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Original article Regional distribution of intensity-duration-frequency (IDF) relationships in Sultanate of Oman

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ABSTRACT

Analysis of extreme rainfall parameters including rainfall intensities is a fundamental requisite in safe planning, designing, and operating various hydrologic and water engineering projects against storms and floods. In arid and semi-arid regions, such as Oman, sufficient long-term rainfall data with short aggregation are usually not available in most locations across the country. This paper presents the development of intensity duration frequency (IDF) curves using the available rainfall data from 65 meteorological stations situated at different elevations and regions throughout Oman. Gumbel distribution was fitted to the observed data and rainfall intensities were found for various return periods. Rainfall analysis showed the average annual rainfall of 109.21 mm with a standard deviation of 92.82 mm, Skewness coefficient of 1.62 and Kurtosis coefficient of 3.08 for all the studied stations from 1977 to 2017. The statistical analysis showed that the estimated rainfall intensities for various return periods are high in the mountainous region compared to the desert or interior region, and the coastal region of the country. Also, the empirical parameters of IDF formula for all studied stations were established using nonlinear regression. Finally, the contour maps for all the parameters were drawn which could be used to determine the IDF relationships for ungauged locations. This study will be useful for the decision makers and practicing hydrologists for planning and design of water resources systems in Oman. © 2023 The Author(s). Published by Elsevier B.V. on behalf of King Saud University. This is an open access

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1. Introduction

Rainfall is a fundamental constituent of the hydrological cycle. Consequently, the determination of rainfall events is important for planning and designing of any hydrologic project including storm and drainage designs, geotechnical and structural projects, water resources systems, and others. However, the development of any hydrological project is highly challenging in the arid region where the rainfall is largely random and erratic both temporally and spatially (Al-Amri and Subyan, 2017). The changes in precipitation as the result of extreme weather events in the water-scarce arid countries is often facing long-term droughts and flash floods;

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damaging coastal, residential and agricultural areas and natural habitats in the arid region (Cosgrove and Loucks, 2015; Gunawardhana and Al-Rawas, 2016). The recent climate change is considered as one of the major challenges for water supply systems and flood risk analysis works (Ishak et al., 2013; Kourtis and Tsihrintzis, 2022). Thus, the quantification of rainfall is performed using intensity-duration-frequency (IDF) curve (Chow et al., 1988) as a tool, to implicate safe design and cost efficiency to the hydrologic and engineering projects for certain return period (Raiford et al., 2007). The site specific IDF is used to study the relationship between rainfall intensity, duration and frequency (or return period) associated with the site location and amenities (Chow et al., 1988).

The IDF relationship was first presented by Bernard (1932). Since then, different forms of IDF relationships have been established by many researchers in the field of engineering, hydrology and environmental studies in several regions of the world. IDF formula was developed by Bell (1969) and Chen (1983) for few regions of United State. Koutsoyiannis et al. (1998) constructed the mathematical framework of IDF curve using data from both rainfall recording and non-recording stations based on probability distribution. But, the probability distributions are considered as





stationary and do not change with time (Vinnarasi and Dhanya, 2022). Whereas, the climate change is likely to alter the climatic extremes over the time, given the stationary IDF curve approach often underestimates the precipitation extremes (Cheng and AghaKouchak, 2014; Shrestha et al., 2017). Several studies using non stationary model using climate indices as covariates were explored in few studies (Li et al., 2015; Bracken et al., 2018; Silva et al., 2021; Vinnarasi and Dhanya, 2022). Raiford et al. (2007) updated the existing IDF curves for the different region of United States; and, acquired those curves at ungauged sites throughout the region using the newly developed rainfall frequency analysis methods. El-Sayed (2011) used iso-pluvial maps in Egypt; Awadallah et al (2011) used regional analysis and satellite data in Angola; Yu et al. (2004) used scaling theory in Taiwan; Ouali and Cannon (2018) used quantile regression technique in Canada for developing the regional IDF at the ungauged sites. Likewise, Noor (2022) proposed method for IDF curve construction with related uncertainty at the ungauged sites using bias correction of satellite rainfall data and its comparison with the observed IDF Curve.

Several researchers have developed the IDF curve for the arid Arabian Peninsula using both empirical formulae and frequency analysis. Various theoretical distribution functions (Generalized Extreme Values (GEV), Gumbel distribution, Generalized Pareto Distribution (GPD), Log Pearson Type III, Log Normal, Exponential distribution and others are normally used in frequency analysis (Sherif et al., 2014; Forestieri et al., 2018; M. Bermúdez et al., 2020). Al Shaikh (1985), and Al Areeq et al. (2021) used Gumbel distribution for development of IDF curve in various region of Saudi Arabia. Elsebaie (2012), Al-Amir and Subyan (2017) used both Gumbel and Log Pearson III distribution; while, AlHassoun (2011), (Al-anazi and El-Sebaie, 2013) used Gumbel, Log Pearson III, and Log Normal distribution for development of IDF curve in several locations of Saudi Arabia. There studies did not show much difference in the rainfall analysis of IDF curve for Gumbel and Log Pearson Type III distribution for the semiarid and flat topographic region.

The development of IDF relationship requires the long-term and continuous historical rainfall data, which is typically not available in most semiarid and arid region countries including Sultanate of Oman. Also, the precipitation events in the region are rare but usually of high intensities in the short duration, resulting in flash floods in an inter-annual scale (Uraba et al., 2019; Aldosari et al., 2020). Precipitation frequency analysis is equally important in nonstructural problems concerning natural risks related with ultimate rainfall events (Maidment, 1993). The data required to compute IDF curves are a record of rainfall depth measurements during fixed intervals of time, normally 5 min intervals (Mays, 2005). Thus, the coarse-resolution precipitation data is converted into the fine time-resolution precipitation using the temporal disaggregation technique (Al-Wagdany, 2021).

Very limited studies in rainfall analysis and climate change projection has been conducted for Oman. Awadallah (2017) designed a storm hyetograph of few stations located at the Northern coastal zone of Oman using Alternating Block Method (ABM)-IDF Curve method. While, Uraba (2019) has developed the IDF curve for Tawi-Atair station in Dhofar region of Southern Oman using twostage downscaling disaggregation approach. Thus, the IDF relationships are not available for most of the regions in Oman. In the absence of a properly developed IDF relationship, the planning and development of water resources systems such as recharge dams, flood protection structures, storm water collection networks and other projects may result in improper design. Also, the developed IDF curves can be adopted to quantify the rainfall rate and predict the flooding for any region. Therefore, this research aims to develop IDF curves for the Oman, by analyzing rainfall data at multiple meteorological stations situated at different elevations and regions throughout the country using Gumbel distribution. The empirical formulae were also developed to evaluate rainfall intensity for several rainfall durations and return periods. Further, the contour maps for all the observed parameters were drawn to establish the IDF relationships for the ungauged location for future predictions and designs.

2. Study area and data collection

Oman (Sultanate of Oman) lies in the southeastern corner of the Arabian Peninsula with total area of 309,500 km² and a coastline 3165 km long. It extends between latitudes of 16°40′ and 26°20′ N and longitudes of 51°50′ and 59°40′ E. The country is bordered by Arabian Gulf in the North, Sea of Oman in the East, Arabian Sea in the Southwest, United Arab Emirates and Saudi Arabia in the West, and Yemen in the Southwest as shown in Fig. 1 (FMO, 2022). Topographically, it is divided into three areas; the coastal plain (fertile plain) extends from Al Batinah Plain in the North to Salalah Plain in South, mountainous region runs from Musandam in the North to Ras Al-Hadd in the Southeast and in Dhofar province, and the internal region (desert, gravel and sand plain) ranges from the coastal plain to the mountainous region covering 82% area of the country (FAO, 2021).

Based on rainfall, Oman experiences the hyper arid (less than100 mm rain), arid (100-250 mm rain) and semiarid (250-500 mm rain) climate at various parts of the country (Kwarteng et al., 2009). The long-term average annual rainfall of the country has been estimated to be 62 mm (MRMWR, 2013). Average annual rainfall in the desert and coastal plain is less than 50 mm; while the rainfall in mountain region is up to 350 mm, and is relatively frequent providing recharge to the aquifers situated at the coastal and interior plains (Al Barwani, 2014). Seasonal summer monsoon is observed from June to September in southern parts of the country, especially in Dhofar Governorate causing change in temperature. Whereas, the rainfall occurs during winter from November to April in the northern and central region of the country (FAO, 2021). In summer, the weather is hot and humid in the coastal region, hot and dry in interior region; while, the weather is moderate and rainy throughout the year in the highlands (FAO, 2021). Rainfall in the country is associated by four principal mechanism; convection rainstorms related with localized strong convection developed mostly in summer, cold front trough from Mediterranean Sea or North Atlantic that brings rainfall to northern part of Oman especially from November to April, tropical cyclones originated from Arabian Sea typically from May to June and October to November, and on-shore southwesterly monsoon current that causes humid environment and brings frequent drizzle, mist, fog, rain in Dhofar region from June to September (Roberts and Wright, 1993; MWR, 1995).

In this study, the rainfall data were obtained from the Ministry of Regional Municipalities and Water Resources (MRMWR). Oman is divided into eleven governates, namely; Musandam, Al-Buraimi, Al-Batinah North, Al Batinah South, Muscat, Adh Dhahirah, Ad-Dakhaliya, Al-Sharqia North, Ash-Sharqia South, Al-Wusta, and Dhofar. Sixty-five monitoring stations are selected to cover the ten governates in the country. Al Wusta govenerate, the desert area is not considered in the study due to lack of enough stations and data for analysis. The selected stations had homogenous and short time interval record for longer period. The record length varies from one station to another, which was because of some missing years of data and initial years of gauge installation at the sites. The record periods were between 20 years to 40 years of rainfall data. The location details and years of record of stations that were used for this study are shown in Table 1 and Fig. 1.



Fig. 1. Study Area with governorate and studied stations (FMO, 2022).

3. Methodology and data analysis

Estimation of IDF curves involved various steps. Initially the rainfall data were analyzed and disaggregated for the shorter period. Collected data from monitoring stations were initially sorted according to the years, rainfall depth and duration. Disaggregation of rainfall data to shorter and regular period was done using the Hydrologic Engineering Center's (HEC) Data Storage System Visual Utility Engine (HEC-DSSVue) software. Maximum rainfall depth is acquired for each monitored year and various durations. Statistical analysis such as mean and standard deviation of the maximum rainfall depth were also obtained for various durations.

Development of IDF is performed by fitting the probability distribution function to extreme rainfall data for specific durations. Based on measurements and fitted relationship, the rainfall intensity over specific duration and return period are determined for the recorded years. Gumbel distribution is used for frequency analysis of the annual maximum rainfall data for the calculation of rainfall depth for each return period. Design durations of 5, 15, 30, 60, 360, 720, 1440 min, and return periods of 2, 5, 10, 25, 50 and 100 years were used in the present study. Further, the parameters of the IDF relationship proposed by Bernard (1932) are obtained using regression. Finally, the contour maps for all the parameters were drawn using SURFER software for determining the IDF relationships for ungauged locations.

3.1. Gumbel distribution

Extreme value Type I (Gumbel) distribution, proposed by German mathematician Emil Gumbel (Gumbel, 1958) is widely used for modeling extreme events in the field of water resources engineering. The distribution had over 50 applications

Station detail with year and length of rainfall records.

