Earth Systems and Environment (2019) 3:463–469
https://doi.org/10.1007/s41748-019-00124-x

ORIGINAL ARTICLE

Annual Daily Maximum Rainfall-Based IDF Curve Derivation Methodology

Zekâi Şen[1,2]

Received: 31 May 2019 / Accepted: 24 September 2019 / Published online: 4 October 2019

Abstract

Intensity–duration–frequency (IDF) curves are among the most demandable information in meteorology, hydrology and engineering water resources design, planning, operation, and management works. This paper suggests their generation based on annual daily maximum rainfall (ADMR) records from Turkey, Ceylanpınar region meteorology stations next to Syrian border. First, available storm rainfall records are used for dimensionless–intensity–duration (DID) curve development, then, the suitable theoretical probability distribution function (PDF) is obtained for the ADMR record series, which provides return periods' identification for a given set of risk values, and finally, the ADMR data combination with the DID curve results in IDF curve set. The application of the methodology is presented for four stations in the Southeastern Province of Turkey, Ceylanpınar drainage basin, next to the Syrian border. The comparison of the newly developed IDF curves with the available measurement-based IDF curves indicated the validity of the proposed approaches with less than 10% error.

Keywords Annual · Daily maximum · Dimensionless · Duration · Frequency intensity · Probability · Rainfall · Return period

1 Introduction

There are plenty of water resources planning and management projects, which require intensity–duration–frequency (IDF) curves for proper water-related designs. These curves express the rainfall duration, return period, and frequency triple relationship on a double logarithmic paper, which provides practical and simple calculations procedure to design rainfall intensity in mm/hour provided that the return period in years, and the design rainfall duration in minutes is decided on.

IDF curves are suggested by different researchers who suggested mathematical or empirical approaches (Chow 1964; Aron et al. 1987; Koutsoyiannis et al. 1998; Hanson 1995; Garcia-Bartual and Schneider 2001). Proper and accurate determination of IDF curves is possible if storm rainfall accumulation records are available. Unfortunately, IDF curves are not available for many areas in the world even in developed countries let along the others.

In the past, different researchers have proposed quite different IDF curve generation procedures for different parts of the world by various methodologies depending on the available data type in the region. Such curves are suggested for the United States by Bell (1969) and Chen (1983); for Vietnam monsoonal region by Nhat et al. (2006) and for the arid and semi-arid regions by different researchers (Venkata Ramana et al. 2008; AlHassoun 2011; Elsebaie 2012; El-Sayed 2011; Wayal and Menon 2014). These authors took into consideration the available recording rain-gauge records. For instance, Bell (1969) explained IDF curves for certain areas of Russia. There are researches from the Kingdom of Saudi Arabia for IDF curve generation by different authors (Al-Amri and Subyani 2017; Al-Shaikh 1985; Al-Khalaf 1997; Elsebaie 2012). Convenient IDF curves are given for Nigeria by Ogarekpe (2014). Das et al. (2016) have developed IDF curves on the basis of Gumbel extreme value probability distribution functions (PDFs). Although classically one needs recording rainfall gauge measurements, but IDF curve construction is suggested by Koutsoyiannis et al. (1998) even from non-recording stations. In cases of

✉ Zekâi Şen
zsen@medipol.edu.tr; zsen@kau.edu.sa

[1] Engineering and Natural Sciences Faculty, Istanbul Medipol University, Beykoz, 34815 Istanbul, Turkey

[2] Department of Meteorology, Center of Excellence for Climate Change Research, King Abdulaziz University, PO Box 80234, Jeddah 21589, Saudi Arabia

