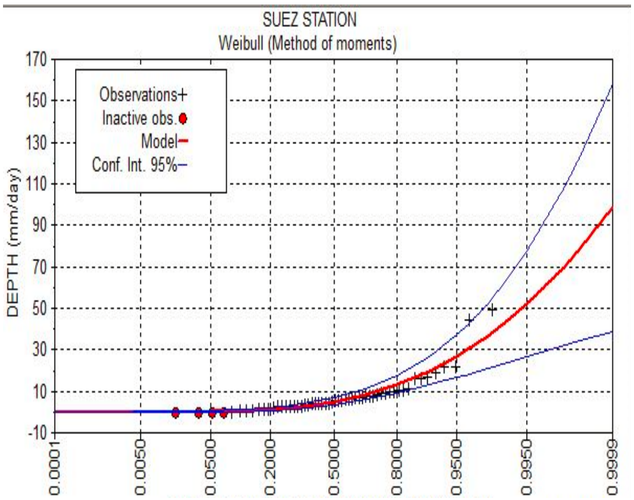

Figure 6. Fitting of the Weibull Distribution.

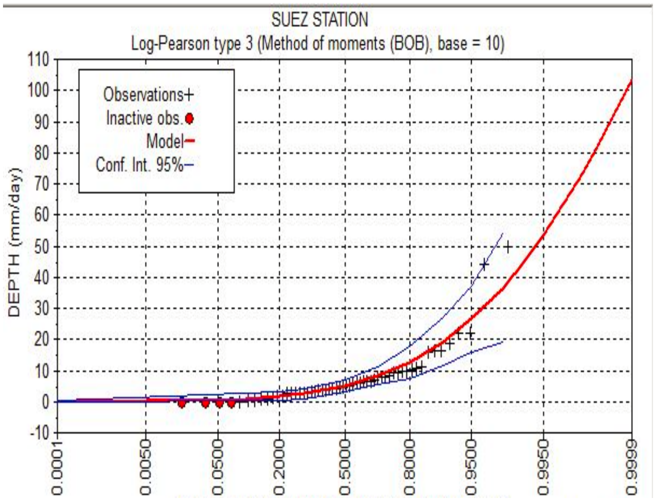

Figure 7. Fitting of the Log-Pearson Type 3distribution.

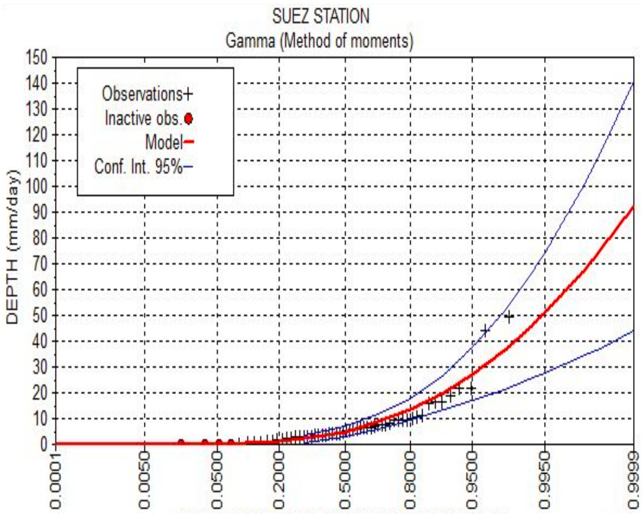

Figure 8. Fitting of the Gamma Distribution.