S.N.	Governorate	Station Name	Easting (m)	Northing (m)	Elevation (m)	Years of Record	Length of Records (Years)
1	Musandam	Ghamda	414 500	2 887 100	45	1981-2017	37
2	Widsundum	Khasah	424 300	2,807,100	37	1983-2017	35
3		Rhaibah	421 936	2,879,218	704	1986-2016	31
4		Sal Ala	436.466	2.880.987	171	1983-2016	34
5		Sima	430 384	2,884 322	129	1981-2017	37
6	Al Buraimi	Al Iuwavf	408 900	2,715,000	634	1996-2016	21
7		AL Ubaylah	413.619	2,679.851	604	1997-2016	20
8		Favvad	415 400	2,658,600	626	1995-2014	22
9		Khatwah	409,000	2,689,600	622	1995-2014	20
10		Mahdah	396 900	2,698,800	437	1985-2016	32
11		Wadi Salmah	377 500	2,682,700	300	1982-2017	36
12		Wadi Sharm	395 400	2,002,700	452	1989-2016	28
13	Al Batinah North	Al Ghuzayfah	449 210	2,652,513	510	1989-2017	29
14		Al Iizzi	450 426	2,689,150	167	1995-2016	22
15		Agair Al Abreein	461 672	2,609,130	741	1997-2016	20
16		Aghat Al Risah	444 008	2,623,051	516	1995_2017	20
17		Havl Al Naid	478 400	2,672,600	922	1997-2016	20
18		Saham	488 292	2,622,000	12	1988_2016	20
10	Al Batinah South	Al Miseen	580 300	2,003,033	363	1993_2016	23
20	A Batman South	Al Wasit	588,000	2,502,000	118	1993_2016	24
20		Ar Rustan	543 500	2,504,500	309	1991_2016	24
21		Barka	589 700	2,550,700	20	1088_2016	20
22		Dhahaah	511 800	2,513,200	916	1983_2016	34
23		Salma	538 700	2,552,500	1124	1902-2016	25
24	Muscat	Buoi	662 700	2,507,700	/33	1004_2016	23
25	Muscat	Havfadh	678 100	2,572,500	208	1994-2010	25
20		Mazara	690,200	2,550,700	130	1981_2016	36
27		Muscat	662 400	2,554,500	7	1992_2016	25
20		Ruwi	657 100	2,610,600	25	1986_2016	31
30		Wadi Al Jappah	650 700	2,010,000	23	1980-2010	20
31		Wadi Al Khawd	614 400	2,580,200	71	1986_2013	25
33	Adh Dhabirah	Dakarah	496 725	2,008,000	916	1980-2015	20
33	Addi Dhannan	Dank	430,723	2,557,504	3/8	1938-2017	20 /1
34		Dhahir	460 765	2,000,400	860	1996_2017	22
35		Kubarah	481 227	2,521,701	481	1995_2017	22
36		Maizi	468 957	2,555,550	738	1997_2016	20
37		Oarn Al Kabsa	469 440	2,005,550	503	1992_2016	25
38		Tanam	445 600	2,559,050	318	1986_2016	31
30	Ad Dakhliyah		508 800	2,555,100	373	1980-2016	22
40	Ad Dakiniyan	liwar	508,000	2,434,000	5/9	1995-2016	22
40		MOD	572 100	2,517,500	1475	1993-2016	22
12		Muchit	625 400	2,545,200	384	1995-2016	24
42		Naid Al Musallah	503,400	2,577,000	642	1993-2010	22
45		Subayb	515 100	2,541,500	13/5	1994-2016	23
45		Tawi Zahir	588 800	2,507,400	7/8	1994-2016	23
45	Ach Sharaiya North	Ad Dariz	671 200	2,340,800	240	1005 2014	20
40	Asii Sharqiya North	Au Daliz Al Mudavbi	615 500	2,497,700	400	1995-2014	20
47		Al Mugaybfab	625,600	2,497,100	409 681	1994-2014	21
40		Haimah	646,000	2,545,400	552	1993-2014	20
49 50		Ibra	656 200	2,520,500	JJZ 455	1994-2010	25
51		Masroop	645 200	2,514,500	433	1982-2010	20
52		Wadi Pani Khalid	712 600	2,493,900	624	1995-2014	20
52	Ach Charging Couth	Al Enjavi	713,000	2,300,900	112	1995-2010	22
55	Asii sharqiya south	Ai rujayj Finc	742,900	2,461,900	115	1967-2015	29
55		FIIIS Jaalan Pani	725,100	2,556,100	23	1995-2015	25
56		Jadidii Dalii Jabal Pani Jabir	707,600	2,443,900	1616	1002 2017	24
50		javai daili javii Spof	707,000	2,525,000	1010	1993-2017	20
57		Jiidi Tahwah	721 100	2,500,297	41/	1997-2010	20
50	Dhofar	Agarbapawrt	731,100	2,479,100	223	1900-2010	51 21
29	DIIUIdi	AqamandWL	240,070	1,095,/40	351 762	1990-2010	21 22
0U 61		Gliddow	19,100	1,895,700	703 806	1995-2017	23
01 62		ridgdyl Mughcavl	184,000	1,907,200	890 75	1990-2017	20 25
62		sadb	204 100	1,071,000	10	1999-2017	23
64		Shor	294,100	1,007,000	40 525	1997-2010	20
65		Zavk	199,000	1,900,700	020 021	1997-2017	21
05		Zdyk	190,900	1,911,600	100	1907-2010	50

ranging from data investigation of rainfall, flood, earthquake, pollution, environmental quality data, sea currents and other owing to its suitability for modeling maxima (Kotz and Nadarajah, 2000). For the development of IDF curves; it is widely used because of its simplicity (Elsebaie, 2012). In addition, it can be used to reach a higher level of safety by finding higher

intensities for shorter duration in the absence of data (Ahmed et al., 2012).

As per Gumbel method the rainfall of specific return period for any desired duration is calculated. The frequency of the precipitation (P_T) in mm for all time intervals with a particular return period (T) in years is computed using the following equations: P. Chitrakar, A. Sana and S. Hamood Nasser Almalki

$$P_T = P_{avg} + KS \tag{1}$$

Where, *K* is the Gumbel frequency factor calculated by Eq.(2) as suggested by Chow (1953):

$$K = -\frac{\sqrt{6}}{\pi} \left[0.577 + \ln \left[\ln \left[\frac{T}{T-1} \right] \right] \right]$$
(2)

 P_{avg} and *S* are the average and standard deviation of the maximum precipitation corresponding to a specific duration, calculated using Eq.(3), and Eq.(4), respectively. Where, P_i is the individual extreme value of rainfall, and *n* is the number of events or years of record.

$$P_{avg} = \frac{1}{n} \sum_{i=n}^{n} P_i \tag{3}$$

$$S = \left[\frac{1}{n-1} \sum_{i=n}^{n} \left(P_i - P_{avg}\right)^2\right]^{\frac{1}{2}}$$
(4)

The *K* is the function of sample size and the return period, thus when multiplied by standard deviation provides the average rainfall of a desired return period. The rainfall intensity I_T (mm/hr) for the return period T_d is calculated using Eq.(5):

$$I_T = \frac{P_T}{T_d} \tag{5}$$

3.2. Log Pearson III distribution

Log Pearson III distribution is a widely used model to compute the rainfall intensity at different rainfall durations and return period using logarithmically transformation of data (Elsebaie, 2012). Following expressions are used in computation of rainfall intensity:

$$P^* = \log(P_i) \tag{6}$$

$$P_T^* = P_{avg}^* + K_T S^* \tag{7}$$

$$P_{avg}^* = \frac{1}{n} \sum_{i=1}^{n} P^*$$
(8)

$$S^* = \left[\frac{1}{n-1}\sum_{i=1}^n \left(P^* - P^*_{avg}\right)^2\right]^{\frac{1}{2}}$$
(9)

$$C_{s} = \frac{n \sum_{i}^{ni} \left(P_{i}^{*} - P_{avg}^{*}\right)^{3}}{(n-1)(n-2)(S^{*})^{3}}$$
(10)

Where P_T^* , P_{avg}^* and S^* are as described earlier in Section 3.1; but is established on the logarithmically transformed Pi values as shown in Eq. (6). K_T is known as the Person frequency factor based on Skewness coefficient (C_s) and return period (T). Cs is obtained using Eq. (10); while K_T is obtained using the tables from hydrological references such as Chow et al. (1988). By knowing the recurrence interval and skewness coefficient, the K_T for the distribution is obtained. Further, the antilog of the solution in Eq. (7) determines the estimated extreme value for the given return period.

3.3. Derivation of IDF empirical formula

The relationship between the rainfall intensity (*I*), rainfall duration (*d*), and the return period (T_R) is defined by the IDF empirical formula. Several steps are followed to establish an equation for the

calculation of rainfall intensity for a specific rainfall period and recurrence interval, which is dependent mainly on the results from the IDF curves. In the study the widely used Bernard equation (Bernard, 1932) is selected to establish the IDF relationship. The following steps and equations were used to the IDF relationship:

$$I = \frac{CT_R^m}{d^e} \tag{11}$$

Where, *I* is the rainfall intensity (mm/hr), *d* is the rainfall duration (minutes), *T* is the return period (years) and the empirical parameters (*C*, *m*, and *e*). Using logarithmic transformation Eq. (11) can be expressed as:

$$\log I = \log \left(CT_R^m \right) - e \log d \tag{12}$$

Further, for a particular *T*, considering *K* as a constant:

$$K = CT_R^m \tag{13}$$

Eq. (7) is rewritten as:

$$\log I = \log K - e \log d \tag{14}$$

The plot of the logarithm of rainfall intensity (log *I*) against the logarithm of time (log *d*) for a specific return period results in a straight line for Eq.(13). From the linear relation the value of log *K* (intercept) and *e* (slope) are derived from each return period plot. The average of the values of *e* represents the empirical parameter e. The parameter *C* and *m* is obtained using logarithmic transformation of Eq. (13):

$$\log K = \log C + m \log T_R \tag{15}$$

By plotting the log K and log T_R in the straight line, the slope (m) and intercepts (log C) are derived. Finally, the values of C, m, and e are substituted in Eq. (11) to obtain the IDF equation.

3.4. Goodness of fit test

The least squares goodness of fit method was also used to evaluate the difference between the observed and calculated rainfall intensities of selected distribution. The goodness of fit is checked using the calculation of coefficient of determination (R^2) using Eq. (17).

$$R^{2} = 1 - \frac{\sum_{i=1}^{n} (X_{i} - Y_{i})^{2}}{\sum_{i=1}^{n} (\bar{Y} - Y_{i})^{2}}$$
(17)

Where, *Xi* and *Yi* are observed and estimated data at time i, *Y* is mean of estimated data and n is total number of data points.

3.5. Contour plots

The contours of the calculated IDF parameters were plotted using SURFER software. The software is mostly used for 3D surface mapping, contour mapping, terrain modeling and others. Kriging interpolation method was used for contouring of the parameters. It is a best unbiased linear estimation method (Isaaks and Srivastava, 1989); and a flexible gridding method that incorporates underlying trends and anisotropy in the natural and efficient manner (Yang et al., 2004).

4. Result and discussion

4.1. Rainfall analysis

Statistical analysis of the annual rainfall (total rainfall) for 65 study location of Oman from year 1977 to 2017 is shown in Table 2. All the monitoring stations have demonstrated highly variable

annual rainfall over the study period. Both annual maximum rainfall of 806.29 mm (Wadi Al Koudh in year 2004) and minimum rainfall of 9.39 mm (Ruwi in year 2003) were observed in Muscat governorate. The Skewness coefficient and Kurtosis coefficient measures the asymmetry and peakedness or flatness of the frequency distribution of the data (Sheskin, 2000). Negative kurtosis and positive kurtosis values indicate the distribution is flatter and sharper in its center than the normal distribution, respectively. Kurtosis coefficient is in the range of -1.429 to 8.167 during the study period that shows higher occurrence of probability near the mean than that in the normal distribution. Skewness coefficient in the range of 0.1 to 2.66 was observed for the stations. The observed positive skewed distribution exhibits much less frequency of occurrence of higher intensity rainfalls and the high frequency of occurrence of annual rainfall below the mean value (see Table 2).

