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Flood Analysis in Western Saudi Arabia

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Abstract. In Western Saudi Arabia, an extremely arid region, rainfall is characterized by extremely high spatial and temporal variability. Flash floods occur immediately after heavy, short rainstorms and destroy human lives and properties. Unfortunately, rainfall and runoff measurements, as well as records of their greatest magnitude, are very scarce. In this study, 20 rain gauges distributed in and around eight dry basins (wadis) in Western Saudi Arabia that have a recorded length of at least 30 years were examined. Log-Pearson type III and EV1 probability density functions (pdf's) were derived by analyzing the maximum annual daily rainfall with different return periods. The EV1 pdf demonstrated the best fit in most cases representing the 50-year return period and providing the best prediction. Hence, this data could be used when planning future project designs. Regional maps of maximum probable precipitation (PMP) and probable maximum flood (PMF) were also produced for the seven major basins. Results from this study can be used to determine future water projects and their management in arid regions.

Keywords: Maximum daily rainfall; floods; probability; Western Saudi Arabia

Introduction

On occasion, flash floods cause heavy destruction to engineered structures and property, as well as loss of human lives. Unfortunately, residents in floodplain and inundation areas are not sufficiently aware of the consequences of flooding due to long periods of aridity. Thus, land at high risk of flooding is developed carelessly for settlement and infrastructure purposes. However, flash floods arise rapidly and flow over extremely dry or nearly dry watercourses (Farquharson *et al.,* 1992; and Flerchinger *et al.,* 2000).

Flood occurrences are complex, depending on interactions between the geological and morphological characteristics of the basin, including rock types, elevation, slope, sediment transport, and flood plain area. Moreover, hydrological phenomena such as rainfall, runoff, evaporation, and surface and groundwater storage influences flash flooding. Just as significant, human impact and interactions also affect flood behavior. Statistical analysis of the hydrologic extremes phenomena have played an important role in engineering water resource designs and management (Katz *et al.*, 2002). Regional flood frequency analysis is used widely for flood estimation and is used in areas with a sparse data network and short flow records (Islam and Kumar, 2003; and Tingsanchali and Karim, 2005).

Rainfall patterns in the Western Saudi Arabia are characterized by extremely high spatial and temporal variability. These characteristics are typical of arid regions, such as Makkah, Jeddah, Rabigh, and villages (Fig. 1). Flash floods take place immediately after heavy-short rainstorms, causing loss of human life and property due to the inability of surrounding terrain to absorb the rainfall. Most rainstorms in this area occur in winter (November to January) and do not exceed three hours with rain gauge records not exceeding 80 mm (Subyani *et al.,* 2009). Therefore, reliable estimates of expected flood discharges and return periods are necessary for future development and protection in areas subject to flash flooding. The key factor in estimating return periods is determining the annual extremes Probability Distribution Function (PDF).

In this study, the maximum annual daily rainfall from 20 rainfall stations in Western Saudi Arabia was evaluated to elucidate a suitable PDF with different return periods and corresponding probable maximum precipitation (PMP) and probable maximum flood (PMF). Among the wadis Na'man, Fatimah, Jeddah, Usfan, Khulays, Qudaid, Thamarah and Rabigh were selected.