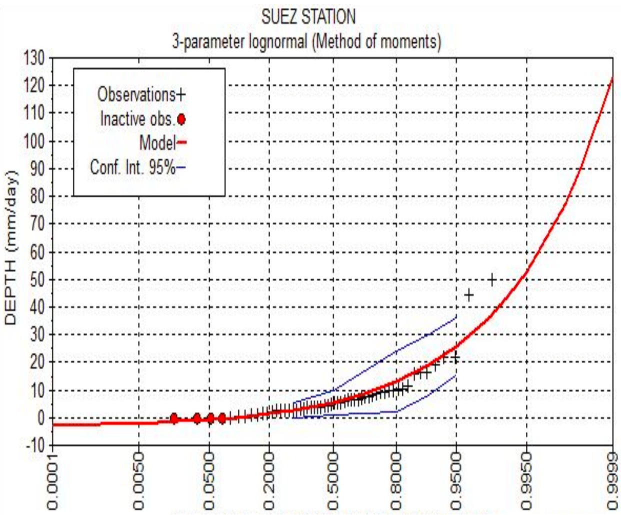

Figure 9. Fitting of the 3-Parameter Lognormal Distribution.

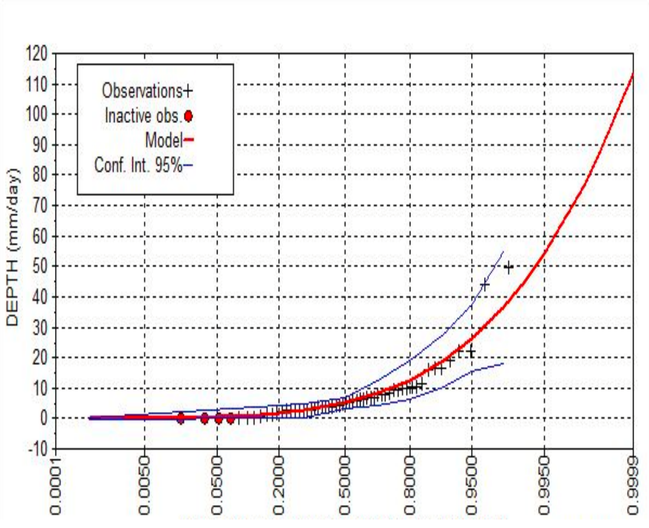

Figure 10. Fitting of the Generalized Gamma Distribution**.**

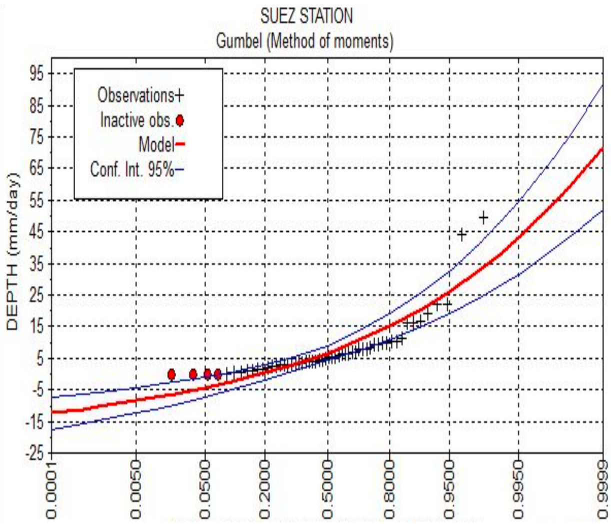

Figure 11. Fitting of the Gumbel Distribution.