The average annual rainfall exhibited for all studied stations from 1977 to 2017 is 109.21 mm with a standard deviation of 92.82 mm, Skewness coefficient of 1.62 and Kurtosis coefficient of 3.08. The observed highest average annual rainfall is 307.1 mm at Subayb, followed by 190.45 mm at Jabal Bani Jabir, 185.22 mm at Rhaibah and, 180.21 at MOD. While the lowest average of 38.41 mm at Al Qusaiba, succeeded by 48.30 mm at Khatwah, 61.15 mm at Tanam, and 61.64 mm at Kubarah. Interestingly, both highest and lowest average annual rainfall was recorded in Ad-Dakhliyah goveronate. Geographically, Subayb, is in the mountainous range at 1345 m elevation, while Al-Qusaiba station is situated in the flat terrain closer to the Al-Wusta desert region at 373 m elevation. Thus, the study shows that the rainfall in the mountainous region is high compared to the desert and the coastal region of the country. Fig. 2 presents the box and whisker plot of annual rainfall at studied governorates during monitoring period. The dataset exhibits the upward or positive skewness in all governorate with average rainfall higher than the median rainfall.

Variation of average annual rainfall (total rainfall) in various governorates of Oman from 1986 to 2016 is shown in Fig. 3. The highest average of 432.74 mm was recorded in 1997 in Musandam governorate located at the Northern Oman. The years 1990 (382.22 Ash-Sharqiya North), 1997 (360.21 at Ad-Dakhliyah), 2007 (361.21 mm at Muscat), and 2010 (347.37 at Ash-Sharqiya South) also recorded the high average rainfall. The lowest average of 20.64 mm was observed in the year 2008 in Ash-Sharqiya North. Similarly, lowest averages were recorded in the years 2001 (20.68 mm at Al-Buraimi), 2008 (21.09 at Ash-Sharqiya North), 2001 (21.28 at Adh-Dhahirah), and 1985 (23.30 mm Muscat). For the study period of 1986 to 2016, a slightly negative trend in average annual rainfall of -1.195 mm/years was observed for overall stations (Fig. 3). Among the studied region, Musandam governorate in northern part of Oman has the highest annual average of 149.81 mm followed by Mountainous area Ad-Dakhaliyah (130.06 mm). The annual average of 113.54 mm, 111.54 mm, 108.02 mm, and 102.54 mm were observed in Dhofar, Al-Batinah South, Ash-Sharqia North and Muscat governorates. While the lowest annual averages were observed at Ash-Sharqiyah North (95.56 mm), Al-Batinah North (91.84 mm), Adh-Dhahirah (83.04 mm) and Al-Buraimi (82.838 mm).

4.2. Intensity-Duration-Frequency (IDF) relationships

Gumbel and Log Pearson Type III distribution were mostly used distribution in arid region in IDF calculation. So, initially both distributions were used at Wadi Al Jannah station to check the best distribution using maximum rainfall records. Rainfall intensities for all the stations is estimated for corresponding rainfall duration (5, 15, 30, 60, 360, 720 and 1440 min) and return periods (2, 5, 10, 25, 50, and 100). Fig. 4 shows the observed and modeled intensity of two distribution; while Table 3 presents the summary of best fit result between two distribution using coefficients of determination (R^2) using Eq. (17) at various return periods. Both models showed the good correlation with values greater than 0.9 at all return period. As best fit result did not showed any major difference two distribution, Gumbel distribution is further used in all the stations in this study.

Table 4 and Fig. 5 shows the calculated rainfall intensities at Rhibah, Aqbat Al-Risah, Wadi Al-Jannah, Subayb, and Mughsayl stations for return periods of 2, 5, 10, 25 and 100 years using Gumbel distribution. The estimation showed the rainfall intensities increased with the return period, while the intensities decreased with the increase in the rainfall duration at all the stations. Subayb station at Ad-Dakhliah, the site with higher annual rainfall is likely to experience high rainfall with longer duration and return period compared to other stations.

Also, higher intensity rainfall at various return periods were witnessed at the higher elevation stations compared to the lower elevation stations. Among the stations presented in Table 4 and Fig. 5, Subayb (elevation 1345 m) has the highest rainfall while Mughsayl (elevation 25 m) has the lowest rainfall for all the return periods as compared to the other stations. Similar observations were reported by Kotoub (2004), where the rational method was used to evaluate the rainfall intensities at various return period for Plain, Hills and Mountains region of Oman, for flood peak and wadi characteristic studies for road network development. These studies showed among three studied regions of Oman, Mountains have the higher intensities rainfall followed by Hills, and Plains has the lowest intensities rainfall for various return periods. Thus, in the mountainous region the estimated rainfall intensities for various return periods are high as compared to the desert or interior region, and the coastal region of the country (Table 4; Fig. 5).

4.3. Intensity-Duration-Frequency (IDF) equation

Estimation of the empirical parameters (C, m, and e) of IDF relationship (Eq. (6) was done using nonlinear regression analysis in Microsoft Excel. Goodness of fit between observed and estimated data was checked using R^2 values. IDF curve for Khasab, Wadi Salmah, Saham, Dhabaah, Wadi Al-Jannah, Dank, Subayb, Ibra, Tahwa and Mughsayl stations presented in log scale are shown in Fig. 4. Also, the IDF curves are parallel to each other (Fig. 6). Table 5 shows the estimated IDF parameter values, IDF equation with R^2 achieved by IDF data analysis. The empirical parameter values for *C* ranged from 417.5 to 8.95, *m* ranged from 0.645 to 0.196, and *e* ranged from 0.79 to 0.391 for the studied stations. The obtained results showed good correlation between the observed and estimated rainfall intensities with high R^2 ranging between 0.994 and 0.851 (Table 5). Therefore, the IDF curved generated at the stations could be further used in the rainfall estimation and in design of water related projects in Oman.

4.4. Empirical IDF parameter contours

The spatial distribution maps of the IDF parameters *C*, *m*, and *e* are shown in Fig. 7. The contours show the smooth variation of parameter over the whole country. But, Due to the absence of monitoring points in the Al-Wusta region, contour lines generated in the middle section of the country are based on the interpolation of data from the neighboring regions. Also, the data from adjacent countries Saudi Arabia and United Arab Emirates were included. Thus, the contour lines extending beyond the Oman's border were based on the interpolation only.

All parameter values are relatively high and more condensed in the Northern part of the country compared to the Southern part.

Statistical information of annual rainfall (mm) at the monitoring stations.