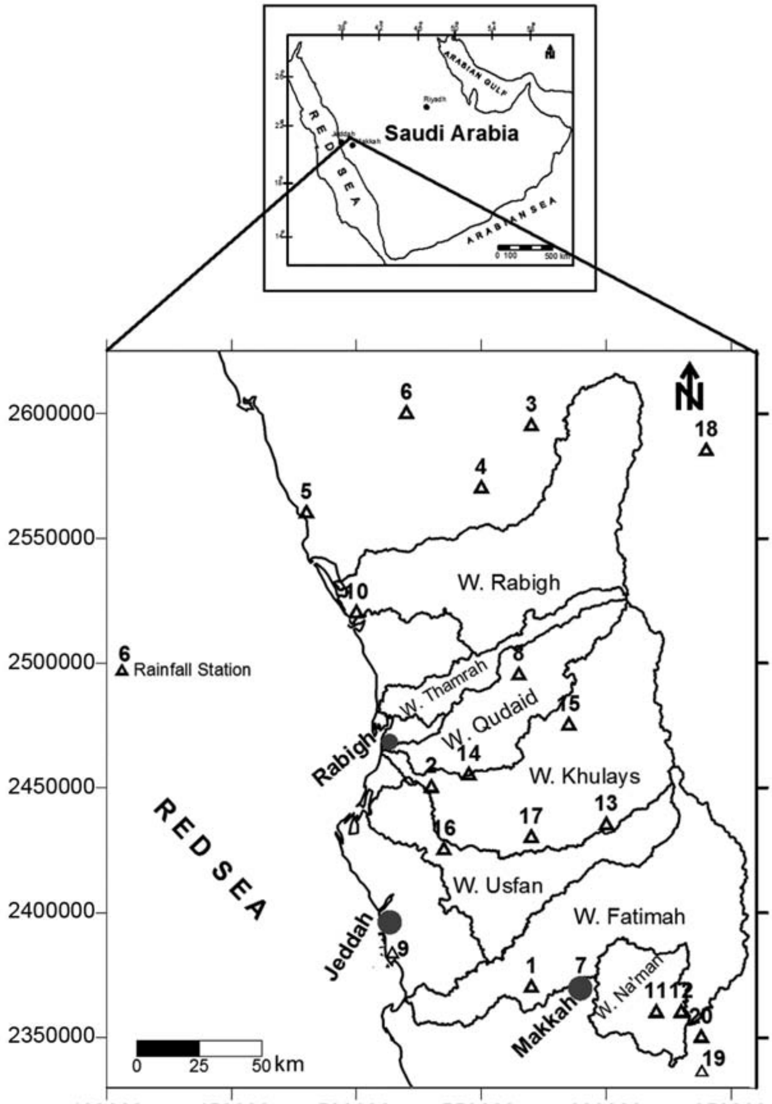

Fig.1. Location map of study area with rainfall stations and Basins in Makkah area.

Review of Flood Estimation

In studies of flooding in arid regions, rainfall records, runoff measurements, and their magnitudes are very important. Unfortunately, data are scarce with most records documenting rainfall events that occur over relatively short durations. Hence, there is a lack of observed data, presenting a major problem for rainfall-runoff modeling. Nouh (1988) used data from 32 arid catchments from different parts of the Kingdom to derive equations for estimating regional floods. Three methods of regional flood frequency analysis were applied and compared to available flood records. From these analyses, it was concluded that the weighted estimate is more accurate than flood estimation through calibrated regional methods. In addition, the Phi-index method, together with an estimate of the annual maximum rainfall depth, produced satisfactory flood estimates for moderate watershed areas that lie between 1000 and 3500 km^2.

Comprehensive rainfall-runoff studies were conducted in five basins within southwest Saudi Arabia over 5 years (Saudi Arabian Dames and Moore, 1988). In this study, short-term rainfall network data in the region, including intensity, duration, and frequency, was assessed. In addition, areal rainfall relationships were elucidated.

Due to a shortage of records (only 4 years were available) gages were grouped to create composite records. Nevertheless, the authors discovered that the areal reduction factors in this region are similar to those in the southwestern United States.

Later, Nouh (1990) used the same catchments to examine the performance of a geomorphological rainfall-runoff model in simulating observed flash flood hydrographs. This study revealed that the morphological model of catchment size (less than 400 km^2) and low infiltration rate with short dry periods can produce reasonable acceptable results; however, the model can produce unsatisfactory results when considering small total rainfall depths. Abdulrazzak *et al.* (1995) discussed and analyzed flood frequency for gaged and ungaged sites in the southwest region of Saudi Arabia. They applied the general formula for probable weighted moment (PWM) and computed parameters for Gumbel and Generalized Extreme Value (GEV) distributions. The annual flood frequencies were determined for 2- to 100-year return periods at each station.

Meigh *et al*. (1997) also analyzed regional flood frequencies in many tropical, sub-tropical, and arid regions around the world. The regression analysis estimation of the Mean Annual Flood (MAF) for the southwest region of Saudi Arabia was represented as:

$$MAF = 0.0625\ AREA^{0.578}\ AAR^{0.727} \quad (1)$$

where *AREA* is the catchment area (km^2), *AAR* is the annual average rainfall (mm), and the coefficient of determination (r^2) is equal to 0.452 (Fig. 2). They also applied the derivation of regional flood frequency curves with general extreme value (GEV) distribution fitted with probability weighted moments (PWM), and, from this, concluded that the GEV is generally applicable over a wide range of catchments and climate belts.