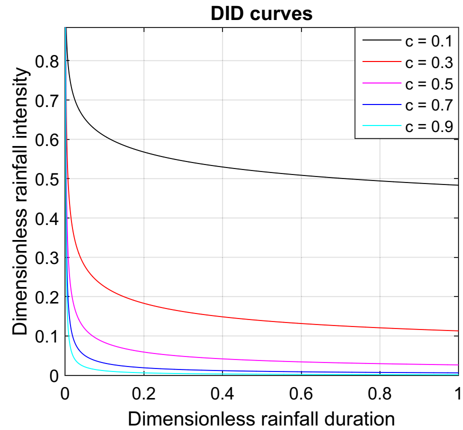

Fig. 1 Dimensionless–intensity–duration curves

recording rain gauges unavailability, several different methodologies are used for IDF curve generations. For instance, Raiford et al. (2007) obtained IDF curves from isohyet map frequency analysis. Based on similar maps El-Sayed (2011) obtained a set of regional IDF curves for the Sinai Peninsula, Egypt. In Malaysia, Liew et al. (2014) adjusted IDF curve at remote locations by information transfer from the nearest stations' meteorological records.

The main purpose of this paper is to propose a new methodology for IDF curve construction by processing the annual daily maximum rainfall (ADMR) records. The basis of the methodology is first to obtain a dimensionless–intensity–duration (DID) curve, which is then converted to IDF curve sets through the ADMR theoretical cumulative distribution functions (CDFs). The application of the suggested method is presented for four ADMR records from Turkey, Ceylanpinar region meteorology stations next to Syrian border.

2 Theoretical Intensity–Duration (ID) Curves

ADMR statistical frequency analysis is achievable by a suitable theoretical probability distribution function (PDF). Among the most frequently used such PDFs are Gamma, logarithmic normal, Gumbel and Pearson type III functions, which are explained in various books and papers (Pearson 1930; Gumbel 1958; Chow 1964; Kite 1977).

In the development of IDF curves, the first step is to find the relationship between the rainfall duration and intensity, i.e., intensity–duration (ID) curves. Provided that a single storm rainfall record is available then one can numerically obtain ID curve. In many regions, recording rain gauges are not available, but one should look for other means for ID curve generation. There are two alternatives for this purpose:

(1) information transfer by means of a convenient method from nearby stations;
(2) adaptation of a hypothetical ID curve;

In this paper, an innovative methodology is developed by means of dimensionless–ID curve (DID) concept. Determination of IDF curves is possible through a convenient PDF and logical–rational mathematical relationship among the three variables, rainfall intensity, I, rainfall duration, t and return period, R. The most commonly used of these theoretical expressions has the following general form (Chow 1964):

$$I = \frac{aR^b}{t^c}. \tag{1}$$

Herein, a, b, and c are model parameters, which can be estimated through the least squares technique provided that the measurement set of I, t and R is available. Equation (1) can be written succinctly also as

Fig. 2 Ceylanpınar study area location

Table 1 Meteorology station locations

Station			Location			PDF parameters	
Name	Number	Record duration	Latitude	Longitude	Elevation	Shape	Scale
Cey. (Ceylanpınar)	17,968	1960–2011	36° 84′ 06″	40° 03′ 07″	360	3.402	0.478
San. (Sanlıurfa)	17,912	1963–2011	37° 75′ 22″	39° 29′ 91″	801	3.763	0.371
Mar. (Mardin	17,275	1960–2013	37° 23′ 36″	40° 63′ 78″	527	3.906	0.475
Diy. (Diyarbakır	17,280	1960–2008	37° 89′ 73″	40° 20′ 27″	865	3.611	0.293

$$I = \frac{d}{t^c}. \quad (2)$$

In this expression $d = aR^b$ represents another constant value, since in any IDF work the return period is a pre-fixed value.

3 Dimensionless–Intensity–Duration (DID) Curve

Provided that the parameters in Eq. (1) are known, it is then possible to obtain the DID curve by execution of the following steps.