Mesendum Charab 57:15 15.79 165.11 125.24 1.14 0.99 Khazab 426.43 10.11 136.54 10.25 0.66 Sal Ala 485.03 17.73 185.22 126.61 0.75 0.15 Al-Burstini 484.03 17.64 123.25 180.02 1.38 1.39 Al-Burstini 444.03 434.04 1.20 128.53 89.02 1.38 1.39 Al-Burstini 234.67 1.23 9.34 64.63 48.30 0.41 1.33 1.39 1.34 1.36 1.33 1.33 1.31 1.34	Governorate	Station Name	Maximum (mm)	Minimum (mm)	Average (mm)	Standard Deviation (mm)	Skewness Coefficient	Kurtosis Coefficient
Maxaba 40-24-3 10.11 19.54 19.93 1.07 000 Na Jah 49.34 17.64 123.25 110.69 1.38 3.42 Sina 48.934 17.64 123.25 110.69 1.38 3.42 Al-Barrini 3.44.07 12.02 12.33 1.80 3.51 Al-Barrini 2.34.07 12.31 66.00 2.56 7.19 Makdon 274.45 17.31 48.30 66.00 2.56 7.19 Makdon 23.51 18.40 64.43 4.43.33 1.17 2.57 Makdon 23.51 18.40 64.63 64.33 1.17 1.55 Advis Al-Abarcein 13.56 1.53 7.405 5.1.45 1.45 1.45 Advis Al-Abarcein 13.56 1.23 1.63 1.23 1.63 1.23 1.63 1.23 1.63 1.23 1.63 1.23 1.63 1.23 1.63 1.64 1.23 1.64	Musandam	Chamda	536.15	15 79	165 11	125.24	1 14	0.99
Bishahn 513.36 17.73 185.22 126.41 0.75 0.05 Al-Bartami Sial Al. 484.03 13.20 128.53 90.02 1.38 1.39 Al-Baver, 19 34.21 128.53 90.02 1.38 1.39 Al-Baver, 19 34.21 128.53 90.02 1.38 1.39 Al-Baver, 19 24.21 128.33 90.22 1.38 1.39 Madah 25.10 18.30 93.37 70.83 0.48 0.34 Madah 25.10 18.30 93.37 70.83 0.48 0.33 Madah 185.10 1.30 1.027 80.40 6.38 1.17 1.45 Al-Chargho 128.51 1.35 1.83 1.027 1.03 0.05 Adar Al-Matain 116.00 1.13 1.028 1.11 1.48 Adar Al-Matain 136.00 1.028 1.028 1.028 1.028 Adar Al-Matain 127.5 1.038	Widsandani	Khacab	126.12	10.11	126.54	123.24	1.14	0.55
sind 493.34 17.44 17.23.25 110.69 1.30 3.42 Sina 44.80 12.33 19.92 1.38 1.39 Al-Buralth 20.44 12.31 36.84 63.02 2.66 7.13 Al-Usyath 22.044 12.31 36.84 63.02 2.66 7.13 Kharvan 224.47 19.33 46.63 60.09 2.66 7.13 Wald Simah 22.697 19.33 46.63 60.09 2.66 7.14 Wald Simah 26.097 19.35 7.465 5.145 1.09 0.44 Al-Jiczi 2.23 1.55 7.874 64.28 1.15 1.61 2.55 Al-Fatinah South Al-Variti 2.755 1.35 7.874 64.28 1.31 1.88 1.61 1.88 0.61 1.83 0.64 1.61 2.53 1.61 2.53 1.61 2.53 1.61 2.53 1.61 2.53 1.61 2.53 1		Phaibab	515.26	17.72	195.34	105.50	0.75	0.00
sima 38.03 12.20 128.53 9002 1.38 1.39 Al-Burnini Al-Jasyah 302.11 10.04 69.81 72.73 2.01 4.51 Fayad 270.44 15.21 66.63 65.02 1.20 1.51 Mahdal 28.10 18.80 65.77 70.89 0.68 0.71 Mahdal 28.10 18.00 66.00 46.91 1.97 7.99 3.91 Al-Batmah 24.00 19.00 66.06 88.61 7.47 1.99 3.91 Al-Batmah 4.50.00 20.03 10.72 1.06.91 2.63 1.62 Al-Batmah 31.90.60 10.16 10.27 1.06.91 1.63 1.62 Al-Batmah 72.82 15.30 1.07.01 1.83 0.64 Al-Batmah 72.82 1.53 1.03.01 1.11.15 1.23 0.64 Al-Batmah 29.72 1.23 1.03.0 1.13.0 1.03.0 1.13		Sal Ala	190.24	17.75	103.22	110.60	1.90	2 42
Al-Baraim Jack 20 L 20 B807 B004 L 20 L 20 <thl 20<="" th=""> L 20 L 20</thl>		Sal Ala	409.34	17.04	125.25	110.09	1.00	5.42
Arbsiz Arbsiz<	Al Duraimi	Siiiid Al Iuuusuf	436.03	13.20	120.33	99.02	1.30	1.99
All between the set of the set o	Al-Dulailli	Al-Juwayi Al-Jubaylah	202.11	25.25	99.97 60.91	00.19 70.72	1.00	5.67
North 17.47 17.33 348.50 0.00 1.66 1.19 Al Batinah 25.10 1.80 95.37 70.89 0.88 0.34 Al Batinah 22.497 19.43 66.63 47.33 1.29 3.91 Al Batinah 23.63 3.66 88.61 7.47.3 1.99 0.44 Adjat Al-Abreein 415.50 1.5.33 110.78 10.89 1.61 2.35 Al Batinah 50.66 1.35 170.75 100.66 1.74 4.66 Al-Abreein 495.56 1.35 170.75 100.06 1.74 4.66 Al-Batinah South Al-Mosia 252.78 1.593 170.10 6.73.76 0.42 2.23 Diababah 558.76 15.53 11.13 1.28 2.23 1.73 1.63.29 1.13 1.28 2.23 Mascar 270.63 17.03 1.66.3 3.33 1.22 2.23 1.33 1.33 3.36 1.33		AI-ODayiali Fauwad	270.44	10.04	09.01	72.75	2.01	4.51
Ali Auxilion 2.51 1.53 38.37 90.00 2.68 1.14 Wardi Shamh 22.407 1.63 1.646 1.83 1.47 2.29 Wardi Shamh 22.08 1.007 80.40 6.36 1.17 1.45 Al-Batinah Sorth Al-Chargarh 32.03 15.35 74.05 51.45 1.09 0.44 Al-Batinah Algair Al-Abreein 41.35 1.135 78.74 64.28 1.31 1.85 Al-Batinah 51.41 92.77 8.492 1.45 1.45 Al-Batinah 51.41 1.22 1.06.01 1.21 1.88 Al-Batinah 77.50 10.005 7.76 1.38 1.38 Al-Batinah 77.45 1.22 1.000 1.23 1.33 Al-Batinah 77.45 1.23 1.23 1.33 1.33 Al-Batinah 77.45 1.23 1.23 1.33 1.33 1.33 1.33 1.33 1.33 1.33		rayyau Khatuuah	270.44	13.21	90.04	05.02	1.20	7.10
Marking 25.10 18.49 95.27 74.05 0.05 0.25 Al Batinah North Micialishim 220.06 1007 88.64 74.73 1.13 1.15 Al Batinah North Al-Chuzyfah 326.01 0.65 88.61 74.73 1.09 0.44 Aplat Al-Abreen 415.50 12.53 110.78 108.42 1.45 Al-Batinah 75.56 11.35 78.74 64.23 1.31 1.88 Al-Batinah 277.55 13.53 127.50 100.06 1.74 4.46 Al-Mixen 279.25 12.36 103.05 73.75 0.34 0.16 Barda 374.05 12.36 103.05 73.75 0.34 0.16 Barda 374.05 13.63 127.50 110.3 1.23 1.03 Barda 374.05 13.63 127.50 113.5 1.33 1.33 Muscat 271.03 10.95 106.70 68.34 1.33 1.33 </td <td></td> <td>KildtWdii</td> <td>274.45</td> <td>17.33</td> <td>48.30</td> <td>55.00</td> <td>2.00</td> <td>7.19</td>		KildtWdii	274.45	17.33	48.30	55.00	2.00	7.19
Al Batinah North Al-24.00 (Al-2000) 12.42 (2) 12.43 (2) 14.30 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.43 (2) 12.44 (2) 12.44 (2) 12.53 (2) <th12.53 (2)<="" th=""> 12.53 (2) 12.53 (2)<</th12.53>		Manuali Manuali Calarah	285.10	18.80	95.37	70.89	0.88	0.34
All Batimal North Addi Shatm 250.08 1.00// Apple Al-Abrevia 250.08 1.00// Apple Al-Abrevia 1.00// Advia Al-Abrevia <td></td> <td>Wadi Saiman</td> <td>224.97</td> <td>19.43</td> <td>64.63</td> <td>48.30</td> <td>1.47</td> <td>2.79</td>		Wadi Saiman	224.97	19.43	64.63	48.30	1.47	2.79
Ab Bathlah Noth Ar Sultiziyani 308 808 68.81 7.47 1.58 3.91 Algar Al-Sultiziyani 30.89 1.63 1.63 1.63 1.64 1.66	Al Datinah Nauth	Wadi Sharm	269.08	10.07	80.40	03.80	1.17	1.45
April 24 203-23 10.33 14.03 3.1-31 1.09 4.44 April 24 Arbivein 415.56 1.15 100.72 108.85 1.65 2.35 Al-Batinal South 460.07 106.13 100.72 106.13 1.65 1.65 Shahan 460.37 13.63 127.50 100.06 1.74 4.46 Al-Muscen 460.37 13.63 127.50 100.06 1.74 4.46 Al-Wissen 297.25 12.36 103.06 7.976 0.94 0.16 Batan 758.57 15.53 11.13 1.58 3.38 <	AI Datiliali NOITII	Al-GIIUZdyidii	202.91	9.00	74.05	74.75	1.99	5.91
Addit Addit <th< td=""><td></td><td>AI-JIZZI</td><td>203.23</td><td>10.35</td><td>/4.05</td><td>51.45 109.0C</td><td>1.09</td><td>0.44</td></th<>		AI-JIZZI	203.23	10.35	/4.05	51.45 109.0C	1.09	0.44
Alphal Al-Aksian 319.86 14.16 32.39 84.22 1.43 1.43 Al-Batinah South Hayi Al-Najd 46.00 20.33 102.72 106.91 2.63 6.62 Al-Batinah South Al-Wati 425.27 11.35 76.70 100.66 1.34 4.64 Al-Butsian 272.57 12.36 107.06 77.76 0.34 0.64 Ar-Butsian 272.57 12.36 107.06 77.76 0.34 0.64 Barka 178.88 13.22 66.79 70.00 1.53 3.83 Muscat 271.03 11.55 13.65 150.11 2.37 6.12 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Muscat 270.37 10.45 25.62 70.77 68.34 1.93 3.16 Muscat 270.37 10.52 12.56 12.11 <td></td> <td>Aqair Al-Abreem</td> <td>415.50</td> <td>13.53</td> <td>110.78</td> <td>108.96</td> <td>1.01</td> <td>2.35</td>		Aqair Al-Abreem	415.50	13.53	110.78	108.96	1.01	2.35
Iayi A'-Naja 486.00 2003 102./2 0.0931 2.63 0.02 Al-Batinah South 44.357 11.33 127.50 100.06 1.74 4.46 Al-Witseen 460.37 13.63 127.50 00.06 1.74 4.46 Al-Witseen 297.27 12.35 10.006 9.73 0.34 0.64 An-Bustan 297.27 12.35 10.30 9.737 0.34 0.35 Salma 297.25 11.73 161.92 111.20 0.23 -1.09 Muscat 297.05 13.65 136.62 121.18 1.77 3.22 Muscat 271.03 10.95 70.67 63.34 1.93 3.16 Muscat 1066.00 39.83 62.81 20.60 2.13 1.74 3.63 Muscat 106.80 99.80 13.34 10.44 92.39 90.38 1.74 3.63 Muscat 10.82 16.27 61.64 50.09 1.4		Aqbat Al-Risan	319.66	14.16	92.97	84.92	1.45	1.45
Al-Batinah South Al-Maiscen 40.37 13.63 78.74 94.48 1.11 1.188 Al-Batinah South Al-Waist 223.78 13.63 70.01 69.18 1.23 0.64 Al-Waist 223.78 13.23 100.06 79.75 0.94 0.16 Barka 178.88 13.22 66.79 37.00 1.29 2.23 Dahabah 53.87 19.58 117.37 161.92 111.20 0.23 -1.08 Muscat 23.07 13.63 13.63 13.65 150.02 120.18 1.77 3.21 Muscat 21.07 13.65 13.025 2.061 1.14 1.17 3.21 Muscat 21.07 13.65 13.026 2.23 2.61 1.14 Muscat 21.66 23.83 10.26 2.23 2.63 1.14 Muscat 270.07 13.65 10.80 2.50 2.63 1.14 Muscat 270.57 81.01 </td <td></td> <td>Hayl Al-Najd</td> <td>486.00</td> <td>20.03</td> <td>102.72</td> <td>106.91</td> <td>2.63</td> <td>6.62</td>		Hayl Al-Najd	486.00	20.03	102.72	106.91	2.63	6.62
Al-Balnan South Al-Wiseen 460.3 13.83 127.30 100.06 1.74 4.44 Al-Wasit 252.78 1533 76.01 63.18 13.8 0.64 Ar-Mustat 297.25 12.36 100.06 73.76 0.94 0.16 Barla 172.98 13.22 66.7 37.00 1.28 2.23 Sine 469.21 18.44 19.42 11.20 1.23 -1.83 Muscat 71.03 19.55 76.65 150.11 2.37 1.22 Muscat 71.03 19.55 70.67 68.34 1.93 3.16 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Muscat 271.03 10.24 14.60 10.80 96.80 1.93 4.25 Mathi 11.40 9.33 1.74 3.60 1.14 3.23		Saham	2/5.56	11.35	/8./4	64.28	1.31	1.88
Ad-Wait 25.7.8 15.93 Ab.01 69.18 1.28 0.04 Ar.Rustaq 272.5 12.36 00.30 77.00 1.29 2.23 Barka 178.98 13.22 66.79 37.00 1.29 2.23 Muscat Salma 374.25 11.73 106.92 111.20 0.23 -1.09 Muscat Salma 374.25 11.52 18.36 136.11 2.37 6.12 Muscat 271.03 1055 70.67 68.34 133 3.16 Nuscat 271.03 1055 70.67 68.34 133 3.16 Nuscat 271.03 1055 70.67 68.34 133 3.16 Nuscat 213.41 166.00 36.30 11.13 7.92.5 6.06 1.14 Adh-Dhahirah 46.40 2.39 70.67 68.34 1.03 4.55 Maid Al-Instan 20.82 16.27 61.64 50.09 1.40 2.	Al-Batinah South	Al-Miseen	460.37	13.63	127.50	100.06	1.74	4.46
Ar-Kustaq 29/25 12.3b 103.0c 79.7b 0.94 0.1b Barka 758.76 19.58 155.03 111.15 1.58 3.39 Muscat Sama 374.25 11.73 161.92 111.25 1.53 1.83 Muscat 271.03 150.2 83.36 150.11 2.37 6.12.9 Muscat 271.03 10.95 70.67 6.8.34 1.93 3.16.1 Muscat 271.03 10.95 70.66 7.92.5 0.96 1.14 Muscat 31.43 10.81 2.06.6 213.61 2.52 8.17 Mdi-Dhahirah 106.60 39.83 62.81 2.50 2.66 1.34 Main 31.43 10.81 9.40 7.416 2.18 5.34 Dank 331.43 10.81 9.40 7.416 2.18 5.34 Main 2.08 6.127 6.164 50.99 1.40 2.23 Main		Al-Wasit	252.78	15.93	/6.01	69.18	1.38	0.64
Barka 174398 13.22 66.79 31.00 1.29 2.23 Muscat Salma 374.25 11.73 161.92 111.20 0.23 -1.09 Muscat Buei 469.21 18.44 12.42 125.00 1.3 1.83 Mazara 352.52 13.65 136.92 121.18 1.77 3.22 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Wadi Al-Jannah 166.00 39.83 62.81 2.560 2.61 7.07 Wadi Al-Manad 860.29 17.83 12.06 2.13.6 2.34 4.25 Daharah 20.08 16.27 61.64 50.09 1.40 2.23 Adh-Dahinh 10.04 92.39 90.38 1.74 3.60 Majar 2.82 76.03 13.02 2.30 5.88 Majar 1		Ar-Rustaq	297.25	12.36	103.06	/9./6	0.94	0.16
Dhabah 558,76 19,58 155,03 111,35 1.58 3.98 Muscat Buei 469,21 18,44 124,22 125,00 1.53 1.83 Muscat 526,25 13,65 136,52 121,18 1.77 3.22 Muscat 271,03 10,95 70,67 68,34 1.93 3.16 Auscat 271,03 10,95 70,67 68,34 1.93 3.16 Muscat 271,03 10,85 70,67 68,34 1.93 3.16 Muscat 10,40 92,39 90,38 1.74 3.60 1.93 4.25 Dank 31,43 10,81 69,40 7,416 2.18 5.34 Majzi 536,76 18,19 165,32 130,82 2.30 5.88 Aubahirah 40,62 19,26 10,13 4.272 1.99 4.10 Aubara 28,65 19,28 74,03 17,126 1.56 2.63		Barka	178.98	13.22	66.79	37.00	1.29	2.23