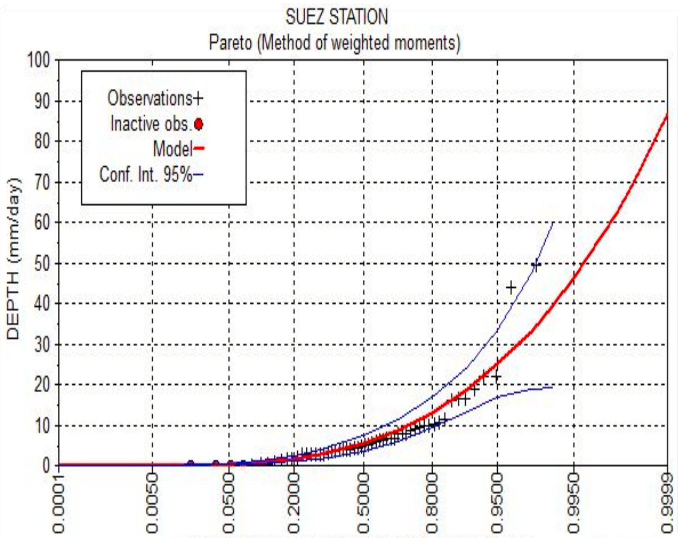

Figure 12. Fitting of the Pareto Distribution**.**

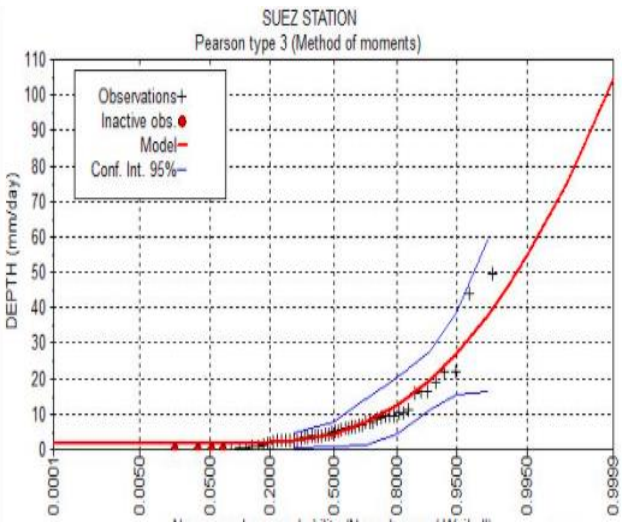

Figure 13. Fitting of the Pearson Type 3distribution

5.2. Model Selection Based on AIC and BIC

To choose which identifies the best class of distributions that give a precise estimation of the event under study. Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are the most common and widely used methods for choosing the appropriate model from the tested distributions. The two criteria are based on the deviation between the fitted distribution and the empirical probability with a penalization that is a function of the number of parameters of the distribution. This methodology in HYFRAN-PLUS software, in addition to the traditional methods of model selection (AIC and BIC). The BIC and AIC values for all tested distributions were calculated, and it was found that the distribution with the smallest BIC and AIC values is the Weibull distribution shown in (table 2). In any case, the difference between the top 3 candidates (Weibull, Log-Pearson Type 3, and Generalized Gamma) is minor even for high return periods such as the 100-year (Table 2). The frequency analysis results of the Weibull distribution fitting to the daily Wadi El Dom-El Ain El Sokhna ground meteorological Suez station rainfall are shown in (Table 3).

Table 2 Comparison Criteria of the Distributions for Suez Station “Method of moments”

Distribution	Number of parameters	100-year rainfall (mm)	BIC	AIC
Weibull	2	44.232	332.442	328.540
Log-Pearson Type 3	3	45.059	333.265	327.411
Gamma	3	45.142	333.312	327.458
3-Parameter Lognormal	2	43.709	334.453	330.550
Generalized Gamma	3	43.755	342.319	336.465
Gumbel	2	37.813	359.872	355.969
Pearson Type 3	3	46.157	*	*
Pareto	2	44.596	*	*

Table 3 Frequency analysis results for the Weibull Distribution.

Return period	Rainfall (mm)	Standard deviation (mm)	Confidence interval (95%) (mm)
100	44.2	10.4	23.9 – 64.6
50	36.6	8.01	20.9 – 52.3
25	29.3	5.88	17.7 – 40.8
20	26.9	5.25	16.6 – 37.2
10	19.9	3.49	13.0 – 26.7
5	13.2	2.07	9.09 – 17.2
3	8.47	1.30	5.93 – 11.0
2	4.98	0.84	3.33 – 6.63

6. INTENSITY DURATION FREQUENCY CURVES

Frequency (IDF) curves estimates, first, daily rainfall data are derived from ground Meteorological station data. Then, the homogeneity of the means and variances are checked for the data. Frequency analysis is carried out and the best distribution is selected based on several criteria and uses daily observed rainfall data to generate short-duration rainfall depths (from 10 minutes to 1440 minutes) sub-daily rainfall duration ratios (Table 4). Daily rainfall depths at various return periods and short-duration rainfall ratios are combined to obtain IDF curves for the research region Wadi El Dom-El Ain El Sokhna Figures (14. A), (14. B), and (14. C).