(1) Intensity values can be calculated for a set of rainfall durations, t, which might be considered for humid areas as 1440 min (24 h) or for semi-arid and arid regions as 720 min or 360 min and 180 min, respectively (Şen 2011),

(2) In this paper, the maximum intensity value is denoted by I_1, and the maximum rainfall duration as $t_{1440} = 1440$,

(3) Divide the intensities (rainfall durations) by the maximum intensity (duration) value, and hence, a DID curve is obtained for the site.

Table 2 Annual daily maximum rainfall amounts (mm)

Year	Cey.	San.	Mar.	Diy.	Year	Cey.	San.	Mar.	Diy.
2010	49.6	28.5	44.9	28.5	1984	–	53.7	33.2	53.7
2009	75.8	44.4	48.5	44.4	1983	–	52.1	46.5	52.1
2008	75.4	43	21.8	43	1982	–	47	145.9	47
2007	50.8	33	34	33	1981	–	64.1	54.4	64.1
2006	62.4	39	61.3	39	1980	–	41.9	40.2	41.9
2005	39.5	28.9	47.2	28.9	1979	–	31.5	83	31.5
2004	61.8	51.2	72.4	51.2	1978	–	27.2	94	27.2
2003	43.1	30.8	43.9	30.8	1977	–	34.8	41.6	34.8
2002	65.8	39.8	31.1	39.8	1976	–	57.5	66.7	57.5
2001	60.6	34.6	38.1	34.6	1975	–	60.9	65.6	60.9
2000	22.6	49	11.1	49	1974	–	38.3	57.8	38.3
1999	14	25.7	17.8	25.7	1973	–	24.7	36.8	24.7
1998	56.3	33.8	30.9	33.8	1972	—	31.6	53.1	31.6
1997	60.5	49.3	65.7	49.3	1971	–	64.7	55.5	64.7
1996	58.3	62.3	42	62.3	1970	–	40.4	38.2	40.4
1995	43.7	23.3	52.2	23.3	1969	–	120.2	54.1	120.2
1994	42.5	40.9	56.4	40.9	1968	–	36.5	61.4	36.5
1993	46.8	49.4	57	49.4	1967	–	55.9	113.2	55.9
1992	70.2	31.5	42.7	31.5	1966	–	29.9	90.6	29.9
1991	46.8	59.5	41.9	59.5	1965	–	37.6	–	37.6
1990	93.3	33.6	28.8	33.6	1964	–	41.7	–	41.7
1989	58.6	58.3	49.6	58.3	1963	–	99.7	–	99.7
1988	62.2	66.8	112.2	66.8	1962	–	31.7	–	31.7
1987	–	29.8	77.9	29.8	1961	–	47.8	–	47.8
1986	–	64.7	46.6	64.7	1960	–	119.5	–	119.5
1985	–	31.6	73.7	31.6	1959	–	39.3	–	39.3