Salma 374.25 11.73 161.92 111.20 0.23 -1.09 Muscat Beie 4692.11 18.44 124.22 12.00 1.53 1.83 Mazara 3 5526.25 13.65 13.652 12.118 1.77 3.22 Muscat 271.03 10.95 70.67 66.3.4 1.93 3.16 Wadi Al-Jannah 166.00 39.83 62.81 25.60 2.61 7.07 Wadi Al-Khawd 860.29 17.83 12.066 213.61 2.52 8.17 Adh-Dhahirah 10.04 92.39 90.38 1.74 3.60 Majzi 363.7 18.19 105.52 13.08 2.30 5.88 Adh-Dahirah 20.02 13.56 61.44 50.34 1.14 0.59 Adh-Dakirah 20.02 13.56 61.44 50.34 1.14 0.59 Adh-Dakirah 190.02 13.56 1.14 1.14 0.59 2.66 63.1		Dhabaah	558.76	19.58	155.03	111.35	1.58	3.98
Muscat Buei 469.21 18.44 124.22 125.00 1.53 1.83 Haydah 672.08 15.02 8.336 15.01 2.37 6.12 Mazara 3 526.25 13.65 136.92 12.11.8 1.77 3.22 Maxata 346.40 9.39 111.26 79.25 0.96 1.14 Madi Al-Khawd 860.29 17.83 120.66 213.61 2.52 8.17 Adh-Dhahirah 166.60 38.3 120.66 213.61 2.52 8.17 Madi-Dhahirah 366.31 10.04 92.39 90.38 1.74 3.60 Dank 31.43 10.04 92.39 90.38 1.74 3.60 Kubarah 20.82 16.27 61.64 50.09 1.40 2.30 Ad-Dakhirah 20.82 19.28 74.03 71.26 1.43 2.30 Ad-Dakirai 19.82 74.03 1.91 4.14 3.99 4.10		Salma	374.25	11.73	161.92	111.20	0.23	-1.09
Hayladh 672.08 15.02 83.36 15.01 2.37 6.12 Muscari 3 526.25 13.65 136.92 121.18 1.77 3.22 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Nuri 346.40 9.33 62.81 25.60 2.61 7.07 Wadi Al-Jannah 166.60 98.83 62.81 25.60 2.61 7.07 Madi Al-Khawd 800.29 17.83 10.266 213.61 2.52 8.17 Adh-Dhahir 31.43 10.81 10.82 90.38 1.74 3.60 Majzi 536.76 18.19 105.32 130.82 2.30 5.88 Qarra Al-Kaba 282.05 19.28 74.03 71.26 1.63 2.66 Ad-Dakhilyah Al-Qusaiba 196.20 13.56 61.14 42.72 1.99 4.10 Ad-Dakir 279.87 11.68 78.73 66.20 1.93 3.99 <td>Muscat</td> <td>Buei</td> <td>469.21</td> <td>18.44</td> <td>124.22</td> <td>125.00</td> <td>1.53</td> <td>1.83</td>	Muscat	Buei	469.21	18.44	124.22	125.00	1.53	1.83
Mazara 3 S26.25 13.65 136.92 121.18 1.77 3.22 Muscat 271.03 10.95 70.67 68.34 1.93 3.16 Ruwi 346.40 9.39 111.26 7.9.25 0.96 1.14 Wadi Al-Khawd 800.29 17.83 120.66 213.61 2.52 8.17 Adh-Dhahira 368.31 10.04 92.39 90.38 1.74 3.60 Majai 536.76 18.19 105.52 10.082 2.30 5.88 Qarn Al-Kaba 282.05 19.28 74.03 71.62 1.65 2.66 Ad-Dakhiyah Al-gusaiba 196.20 13.55 61.14 40.27 1.99 4.10 Musoit 279.47 1.68 78.73 66.20 1.93 3.99 Ad-Dakhiyah Al-Gusaiba 11.68 78.73 66.20 1.93 3.99 Ad-Dakhiyah 131.48 1.021 115.67 2.15 6.23		Hayfadh	672.08	15.02	83.36	150.11	2.37	6.12
Muscat 271.03 10.95 70.67 68.34 1.33 3.16 Wadi Al-Shawd 346.40 9.39 111.26 79.25 0.96 1.14 Wadi Al-Shawd 860.29 17.83 120.66 213.61 2.52 8.77 Adh-Dhahirah 10.22 14.60 108.80 96.80 1.33 4.25 Dank 331.43 10.04 92.39 90.38 1.74 3.60 Dhahir 368.31 10.04 92.39 90.38 1.74 3.60 Majzi 536.76 18.19 105.32 130.82 2.30 5.88 Qarn Al-Kabsa 28.05 19.28 74.03 71.26 1.65 2.66 Ad-Dakhirjah Al-Qusaiba 166.64 12.11 3.841 42.72 1.99 4.10 MoD 73.487 23.96 180.21 155.67 2.15 6.31 MoD 73.487 23.96 180.21 155.67 2.15 6.31 <		Mazara 3	526.25	13.65	136.92	121.18	1.77	3.22
Ruvi 346.40 9.39 111.26 7.9.25 0.96 1.14 Adh-Dhahirah 166.00 39.38 162.81 25.60 26.1 7.77 Adh-Dhahirah 410.22 14.80 108.80 96.80 1.33 4.25 Dank 31.43 10.81 69.04 7.416 2.18 5.34 Dank 363.31 10.81 69.04 7.416 2.18 5.34 Majzi 56.76 18.19 105.32 130.82 2.30 5.88 Add-Dakhiyah 169.60 12.11 38.41 5.34 1.05 2.66 Ad-Dakhiyah 169.60 12.13 38.41 4.27.2 1.99 4.10 Jivar 24.94.7 18.07 64.37 62.74 1.43 2.39 Ad-Dakhiyah 169.64 12.11 38.41 42.72 1.99 4.10 Jivar 24.94.7 18.07 66.20 1.33 3.99 Majd-Al-Masalah 33.143 <td></td> <td>Muscat</td> <td>271.03</td> <td>10.95</td> <td>70.67</td> <td>68.34</td> <td>1.93</td> <td>3.16</td>		Muscat	271.03	10.95	70.67	68.34	1.93	3.16
Waid Al-Jannah 166.60 39.83 62.81 2.50 2.61 7.07 Adh-Dhahirah Dakarah 410.22 14.60 108.80 96.80 1.93 4.25 Dank 331.43 10.04 92.39 90.38 1.74 5.36 Kubarah 200.82 16.27 61.64 50.09 1.40 2.23 Adr-Dakhirah 208.82 16.27 61.61.4 50.30 1.40 2.23 Qarn Al-Kabaa 28.05 19.28 74.03 71.26 1.65 2.66 Adr-Dakhiryah Al-Qusaiba 196.64 12.11 38.41 42.72 1.99 4.10 Mabir 27.987 11.68 78.73 66.20 1.93 3.99 Mubir 279.87 11.68 78.73 66.20 1.93 3.99 Ash-Sharqiya North Ad-Dariz 33.47 17.08 72.27 18.17 1.14 1.43 Ash-Sharqiya South Ad-Dariz 33.43 13.24		Ruwi	346.40	9.39	111.26	79.25	0.96	1.14
Wafi Al-Kbawd 880.29 17.83 12.06 21.361 2.52 8.17 Adh-Dhahirah 410.22 14.60 108.80 96.80 1.93 4.25 Dank 31.43 10.81 69.40 74.16 2.18 5.34 Dahir 368.31 10.04 92.39 90.38 1.74 3.60 Kubarah 200.82 16.27 61.64 50.09 1.40 2.23 Majzi 536.76 18.19 105.32 13.08 2.80 5.88 Quran Al-Kabas 282.05 19.28 74.03 71.26 1.65 2.66 Tanam 2 196.20 13.36 61.14 50.34 1.43 2.39 Md-Dakhilyah 199.42 18.07 64.37 62.74 1.43 2.39 Musbir 279.87 11.68 78.73 66.20 1.93 3.99 Musbir 33.447 1.020 104.79 81.14 1.14 1.39 Ash-Sharqiya No		Wadi Al-Jannah	166.60	39.83	62.81	25.60	2.61	7.07
Adh-Dhahirah Dakarah 41022 14.60 1080 96.80 1.93 4.25 Dak 331.43 10.04 92.39 97.38 1.74 3.60 Dahir 368.31 10.04 92.39 90.38 1.74 3.60 Majzi 536.76 18.19 105.32 130.82 2.30 5.88 Qarn Al-Kabsa 282.05 19.28 74.03 71.26 1.65 2.66 Md-Dakihliyah Al-Qusaiba 169.64 12.11 38.41 42.72 1.99 4.10 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Mubbit 279.87 11.68 78.73 66.20 1.93 3.99 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Ad-Mudyhfah 334.47 17.08 73.07 81.55 1.96 4.81 Ad-Dariz 384.47 16.62 73.07 81.55 1.96 </td <td></td> <td>Wadi Al-Khawd</td> <td>860.29</td> <td>17.83</td> <td>120.66</td> <td>213.61</td> <td>2.52</td> <td>8.17</td>		Wadi Al-Khawd	860.29	17.83	120.66	213.61	2.52	8.17
Dank 331.43 10.81 69.40 74.16 2.18 5.34 Hahir 368.31 10.04 92.39 90.38 1.74 360 Kubarah 200.82 16.27 61.64 50.09 1.40 2.23 Majzi 56.67 18.19 105.32 130.82 2.30 5.88 Carm Al-Kabsa 282.05 13.56 61.14 50.34 1.14 0.59 Ad-Dakhliyah 196.20 13.56 61.14 50.34 1.14 0.59 MoD 74.93 23.96 180.21 155.67 2.15 6.31 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 31.48 10.20 104.79 81.14 1.14 1.39 Subayb 655.50 27.50 307.10 25.47 0.16 -1.43 Ad-Mudaybi 331.62 12.66 73.02 79.98 2.05 4.66 Al-Mudaybi	Adh-Dhahirah	Dakarah	410.22	14.60	108.80	96.80	1.93	4.25
Dhahir 368.31 10.04 92.39 90.38 1.74 3.60 Majzi 368.51 16.27 61.64 50.09 1.40 2.23 Majzi 356.76 18.19 105.32 130.82 2.30 5.88 Qarn Al-Kabsa 282.05 19.28 7.40.3 71.26 1.65 2.66 Jiwar 296.20 13.36 61.14 50.34 1.14 0.59 MOD 734.87 23.96 180.21 155.67 2.15 6.31 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Ash-Sharqiya North Ad-Dariz 33.44 10.20 104.79 81.14 1.14 1.39 Ash-Sharqiya North Ad-Dariz 33.447 17.08 72.57 81.71 1.97 4.80 Ash-Mudayhi 33.162 12.66 7.302 7.98 2.05 4.66 Al-Mudayhi 33.162 12.66 7.302 7.98 2.46		Dank	331.43	10.81	69.40	74.16	2.18	5.34
Kubarah 200.82 16.27 61.64 50.09 1.40 2.23 Ad-Dakhiyah Bajzi 53.676 18.19 105.32 10.082 2.30 5.88 Ad-Dakhiyah 196.20 13.56 61.14 50.34 1.165 2.66 Ad-Dakhiyah 196.20 13.56 61.14 50.34 1.14 0.59 Ad-Dakhiyah 196.20 13.56 61.14 50.34 1.14 0.59 Mubrit 249.47 18.07 64.37 62.74 1.43 2.39 Mubrit 279.87 11.68 78.73 66.20 1.93 3.99 Subayb 655.50 2.7.50 307.10 22.547 0.16 -1.43 Ad-Dariz 31.42 17.08 72.57 81.71 1.97 4.80 Ad-Dariz 31.42 12.56 73.02 79.98 2.05 4.66 Al-Mudaybin 31.62 12.66 73.02 79.98 2.05 4.66 <tr< td=""><td></td><td>Dhahir</td><td>368.31</td><td>10.04</td><td>92.39</td><td>90.38</td><td>1.74</td><td>3.60</td></tr<>		Dhahir	368.31	10.04	92.39	90.38	1.74	3.60
Majei 536.76 18.19 105.32 13.082 2.30 5.88 Ad-Dakhliyah 196.20 13.56 61.14 50.34 1.14 0.59 Ad-Dakhliyah 14-Qusaiba 196.20 13.56 61.14 50.34 1.14 0.59 MoD 734.87 23.96 180.21 155.67 2.15 6.31 Musbit 279.77 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 331.48 10.20 104.79 81.14 1.14 1.39 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Ash-Sharqiya North Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Ash-Muqayhfah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Mario Bani Khalid 514.33 13.24 129.17 126.03		Kubarah	200.82	16.27	61.64	50.09	1.40	2.23
Qarn Al-Kabsa 282.05 19.28 74.03 71.26 1.65 2.66 Ad-Dakhliyah Ianam 2 196.02 13.56 61.14 50.34 1.1 50.34 Ad-Dakhliyah Ianam 2 249.47 18.07 64.37 62.74 1.43 2.39 MuD 734.87 23.96 180.21 155.67 2.15 63.1 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 331.48 10.20 104.79 81.14 1.14 1.39 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Ash-Sharqiya North Ad-Dariz 331.62 12.66 73.02 79.98 2.05 4.66 Al-Mudaybi 331.62 12.66 73.02 79.98 2.05 4.66 Al-Mudaybi 33.447 16.08 73.07 81.55 1.96 4.81 Marcon 344.481 12.57 80.05		Majzi	536.76	18.19	105.32	130.82	2.30	5.88
Ad-Dakhliyah Tanam 2 196.20 13.56 61.14 50.34 1.14 0.59 Ad-Dakhliyah Al-Qusaiba 169.64 1.11 18.81 42.72 1.99 4.10 Jiwar 249.47 18.07 64.37 62.74 1.43 2.39 MOD 734.87 23.96 180.21 155.67 2.15 6.31 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 331.48 10.20 104.79 81.14 1.14 1.39 Ash-Sharqiya North Ad-Dariz 394.47 17.08 72.57 81.71 1.97 4.80 Al-Mudaybit 331.62 12.66 73.02 79.98 2.05 4.66 Al-Mudaybit 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 11.070 1.47 1.49 Masroon 344.81 12.57 80.05 76.89		Qarn Al-Kabsa	282.05	19.28	74.03	71.26	1.65	2.66
Ad-Dakhliyah Al-Qusaiba 169.64 12.11 38.41 42.72 1.99 4.10 jiwar 249.47 18.07 64.37 62.74 1.43 2.39 MOD 734.87 23.96 180.21 155.67 2.15 6.31 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Ash-Sharqiya North Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Ash-Sharqiya North Ad-Dariz 334.47 16.08 73.02 79.98 2.05 4.66 Al-Muqayhfah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 12.787 110.70 1.47 1.28 Ash-Sharqiya South Al-Fuljayi 442.46 10.65 84.90 95.27 2.39 6.80 Masroon 344.81		Tanam 2	196.20	13.56	61.14	50.34	1.14	0.59
jiwar 249.47 18.07 64.37 62.74 1.43 2.396 MOD 734.87 23.96 180.21 155.67 2.15 6.31 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 331.48 10.20 104.79 81.14 1.14 1.39 Tawi Zahir 497.43 11.99 142.37 109.00 1.85 4.79 Ash-Sharqiya North Ad-Dariz 334.47 17.08 7.257 81.71 1.97 4.80 Al-Muqayhfah 334.47 16.06 73.02 79.98 2.05 4.66 Al-Muqayhfah 34.47 16.06 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Ibra 382.48 10.49 13.17 96.76 1.47 1.49 Ash-Sharqiya South Al-Fuljayi 442.46 10.65 84.90 95.27 2	Ad-Dakhliyah	Al-Qusaiba	169.64	12.11	38.41	42.72	1.99	4.10
MOD 734.87 23.96 180.21 155.67 2.15 6.31 Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 331.48 10.20 104.79 81.14 1.14 1.39 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Tawi Zahir 497.43 11.99 142.37 109.00 1.85 4.79 Ash-Sharqiya North Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Al-Mudaybi 331.62 12.66 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Masroon 514.33 13.24 129.17 126.03 1.82 3.41 </td <td></td> <td>Jiwar</td> <td>249.47</td> <td>18.07</td> <td>64.37</td> <td>62.74</td> <td>1.43</td> <td>2.39</td>		Jiwar	249.47	18.07	64.37	62.74	1.43	2.39