Table 4 Intensity-Duration-Frequency Values for Suez Station (Wadi El Dom).

Frequency period (Year)	Storm Duration (min)								
	10	20	30	60	120	180	360	720	1440
100	60.09	41.91	33.73	21.77	14.07	10.18	5.85	3.31	1.84
50	49.76	34.70	27.93	18.03	11.65	8.43	4.84	2.74	1.53
25	39.83	27.78	22.36	14.43	9.32	6.75	3.87	2.19	1.22
10	27.05	18.87	15.19	9.80	6.33	4.58	2.63	1.49	0.83
5	17.94	12.52	10.07	6.50	4.20	3.04	1.75	0.99	0.55
2	6.77	4.72	3.80	2.45	1.58	1.15	0.66	0.37	0.21

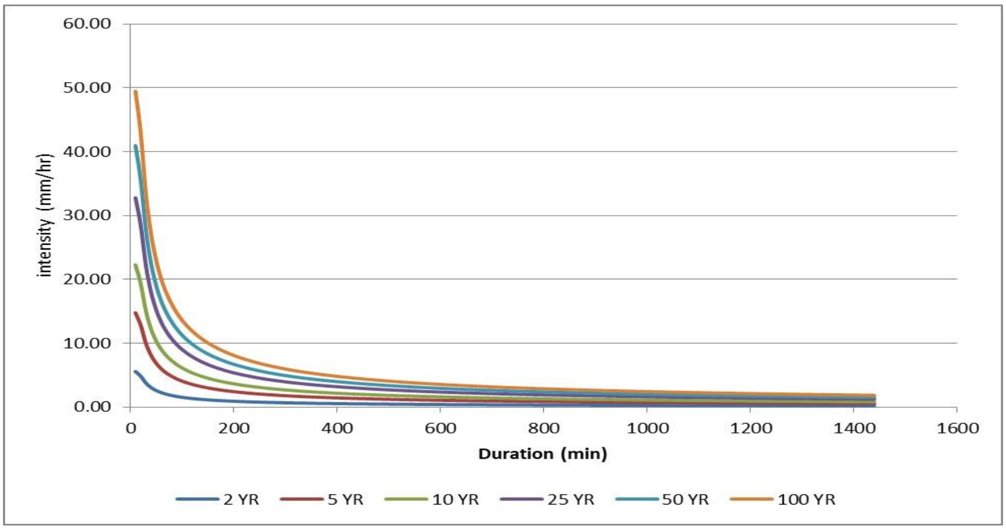

Figure (14.A) Intensity-Duration-Frequency Curves for Suez Station (Wadi El Dom)