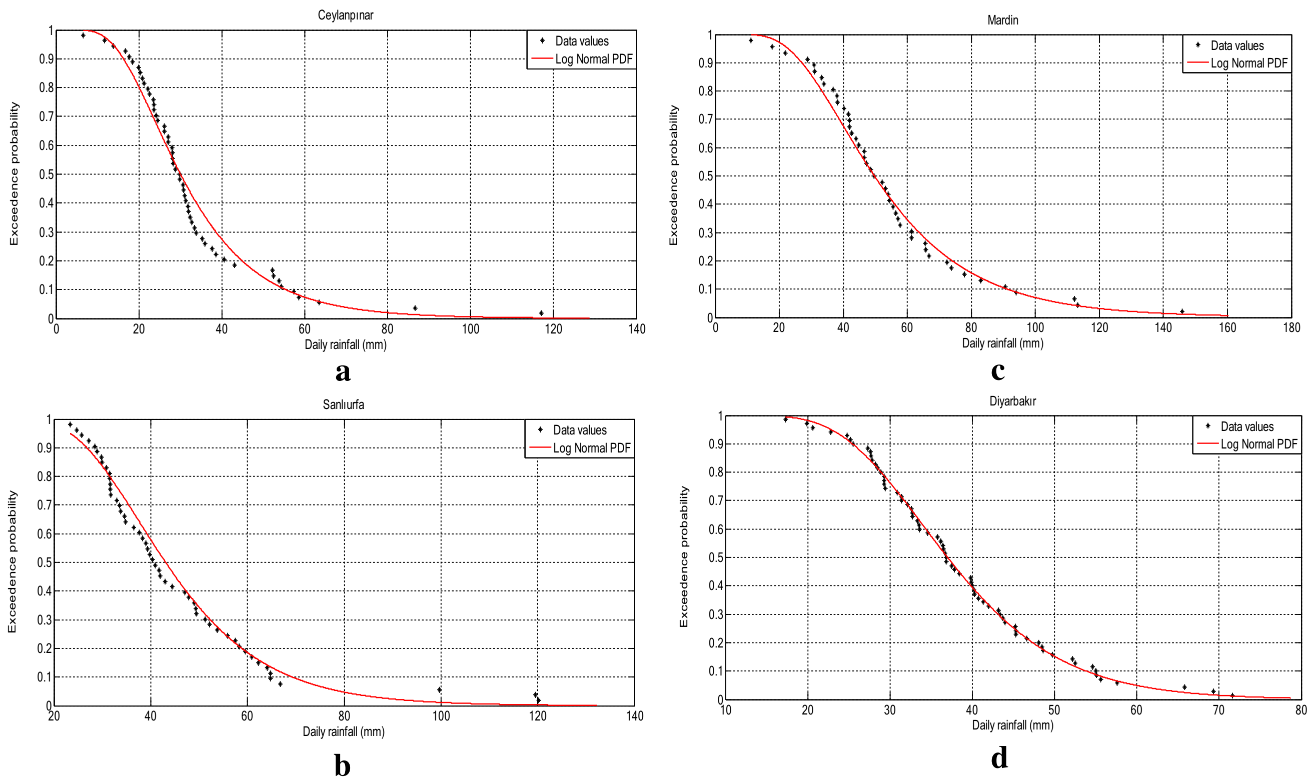

Fig. 3 Logarithmic-normal PDF fittings, **a** Ceylanpınar, **b** Sanlıurfa, **c** Mardin, **d** Diyarbakır

The application of these steps to Eq. (2) with different sets of *c* and *d* values results in the same DID curve, as presented in Fig. 1.

It is important to notice that the DID curves depend only on one parameter, *c*; whatever the value of *d* they all come on the same DID curve. One can obtain similar DID curves for any given value of *c*. This figure shows that for high

Table 3 Return periods and rainfall amounts (mm)

Station name	Return periods					
	2-year	5-year	10-year	25-year	50-year	100-year
Ceylanpınar	30.02	44.89	55.40	69.33	80.13	91.29
Sanlıurfa	43.07	58.84	69.26	82.42	92.21	102.02
Mardin	49.70	74.10	92.30	114.07	131.71	149.90
Diyarbakır	37.00	47.33	53.84	61.76	67.49	73.10

Table 4 Rainfall amounts (mm)

Station name	Exceedence probabilities					
	0.50	0.20	0.10	0.04	0.02	0.01
	Return period (year)					
	2	5	10	25	50	100
Ceylanpınar	30.02	44.98	55.40	69.33	80.13	91.29
Sanlıurfa	43.07	58.84	69.26	82.42	92.21	102.12
Mardin	49.70	74.10	91.30	114.07	131.71	149.90
Diyarbakır	37.00	47.33	53.84	61.76	67.49	73.10

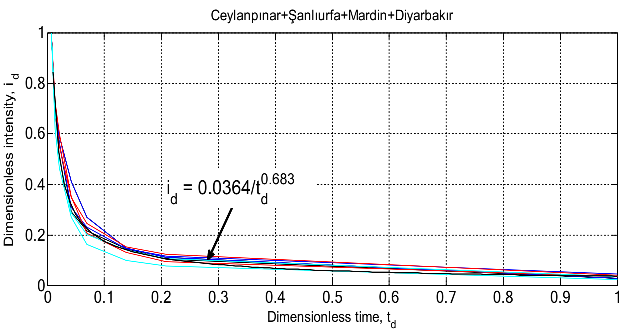

Fig. 4 DID curves

rainfall intensity regions, c is close to 0.9, whereas for low intensity has small c values. Most often in practical studies, its value is in the medium around 0.5–0.7 range.