Musbit 279.87 11.68 78.73 66.20 1.93 3.99 Najd Al-Musallah 31.48 10.20 104.79 81.14 1.14 1.93 Subayb 655.50 27.50 307.10 225.47 0.16 -1.43 Ash-Sharqiya North 40-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Al-Mudaybit 331.62 12.66 73.02 79.98 2.05 4.66 Al-Muqayfrah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.49 Mayoon 34.481 12.57 80.05 76.89 2.46 7.21 Maroon 344.81 12.57 80.05 76.89 2.46 7.21 Maroon 344.81 12.57 80.05 76.89 2.46 7.21 Ash-Sharqiya South Al-Fuljayi 442.46 10.65 84.90 9.527 2.		MOD	734.87	23.96	180.21	155.67	2.15	6.31
Naji Al-Musallah 331.48 10.20 104.79 81.14 1.14 1.39 Ash-Sharqiya North Tawi Zahir 497.43 11.99 142.37 109.00 1.65 4.79 Ash-Sharqiya North Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Al-Mudaybi 331.62 12.66 73.02 79.98 2.05 4.66 Al-Mudaybia 392.14 11.25 127.87 110.70 1.47 1.28 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Masroon 344.81 12.57 80.05 76.89 2.45 3.41 Ash-Sharqiya South Al-Fuljayj 442.46 10.65 84.90 95.27 2.39 6.80 Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jabal Bani Jabir 76.523 36.53		Musbit	279.87	11.68	78.73	66.20	1.93	3.99
Subayb655.5027.50307.10225.470.16-1.43Tawi Zahir497.4311.99142.37109.001.854.79Ash-Sharqiya NorthAd-Dariz334.4717.0872.5781.711.974.80Al-Mudaybi331.6212.6673.0279.982.054.66Al-Muqayhfah334.4716.0873.0781.551.964.81Haimah392.1411.2512.787110.701.471.28Ibra382.4810.49113.1796.761.471.49Masroon344.8112.5780.0576.892.467.21Wadi Bani Khalid514.3313.24129.17126.031.823.41Ash-Sharqiya SouthAl-Fuljayj442.4610.6584.9095.272.396.80Fins306.3014.8693.6878.061.221.021.02Jaala Bani216.8720.0964.6449.942.515.93Jabal Bani Jabir755.2336.53190.45165.531.975.07Snaf368.8020.70107.10106.681.310.75DhofarAqarhanavt438.0019.01141.98125.261.300.83Ghadow676.9322.05136.92159.372.015.03Hagayf411.1511.95108.61102.482.033.98Mughsayl173.9713.5283.3445.09<		Najd Al-Musallah	331.48	10.20	104.79	81.14	1.14	1.39
Ash-Sharqiya North Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Ash-Sharqiya North Al-Mudaybi 331.62 12.66 73.02 79.98 2.05 4.66 Al-Muqayhfah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Jalan Bani Zhayi 42.46 10.65 84.90 95.27 2.39 6.80 Jalalan Bani 216.87 20.09 64.64 49.94		Subayb	655.50	27.50	307.10	225.47	0.16	-1.43
Ash-Sharqiya North Ad-Dariz 334.47 17.08 72.57 81.71 1.97 4.80 Al-Mudaybi 331.62 12.66 73.02 79.98 2.05 4.66 Al-Mudaybfah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Ibra 382.48 10.49 113.17 96.76 1.47 1.49 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Wadi Bani Khalid 514.33 13.24 129.17 126.03 1.82 3.41 Ash-Sharqiya South Al-Fuljayj 42.46 10.65 84.90 95.27 2.39 6.80 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Jabal Bani Jabir 765.23 36.63 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Dhofar Aqarhanavt 438.00 <t< td=""><td></td><td>Tawi Zahir</td><td>497.43</td><td>11.99</td><td>142.37</td><td>109.00</td><td>1.85</td><td>4.79</td></t<>		Tawi Zahir	497.43	11.99	142.37	109.00	1.85	4.79
Al-Mudaybi 331.62 12.66 73.02 79.98 2.05 4.66 Al-Muqayhfah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Ibra 382.48 10.49 113.17 96.76 1.47 1.49 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Masroon 36.30 14.86 93.68 78.06 1.22 1.02 Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jaalan Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.00 20.70 107.10 106.68 1.31 0.75 Snaf 38.00 19.01 141.98 125.26 1.30 0.83	Ash-Sharqiya North	Ad-Dariz	334.47	17.08	72.57	81.71	1.97	4.80
Al-Muqayhfah 334.47 16.08 73.07 81.55 1.96 4.81 Haimah 392.14 11.25 127.87 110.70 1.47 1.28 Ibra 382.48 10.49 113.17 96.76 1.47 1.49 Masroon 344.81 12.57 80.05 76.89 2.46 7.21 Wadi Bani Khalid 514.33 13.24 129.17 126.03 1.82 3.41 Ash-Sharqiya South Al-Fuljayj 442.46 10.65 84.90 95.27 2.39 6.80 Jaalan Bani 216.87 20.09 64.64 49.94 2.20 1.02 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Dhofar Aqarhanawt 438.00 20.70 107.10 106.68 1.31 0.75 Jabal Bani Jabir 76.93 22.05 136.92 15.93 2.01 5.03 Maryanawt 438.00 19.01 141.98 </td <td></td> <td>Al-Mudaybi</td> <td>331.62</td> <td>12.66</td> <td>73.02</td> <td>79.98</td> <td>2.05</td> <td>4.66</td>		Al-Mudaybi	331.62	12.66	73.02	79.98	2.05	4.66
Haimah392.1411.25127.87110.701.471.28Ibra382.4810.49113.1796.761.471.49Masroon344.8112.5780.0576.892.467.21Madi Bani Khalid514.3313.24129.17126.031.823.41Ash-Sharqiya SouthAl-Fuljayj442.4610.6584.9095.272.396.80Jalan Bani216.8720.0964.6449.942.515.93Jabal Bani Jabir765.2336.53190.45165.531.975.07Snaf368.8020.70107.10106.681.310.75DhofarAqarhanawt438.0019.01141.98125.261.300.83Hagayf411.1511.95108.61102.482.033.98Mughsayl173.9713.5283.3445.090.10-0.78Sadh156.4133.2166.4534.201.381.35Agayf410.5010.4698.0573.221.092.73All Stations154.10126.920.76-0.562.411.35All Stations104.6598.0573.221.092.73		Al-Muqayhfah	334.47	16.08	73.07	81.55	1.96	4.81
Ibra 382.48 10.49 113.17 96.76 1.47 1.49 Marroon 344.81 12.57 80.05 76.89 2.46 7.21 Wadi Bani Khalid 514.33 13.24 129.17 126.03 1.82 3.41 Ash-Sharqiya South Herulayj 442.46 10.65 84.90 95.27 2.39 6.80 Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Dhofar Aqarhanavt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Adah 156.41 33.21 664.55 34.20 1.38<		Haimah	392.14	11.25	127.87	110.70	1.47	1.28
Masroon344.8112.5780.0576.892.467.21Wadi Bani Khalid514.3313.24129.17126.031.823.41Ash-Sharqiya SouthAl-Fuljayj442.4610.6584.9095.272.396.80Fins306.3014.8693.6878.061.221.02Jaalan Bani216.8720.0964.6449.942.515.93Jabal Bani Jabir765.2336.53190.45165.531.975.07Snaf368.8020.70107.10106.681.310.75Snaf368.8020.70107.10106.681.310.75DhofarAqarhanawt438.0019.01141.98125.261.300.83Ghadow676.9322.05136.92159.372.015.03Hagayf411.1511.95108.61102.482.033.98Mughsayl173.9713.5283.3445.090.131.35Sadh156.4133.2166.4534.201.381.35Sher394.3514.20154.10126.920.76-0.56Zayk 1340.5010.4698.0573.221.092.73All Stations56.297.83109.21*92.82*1.62*3.08*		Ibra	382.48	10.49	113.17	96.76	1.47	1.49
Wadi Bani Khalid 514.33 13.24 129.17 126.03 1.82 3.41 Ash-Sharqiya South Al-Fuljayj 442.46 10.65 84.90 95.27 2.39 6.80 Fins 306.30 14.86 93.68 78.06 1.22 1.02 Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Tahwah 3 442.46 12.36 84.69 91.69 2.52 7.57 Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Mughsayl 173.97 13.52 83.34 45.09 0.1 3.98 Sadh 156.41 33.21 66.455 34.20 1.38<		Masroon	344.81	12.57	80.05	76.89	2.46	7.21
Ash-Sharqiya South Al-Fuljayj 442.46 10.65 84.90 95.27 2.39 6.80 Fins 306.30 14.86 93.68 78.06 1.22 1.02 Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Tahwah 3 442.46 12.36 84.69 91.69 2.52 7.57 Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.138 1.35 Sadh 156.41 33.21 66.455 34.20 1.38		Wadi Bani Khalid	514.33	13.24	129.17	126.03	1.82	3.41
Fins 306.30 14.86 93.68 78.06 1.22 1.02 Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Tahwah 3 442.46 12.36 84.69 91.69 2.52 7.57 Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Sadh 156.41 33.21 66.45 34.20 1.38 1.35 Sher 394.35 14.20 154.10 126.92 0.76 -0.56	Ash-Sharqiya South	Al-Fuljayj	442.46	10.65	84.90	95.27	2.39	6.80
Jaalan Bani 216.87 20.09 64.64 49.94 2.51 5.93 Jabal Bani Jabir 765.23 36.53 190.45 165.53 1.97 5.07 Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Sadh 156.41 33.21 66.45 34.20 1.35 1.35 Sadh 394.35 14.20 154.10 126.92 0.76 -0.56 Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations 56.29 7.83 109.21* 92.82* 1.62* 3.08*		Fins	306.30	14.86	93.68	78.06	1.22	1.02
Jabal Bani Jabir765.2336.53190.45165.531.975.07Snaf368.8020.70107.10106.681.310.75Tahwah 3442.4612.3684.6991.692.527.57DhofarAqarhanawt438.0019.01141.98125.261.300.83Ghadow676.9322.05136.92159.372.015.03Hagayf411.1511.95108.61102.482.033.98Mughsayl173.9713.5283.3445.090.10-0.78Sadh156.4133.2166.4534.201.381.35Sher394.3514.20154.10126.920.76-0.56Zayk 1340.5010.4698.0573.221.092.73All StationsKo297.83109.21*92.82*1.62*3.08*		Jaalan Bani	216.87	20.09	64.64	49.94	2.51	5.93
Snaf 368.80 20.70 107.10 106.68 1.31 0.75 Tahwah 3 442.46 12.36 84.69 91.69 2.52 7.57 Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Sadh 156.41 33.21 66.45 34.20 1.38 1.35 Sher 394.35 14.20 154.10 126.92 0.76 -0.56 Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations 560.29 7.83 109.21* 92.82* 1.62* 3.08*		Jabal Bani Jabir	765.23	36.53	190.45	165.53	1.97	5.07
Tahwah 3 442.46 12.36 84.69 91.69 2.52 7.57 Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Sadh 156.41 33.21 664.55 34.20 1.38 1.35 Sher 394.35 14.20 154.10 126.92 0.76 -0.56 Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations 860.29 7.83 109.21* 92.82* 1.62* 3.08*		Snaf	368.80	20.70	107.10	106.68	1.31	0.75
Dhofar Aqarhanawt 438.00 19.01 141.98 125.26 1.30 0.83 Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Sadh 156.41 33.21 66.45 34.20 1.38 1.35 Sher 394.35 14.20 154.10 126.92 0.76 -0.56 Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations Kence Sec.29 7.83 109.21* 92.82* 1.62* 3.08*		Tahwah 3	442.46	12.36	84.69	91.69	2.52	7.57
Ghadow 676.93 22.05 136.92 159.37 2.01 5.03 Hagayf 411.15 11.95 108.61 102.48 2.03 3.98 Mughsayl 173.97 13.52 83.34 45.09 0.10 -0.78 Sadh 156.41 33.21 66.45 34.20 1.38 1.35 Sher 394.35 14.20 154.10 126.92 0.76 -0.56 Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations 860.29 7.83 109.21* 92.82* 1.62* 3.08*	Dhofar	Aqarhanawt	438.00	19.01	141.98	125.26	1.30	0.83
Hagayf411.1511.95108.61102.482.033.98Mughsayl173.9713.5283.3445.090.10-0.78Sadh156.4133.2166.4534.201.381.35Sher394.3514.20154.10126.920.76-0.56Zayk 1340.5010.4698.0573.221.092.73All Stations860.297.83109.21*92.82*1.62*3.08*		Ghadow	676.93	22.05	136.92	159.37	2.01	5.03
Mughsayl173.9713.5283.3445.090.10-0.78Sadh156.4133.2166.4534.201.381.35Sher394.3514.20154.10126.920.76-0.56Zayk 1340.5010.4698.0573.221.092.73All Stations860.297.83109.21*92.82*1.62*3.08*		Hagayf	411.15	11.95	108.61	102.48	2.03	3.98
Sadh156.4133.2166.4534.201.381.35Sher394.3514.20154.10126.920.76-0.56Zayk 1340.5010.4698.0573.221.092.73All Stations860.297.83109.21*92.82*1.62*3.08*		Mughsayl	173.97	13.52	83.34	45.09	0.10	-0.78
Sher 394.35 14.20 154.10 126.92 0.76 -0.56 Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations 860.29 7.83 109.21* 92.82* 1.62* 3.08*		Sadh	156.41	33.21	66.45	34.20	1.38	1.35
Zayk 1 340.50 10.46 98.05 73.22 1.09 2.73 All Stations 860.29 7.83 109.21* 92.82* 1.62* 3.08*		Sher	394.35	14.20	154.10	126.92	0.76	-0.56
All Stations 860.29 7.83 109.21* 92.82* 1.62* 3.08*		Zayk 1	340.50	10.46	98.05	73.22	1.09	2.73
	All Stations		860.29	7.83	109.21*	92.82*	1.62*	3.08*