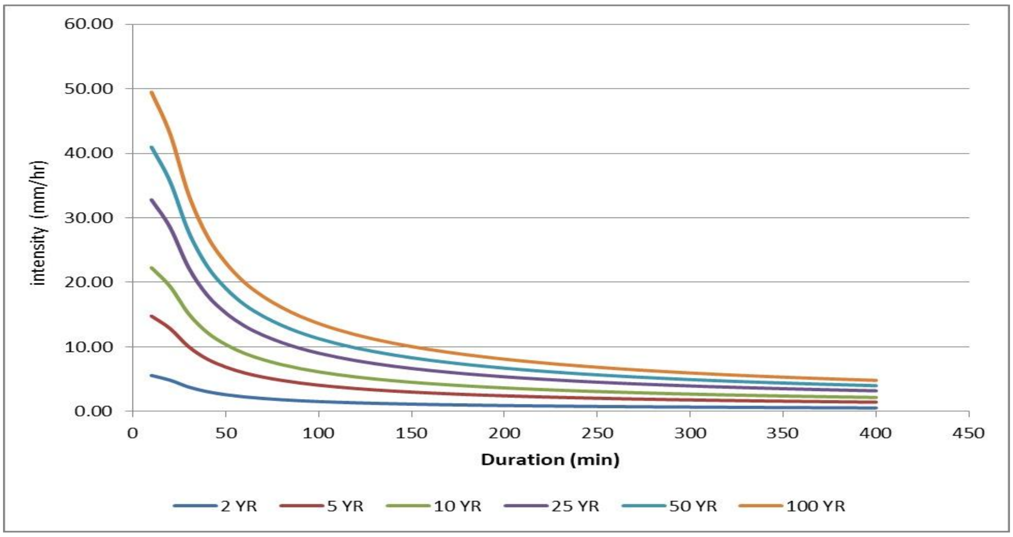

Figure (14.B) Intensity-Duration-Frequency Curves for Suez Station (Wadi El Dom).

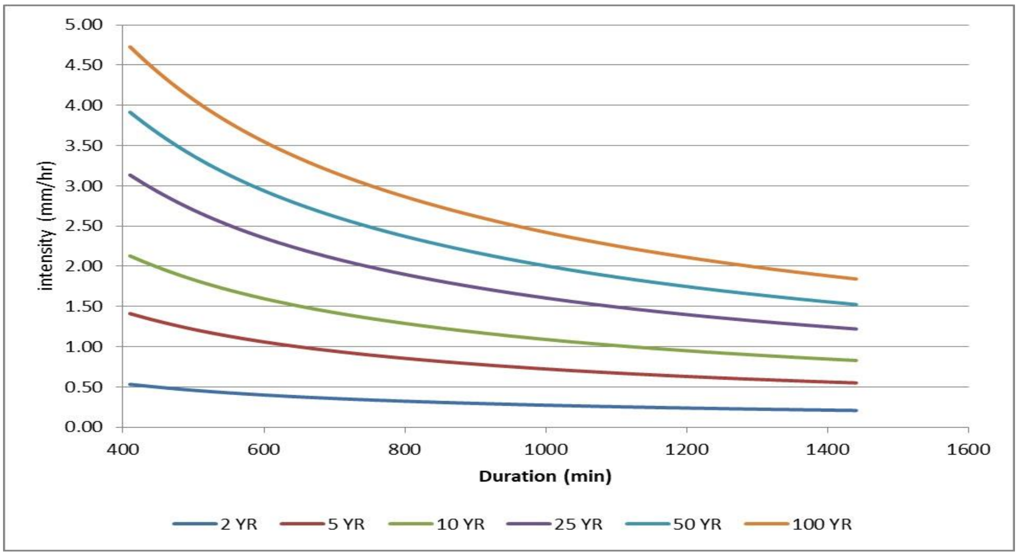

Figure (14.C) Intensity-Duration-Frequency Curves for Suez Station (Wadi El Dom).

7. CONCLUSION

Intensity–duration–frequency (IDF) estimates, for regions with poor rainfall measurements, where reliable data for daily maximum precipitation is not available. Using rainfall measurements obtained from meteorological stations in Suez. The most popular and widely used distribution of probability functions methods has by applied to determine the maximum precipitation depth in this study for varied return periods of 2, 5, 10, 25, 50, and 100 years using HyfranPlus. And was demonstrated that the findings obtained using the Weibull approach were better than other distributions. The goal of this paper is to create IDF curves for the Wadi El Dom-El Ain El Sokhna, Egypt using NRCS temporal dimensionless rainfall distributions. The parameterization of the IDF relation for different durations allows better understanding and realization of spatiotemporal analysis of the characteristics of rainfall in the area. The suggested relationship between intensity, duration, and frequency will facilitate the assessment of flood hazards. The Wadi El Dom-El Ain El Sokhna is exposed to heavy rains and frequent dangers, and this causes a lot of damage to human lives and tourist villages. Therefore, forecasting floods to protect citizens and tourism investments is very important. These results help decision-makers greatly in predicting the risks of floods and designing the necessary protection work.

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