The availability of DID curve provides opportunity for possible intensity–duration curves' determination from the ADMR data PDF.

4 IDF Curves Generation and Application

As mentioned in the previous section, the determination of the AMDR PDF from a set of data opens way to calculate any AMDR value corresponding to a given risk level. It must be remembered at this stage that the risk, r, is the reverse of the return period, R, $r = 1/R$, which implies that an IDF curve provides numerical information about the intensity provided that return period is given.

The study area, Ceylanpınar, is near the Turkish–Syrian political boundary, as shown in Fig. 2. Four meteorology station record and location characteristics are given in Table 1. This area is one of the most significant zones in Turkey for surface and groundwater resources with transboundary problems. The ADMR records are given in Table 2 for each station for 1440-min duration.

IDF curve from AMDR and DID values can be calculated after the application of the following steps.

(1) The most suitable theoretical PDF is identified from the AMDR data availability at each station. After necessary calculations, it appears that the logarithmic normal PDF is suitable for each station as in Fig. 3, where the point scatters and the theoretical PDF function are shown together. It is to be noticed that rather than the CDF, its corresponding CDF is used in the applications,

(2) The return period, R, (risk, r) set is considered as $R = 2$ years ($r = 0.50$), $R = 5$ years ($r = 0.20$), $R = 10$ years ($r = 0.10$), $R = 25$ years ($r = 0.04$), $R = 50$ years ($r = 0.02$), and $R = 100$ years ($r = 0.01$). Accordingly, calculated rainfall amounts for 1440-min duration are presented in Table 3 for each meteorology station.