Note: * represents the average values.

Particularly, the high values were observed along the Al-Hajar mountain range that runs parallel to the Al Batinah Coast. Values of the parameters are lower at the flat areas than the ones in the higher altitude areas of Al Batinah region. Also, the values were observed declining steadily along the coastal plains. There is no literature found on the generation of IDF curve and its parameters at



Fig. 2. Box and Whisker plot showing annual rainfall at different governorate during study period.



Fig. 3. Variation of average annual total rainfall in various governorate.



Fig. 4. Observed and Modeled rainfall intensity at Wadi Al Jannah Station using A) Gumbel and B) Log Pearson Type III distributions at various return periods (2, 5, 10, 25, 50, 100 years).

Summary of best fit distribution at various return periods for Wadi Al Jannah station.

Distribution	Return Period							
	2	5	10	25	50	100		
	Coefficient of Determination (R ²)							
Gumbel Log-Pearson Type III	0.998 0.999	0.995 0.997	0.992 0.995	0.992 0.991	0.992 0.988	0.991 0.985		

Rainfall Intensity (mm/hr) at Rhibah, Aqbat Al Risah, Wadi Al Jannah, Subayb and Mughsayl station at various duration and return period using Gumbel Distribution.

Station	Rainfall Duration, d (hr)	Return Period, T (Years)						
(Governorate)			2	5	10	25	50	100
			Frequency Factor, K					
			-0.1644	0.7198	1.3052	2.0449	2.5936	3.1383
			Rainfall Int	ensity-I (mm/l	ır)			
Rhibah	704	0.833	36.04	69.90	92.32	120.65	141.67	162.53
(Musandam)		0.25	21.65	41.04	53.88	70.11	82.15	94.10
		0.5	16.58	29.19	37.54	48.09	55.91	63.68
		1	11.92	19.54	24.59	30.97	35.71	40.40
		360	3.58	6.16	7.87	10.03	11.63	13.22
		720	2.50	3.97	4.94	6.17	7.08	7.98
		1440	1.71	2.60	3.19	3.93	4.48	5.02
Aqbat Al-Risah	516	0.833	44.34	74.18	93.93	118.89	137.41	155.78
(Al-Batinah North)		0.25	26.36	43.81	55.37	69.98	80.81	91.57
		0.5	17.51	30.73	39.48	50.54	58.74	66.88
		1	11.14	19.69	25.35	32.50	37.80	43.07
		360	2.32	4.05	5.20	6.66	7.74	8.80
		720	1.38	2.27	2.86	3.60	4.16	4.71
		1440	0.87	1.39	1.72	2.15	2.47	2.78
Wadi Al-Jannah	220	0.833	18.78	39.97	54.00	71.72	84.87	97.92
(Muscat)		0.25	8.87	19.80	27.04	36.19	42.97	49.70
		0.5	5.94	12.07	16.13	21.26	25.06	28.84
		1	3.65	7.12	9.42	12.33	14.48	16.62
		360	0.89	1.63	2.12	2.74	3.20	3.65
		720	0.56	1.00	1.30	1.67	1.95	2.22
		1440	0.39	0.81	1.09	1.45	1.71	1.97
Subayb	1345	0.833	116.65	167.11	200.52	242.73	274.05	305.13
(Ad- Dakhaliyah)		0.25	74.58	114.22	140.47	173.63	198.23	222.64
		0.5	51.15	80.74	100.32	125.07	143.43	161.66
		1	30.39	47.92	59.52	74.18	85.05	95.85
		360	8.06	13.32	16.80	21.19	24.46	27.69
		720	4.43	7.60	9.70	12.35	14.32	16.27
		1440	2.60	4.5	5.76	7.35	8.53	9.70
Mughsayl	25	0.833	15.29	35.23	48.42	65.10	77.47	89.75
(Dhofar)		0.25	8.24	18.91	25.97	34.89	41.51	48.08
-		0.5	5.69	12.50	17.01	22.71	26.93	31.13
		1	3.94	7.71	10.21	13.36	15.70	18.02
		360	1.10	2.20	2.93	3.86	4.54	5.22
		720	0.76	1.44	1.90	2.47	2.90	3.32
		1440	0.51	0.92	1.19	1.53	1.78	2.03



Fig. 5. Rainfall intensity at different durations and return periods at Rh (Rhibah), Aq (Aqbal Al-Risah), Wa (Wadi Al Jannah), Su (Subayb), and Mu (Mughsayl) stations.

the various stations covering whole of Oman. Therefore, the generated contour maps could be used to estimate the empirical parameters; construct the IDF formula and curves and estimate the rainfall intensities for various rainfall duration and return periods at ungauged locations. Especially in the arid region where the rainfall is erratic and unpredictable with both space and time local IDF



Fig. 6. IDF curve for Khasab, Wadi Salmah, Saham, Dhabaah, Wadi Al-Jannah, Dank, Subayb, Ibra, Tahwa, and Mughsayl station.

P. Chitrakar, A. Sana and S. Hamood Nasser Almalki

Table 5

IDF parameter and equation with coefficient of determination for studied stations.