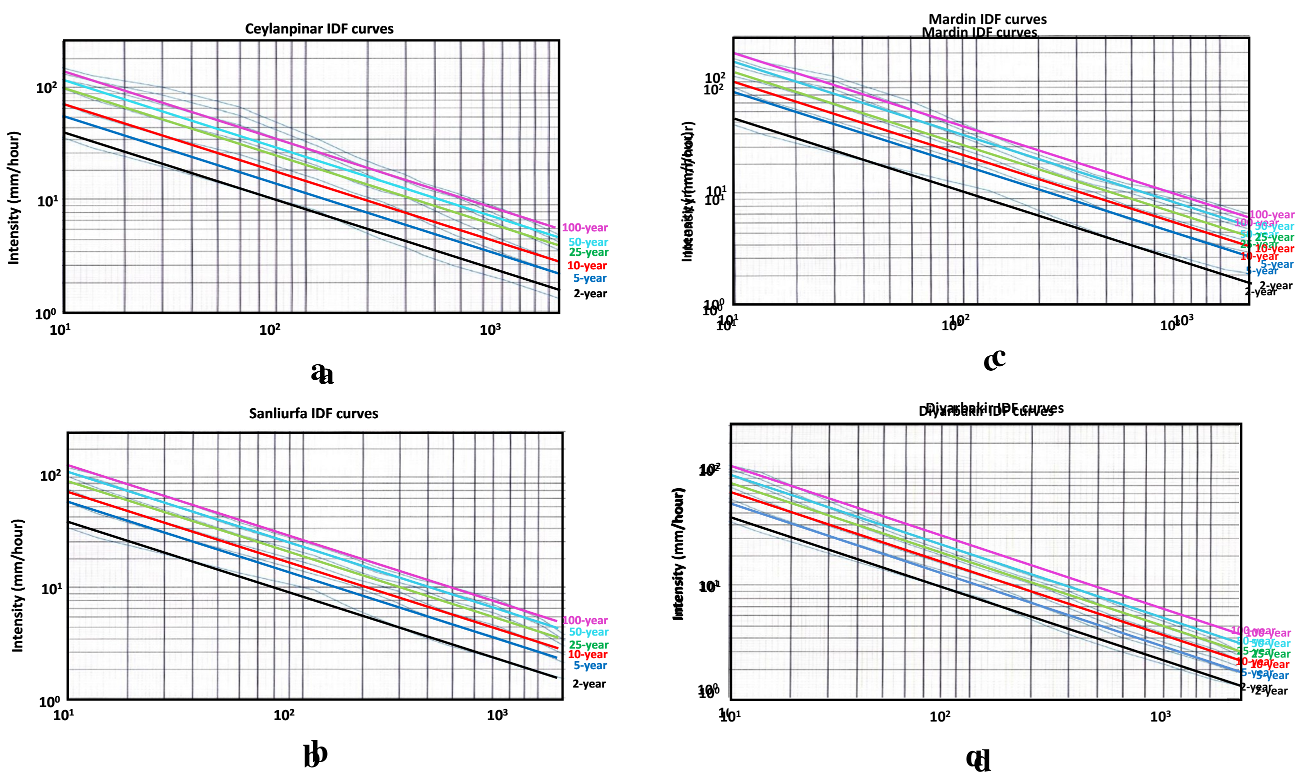

Fig. 5 IDF curves **a** Ceylanpınar, **b** Sanlıurfa, **c** Mardin, **d** Diyarbakır

(3) The rainfall amount logarithmic normal PDF helps to calculate risk for each return period. Table 4 presents the rainfall amounts corresponding to exceedence probabilities at each station.
(4) Available information at these four stations are transferred to DID curve, as shown in Fig. 4:

$$i_d = \frac{0.0364}{d_d^{0.683}}, \tag{3}$$

where d_d and i_d are dimensionless duration and intensity, respectively.

(5) After knowing the value of d_d, one can calculate for any rainfall duration, t, from full duration, $t_r = 1440$ min, according to the following expressions:

$$t = t_r t_d. \tag{4}$$

The rainfall intensity can be calculated by taking into account the rainfall amounts from Table 4, the intensity as

$$i = i_d r_e. \tag{5}$$

(6) Fig. 5 exposes the application of all the previous steps at each station. The results of this research are plotted on the same IDF curves that have been obtained from the recording rain-gauge storm rainfall measurement charts. It is obvious that the methodology in this paper yields almost the same results, which indicate the validity of suggested procedure. In Fig. 5, broken lines are obtained from a set of individual storm rainfall charts at each station.

5 Conclusions

The rainfall intensity concept and its derivation from recording rainfall charts are among the basic requirements for any hydrological engineering water resources management and design studies. In general, intensity–duration–frequency (IDF) curves are not available, but few might exist for some specific areas. Although storm rainfall records are not available, but annual daily maximum rainfall (ADMR) data are registered at each meteorology station. The question is how to benefit from the ADMR records for IDF curve generation? In this paper, three steps are suggested for IDF curve establishment from the ADMR records. These are determination of the most suitable theoretical probability distribution function (PDF) from ADMR records, dimensionless–intensity–duration (DID) curve development and conversion of the ADMR records to IDF curves through the DID curve. The application of the methodology is presented for data from the four meteorology stations from the southeastern province of Turkey, Ceylanpınar near the Syrian border. For each station, there are IDF curves and ADMR records for many years. The IDF curves are obtained through the DID methodology and they are compared with the already existing IFD curves and the relative error between the two sets is less than 10%, which shows the validity of the proposed methodology.