Governorate	Station Name	IDF Parameters			IDF Formula	Coefficient of determination	
		С	m	e	$(I = \frac{CT_R^m}{d^e})$	(R ²)	
Musandam	Ghamda	73.3	0.435	0.641	$I = \frac{73.3T_R^{0.435}}{4.641}$	0.914	
	Khasab	84.6	0.377	0.648	$I = \frac{\frac{d^{-0.377}}{84.6T_R^{0.377}}}{\frac{d^{-548}}{84.6T_R^{0.377}}}$	0.931	
	Rhaibah	71.4	0.405	0.599	$I = \frac{\frac{d^{-1.0.0}}{71.4T_R^{0.405}}}{\frac{d^{-5.00}}{70.599}}$	0.930	
	Sal Ala	24.0	0.645	0.596	$I = \frac{24T_R^{0.645}}{4^{0.596}}$	0.861	
	Sima	33.6	0.580	0.614	$I = \frac{\frac{1}{33.6T_R^{0.58}}}{\frac{1}{d^{0.614}}}$	0.870	
Al-Buraimi	Al-Juwayf	144.6	0.319	0.713	$I = \frac{\frac{144.6T_R^{0.319}}{\frac{10.713}{10}}$	0.994	
	Al-Ubaylah	111.5	0.317	0.713	$I = \frac{\frac{1}{11.5T_R^{0.317}}}{\frac{1}{d^{0.713}}}$	0.948	
	Fayyad	168.0	0.279	0.685	$I = \frac{168T_R^{0.279}}{_{d^{0.685}}}$	0.990	
	Khatwah	27.8	0.390	0.575	$I = \frac{\frac{u}{27.9T_R^{0.39}}}{\frac{u}{d^{0.575}}}$	0.926	
	Mahdah	65.4	0.403	0.627	$I = \frac{\frac{d}{65.4T_R^{0.403}}}{\frac{d}{6627}}$	0.934	
	Wadi Salmah	75.1	0.398	0.672	$I = \frac{\frac{1}{75.1T_R^{0.398}}}{\frac{1}{d^{0.672}}}$	0.924	
	Wadi Sharm	145.5	0.371	0.691	$I = \frac{\frac{1}{145.5T_R^{0.371}}}{\frac{1}{d^{0.691}}}$	0.932	
Al-Batinah North	Al-Ghuzayfah	9.0	0.347	0.413	$I = \frac{9T_R^{0.347}}{d^{0.413}}$	0.937	
	Al-Jizzi	130.6	0.444	0.746	$I = \frac{\frac{1}{130.6T_R^{0.444}}}{\frac{1}{d^{0.746}}}$	0.915	
	Aqair Al-Abreein	70.9	0.416	0.618	$I = \frac{70.9T_R^{0.416}}{d^{0.618}}$	0.918	
	Aqbat Al-Risah	166.1	0.325	0.734	$I = \frac{\frac{166.1T_R^{0.325}}{d^{0.734}}}{I}$	0.946	
	Hayl Al-Najd	229.8	0.313	0.740	$I = \frac{229.8T_R^{0.313}}{d^{0.74}}$	0.851	
	Saham	70.9	0.416	0.618	$I = \frac{70.9T_R^{0.416}}{d^{0.618}}$	0.918	
Al-Batinah South	Al-Miseen	168.9	0.301	0.651	$I = \frac{\frac{168.9T_R^{0.301}}{d^{0.651}}}{I}$	0.953	
	Al-Wasit	137.6	0.350	0.683	$I = \frac{137.6T_R^{0.35}}{d^{0.683}}$	0.939	
	Ar-Rustaq	129.5	0.360	0.664	$I = \frac{129.5T_R^{0.36}}{d^{0.664}}$	0.936	
	Barka	90.1	0.566	0.742	$I = \frac{90.1T_R^{0.566}}{d^{0.742}}$	0.963	
	Dhabaah	82.5	0.437	0.643	$I = \frac{82.5T_R^{0.437}}{d^{0.643}}$	0.913	
	Salma	176.4	0.311	0.652	$I = \frac{\frac{176.4T_R^{0.311}}{d^{0.652}}}{1}$	0.949	
Muscat	Buei	157.8	0.324	0.577	$I = \frac{157.8T_R^{0.324}}{d^{0.577}}$	0.957	
	Hayfadh	74.8	0.216	0.391	$I = \frac{74.8T_{g}^{0.216}}{d^{0.391}}$	0.991	
	Mazara	99.0	0.303	0.743	$I = \frac{99T_R^{0.303}}{d^{0.743}}$	0.960	
	Muscat	42.8	0.452	0.658	$I = \frac{\frac{42.8T_R^{0.452}}{d^{0.658}}}{d^{0.658}}$	0.922	
	Ruwi	167.0	0.307	0.644	$I = \frac{167T_R^{0.307}}{d^{0.644}}$	0.990	
	Wadi Al-Jannah	58.3	0.412	0.726	$I = \frac{58.3T_R^{0.412}}{d^{0.726}}$	0.920	
	Wadi Al-Khawd	109.2	0.453	0.568	$I = \frac{109.2T_R^{0.453}}{d^{0.568}}$	0.949	
Adh-Dhahirah	Dakarah	205.1	0.211	0.654	$I = \frac{205.1T_R^{0.211}}{d^{0.654}}$	0.977	
	Dank	37.4	0.430	0.612	$I = \frac{37.4T_R^{0.43}}{d^{0.612}}$	0.914	
	Dhahir	170.9	0.266	0.703	$I = \frac{\frac{170.9T_R^{0.266}}{d^{0.703}}}{d^{0.703}}$	0.961	
	Kubarah	175.2	0.373	0.775	$I = \frac{175.2T_R^{0.373}}{d^{0.775}}$	0.932	
	Majzi	193.8	0.304	0.733	$I = \frac{193.8T_R^{0.304}}{d^{0.733}}$	0.951	
	Qarn Al-Kabsa	97.6	0.458	0.694	$I = \frac{97.6T_R^{0.458}}{d^{0.694}}$	0.914	
	Tanam	89.7	0.384	0.683	$I = \frac{89.7T_R^{0.384}}{d^{0.683}}$	0.939	
Ad-Dakhliyah	Al Qusaiba	177.0	0.299	0.708	$I = \frac{177T_R^{0.299}}{d^{0.708}}$	0.959	
	Jiwar	175.6	0.398	0.790	$I = \frac{175.6T_R^{0.398}}{d^{0.790}}$	0.924	
	MOD	309.4	0.196	0.681	$I = \frac{309.4T_R^{0.196}}{d^{0.681}}$	0.980	
	Musbit	381.0	0.248	0.653	$I = \frac{381T_R^{0.248}}{d^{0.653}}$	0.973	
	Najd Al-Musallah	251.6	0.332	0.753	$I = \frac{251.6T_R^{0.332}}{d^{0.753}}$	0.990	
	Subayb	417.5	0.249	0.654	$I = \frac{336.3T_R^{0.249}}{d^{0.654}}$	0.972	
	Tawi Zahir	263.3	0.219	0.685	$I = \frac{26.3T_R^{0.219}}{d^{0.685}}$	0.994	

(continued on next page)

Table 5 (continued)

Governorate	Station Name	IDF Parameters			IDF Formula	Coefficient of determination	
		С	m	e	$(I = \frac{CT_R^m}{d^e})$	(R ²)	
Ash Sharqiya North	Ad-Dariz	180.1	0.211	0.606	$I = \frac{180.1T_R^{0.211}}{d^{0.606}}$	0.956	
	Al-Mudaybi	195.1	0.218	0.676	$I = \frac{195.1T_R^{0.218}}{d^{0.676}}$	0.994	
	Al-Muqayhfah	179.8	0.294	0.696	$I = \frac{\frac{1}{179.8T_R^{0.294}}}{\frac{1}{d^{0.696}}}$	0.956	
	Haimah	265.8	0.237	0.685	$I = \frac{\frac{265.8T_R^{0.237}}{d^{0.685}}}{I}$	0.969	
	Ibra	144.7	0.425	0.740	$I = \frac{\frac{1}{144.7T_R^{0.425}}}{\frac{1}{d^{0.74}}}$	0.914	
	Masroon	114.1	0.407	0.741	$I = \frac{\frac{114.1T_R^{0.407}}{10.741}}{10.741}$	0.955	
	Wadi Bani Khalid	279.0	0.238	0.670	$I = \frac{279T_R^{0.238}}{d^{0.67}}$	0.973	
Ash-Sharqiya South	Al-Fujayj	102.1	0.352	0.583	$I = \frac{\frac{102.1T_R^{0.352}}{d^{0.583}}}{d^{0.583}}$	0.940	
	Fins	168.1	0.245	0.631	$I = \frac{168.1T_R^{0.245}}{d^{0.631}}$	0.969	
	Jaalan Bani	45.9	0.242	0.569	$I = \frac{45.9T_R^{0.242}}{d^{0.569}}$	0.970	
	Jabal Bani Jabir	105.1	0.397	0.580	$I = \frac{105.1T_R^{0.397}}{d^{0.580}}$	0.924	
	Snaf	148.6	0.214	0.547	$I = \frac{148.6T_R^{0.214}}{d^{0.547}}$	0.985	
	Tahwah	94.9	0.345	0.576	$I = \frac{94.9T_R^{0.345}}{d^{0.576}}$	0.943	
Dhofar	Aqarhanawt	37.6	0.584	0.552	$I = \frac{37.6T_R^{0.584}}{d^{0.552}}$	0.968	
	Ghadow	25.8	0.632	0.566	$I = \frac{25.8T_R^{0.632}}{d^{0.566}}$	0.929	
	Hagayf	71.4	0.405	0.548	$I = \frac{71.4T_R^{0.405}}{d^{0.548}}$	0.912	
	Mughsayl	42.8	0.452	0.658	$I = \frac{42.8T_R^{0.452}}{d^{0.658}}$	0.908	
	Sadh	90.4	0.268	0.651	$I = \frac{90.4T_R^{0.268}}{d^{0.651}}$	0.968	
	Sher	114.1	0.407	0.645	$I = \frac{\frac{114.1T_R^{0.407}}{d^{0.645}}}{d^{0.645}}$	0.921	
	Zayk	52.4	0.507	0.635	$I = \frac{52.4T_R^{0.507}}{d^{0.635}}$	0.887	

curves development would be valuable. Also, using new IDF curve concentrated in the actual study area rather than using one generalized regional IDF curve will provide appropriate rainfall data for flood, storm water, road-bridge design and other environmental studies.

5. Conclusions

Intensity-duration-frequency (IDF) curves are utilized in the hydrologic and water engineering projects water resource projects in planning and designing of storm drainage, flood protection, bridges and culverts, water impounding facilities, and other water resources systems. In this study the development of IDF curves was done using Bernard's equation. Gumbel distribution was used to obtain rainfall intensities for various durations and return periods. The historical rainfall data obtained from the Ministry of Regional Municipalities and Water Resources (MRMWR) at 65 gauging stations situated at different elevation and regions throughout Oman were used in the study. IDF curves and empirical formulas were derived for rainfall durations (5, 15, 30, 60, 360, 720, and 1440 min) for various return periods (2, 5, 10, 25, 50, and 100 years).

Rainfall analysis exhibited the average annual rainfall of 109.21 mm with a standard deviation of 92.82 mm, Skewness coefficient of 1.62 and Kurtosis coefficient of 3.08 for all the studied stations from 1977 to 2017. The study also shows that the rainfall in the mountainous region is high compared to the desert and the coastal region of the country. Also, IDF analysis indicated the higher intensity rainfall at various return periods was witnessed at the higher elevation stations compared to the lower elevation stations. IDF empirical parameters estimation using nonlinear regression provided the parameter values for *C* ranging from 417.5 to 8.95, *m* ranging from 0.645 to

0.196, and *e* ranging from 0.79 to 0.391 for the studied stations.

Finally, the contour maps of spatial distribution of the IDF parameters were plotted for whole country. The parameter values were moderately high and more condensed in the northern part of the country along the Al-Hajar mountain range as compared to the southern part and along the flat terrain of the country. The created contour maps may be helpful in estimating the empirical parameters of the IDF formula and then estimate the rainfall intensities for various rainfall durations and return periods at ungauged locations. The outcome of this study will be helpful in planning, designing and decision making of future water resources and urban drainage projects.

In addition to sampling error, errors due to weather and climate change, and model errors from the short length of data also cause uncertainties in design of rainfall estimation. In any hydraulic and hydrologic structure, the design flow is usually considered for 100 years. Therefore, in this study the rainfall intensities for 100 years were considered despite the short length of rainfall data. So it is recommended to use sufficient length of rainfall data and to use uncertainty analysis methods (Bayesian methods, Cross validation approaches, Bootstrapping, and other methods) in designs to increase credibility of any project. The preliminary research in development of IDF curves in Oman is presented in this study. However, development of regional and more comprehensive studies along with detailed orographic factors in in addition to elevation are intended, in collaboration with neighboring GCC and other countries.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



Fig. 7. Spatial distribution contour map of empirical IDF parameters (a) C, (b) m, and (c) e.

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