References

Aron G, Wall DJ, White EL, Dunn CN (1987) Regional rainfall intensity-duration-frequency curves for Pennsylvania. Water Resour Bull 23(3):479–485

Al-Amri NS, Subyani AM (2017) Generation of rainfall intensity duration frequency (IDF) curves for ungauged sites in arid region. Earth Syst Environ 1(1):8. https://doi.org/10.1007/s41748-017-0008-8 **(Springer international publishing)**

AlHassoun S (2011) Developing empirical formulae to estimate rainfall intensity in Riyadh region. J King Saud Univ Eng Sci 23:81–88

Al-Khalaf HA (1997) Predicting short duration, high-intensity rainfall in Saudi Arabia, M.S. Thesis, Faculty of the College of Graduate Studies; King Fahad University of Petroleum and Minerals, Dahran (K.S.A)

Al-Shaikh (1985) Rainfall frequency studies for Saudi Arabia. M.S. Thesis. Civil Engineering Department, King Saud University, Riyadh (K.S.A)

Bell FC (1969) Generalized rainfall-duration-frequency relationships. J Hydraul Div ASCE 95:311–327

Chen CI (1983) Rainfall intensity-duration-frequency formulas. J Hydraul Eng 109(12):1603–1621

Chow VT (1964) Handbook of applied hydrology. McGraw-Hill, New York

Das R, Goswami D, Sarma B (2016) Generation of intensity duration frequency curve using short duration rainfall data for different return period for Guwahati city. Int J Sci Eng Res 7(7):908–911

El-Sayed EA (2011) Generation of rainfall intensity duration frequency curves for ungauged sites. Nile Basin Water Sci Eng J 4(1):112–124

Elsebaie I (2012) Developing rainfall intensity–duration–frequency relationship for two regions in Saudi Arabia. J King Saud Univ Eng Sci 24:131–140

Garcia-Bartual R, Schneider M (2001) Estimating maximum expected short-duration rainfall intensities from extreme convective storms. Phys Chem Earth (B) 26(9):675–681

Gumbel EJ (1958) Statistics of extremes. Columbia University Press, New York

Hanson CL (1995) Short-duration-rainfall intensity equations for drainage design. J Irrig Drain Eng 121(2):219–221

Kite GW (1977) Frequency and risk analysis in hydrology. Water Res. Publications, Fort Collins

Koutsoyiannis D, Kozonis D, Manetas A (1998) A mathematical framework for studying rainfall intensity- duration-frequency relationships. J Hydrol 206:118–135

Liew SC, Raghavan SV, Liong SH (2014) Development of intensity–duration–frequency curves at ungauged sites: risk management under changing climate. Geosci Letters 1:8

Nhat L, Tachikawa Y, Takara K (2006) Establishment of intensity-duration-frequency curves for precipitation in the monsoon area of Vietnam. Ann Disas Prev Res Inst Kyoto Univ 49B:93–103

Ogarekpe N (2014) Development and comparison of different intensity duration frequency models for calabar, Nigeria. Niger J Technol 33(1):33–42

Pearson K (1930) Tables of statisticians and biometricians (ed.), Part I, 3rd edn. The Biometric Laboratory, University College, London. Cambridge University Press, London

Raiford JP, Aziz NM, Khan AA, Powell DN (2007) Rainfall depth–duration–frequency relationships for South Carolina, North Carolina, and Georgia. Am J Env Sci 3:78–84

Şen Z (2011) Intensity-duration-frequency (IDF) curve generations for Saudi Arabian meteorology stations. Saudi Geological Survey, Confidential Report, Jeddah

Venkata RR, Chakravorty B, Samal NR, Pandey NG, Mani P (2008) Development of intensity duration frequency curves using L-moment and GIS technique. J Appl Hydrol 21(1–2):88–100

Wayal AS, Menon K (2014) Intensity–duration–frequency curves and regionalization. Int J Innov Res Adv Eng 1(6):28–32