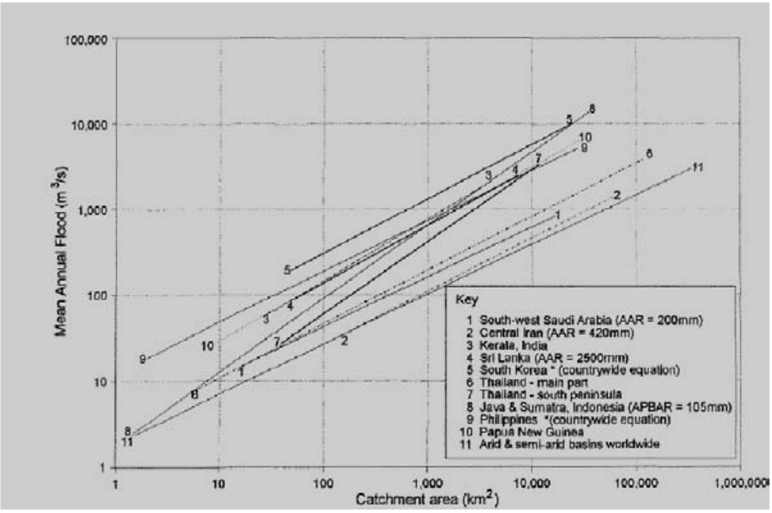

Fig. 2. Worldwide mean annual flood prediction (From: Meigh *et al.*,1997).

Şen and Subai' (2002) presented basic calculations for flooding and sedimentation that are necessary in selecting sites for dam construction in southwest Saudi Arabia. The mean values of the runoff coefficient, C_R, for the catchment of four gauged streams in some parts of southwestern Saudi Arabia ranged from 0.048 to 0.078. The relationship between log C_R and log A (catchment area) can be represented as a straight line (Fig. 3) of the form,

$$C_R = A^{-0.359} \quad (2)$$

For predicting regional annual maximum floods, Nouh (2006) proposed a multiple regression model for drainage basins at altitudes greater than 8 m. This model can be specified as,

$$Q_{av} = \xi_0 \, AREA^{\zeta 1} \, ELEV^{\zeta 2} \varepsilon \qquad 3$$

where Q_{av} is the annual maximum flood (m^3/s), AREA is the size of drainage basin (km^2), ELEV is the mean elevation of the basin (m), ξ_0 , ζ_1, and ζ_2 are regression parameters, and **ε** is the regression error.

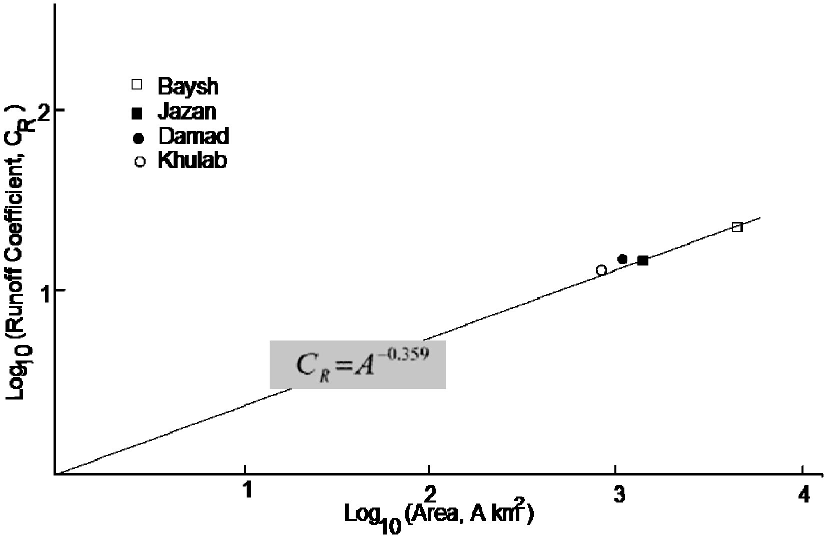

Fig. 3. Runoff coefficient as a function of area for gauged wadis in Southwest Saudi Arabia (Şen and Subai', 2002).

Methodology

Rainfall frequency analysis is a statistical tool that is applied to the study of random hydrological variables such as the annual maximum rainfall. In this analysis, two types of uncertainty exist. One is associated with the randomness of future rainfall events, and another is linked to the estimation of suitable relative frequency. The distribution of rainfall events can be estimated by fitting a PDF to the observed data. The cumulative PDF represents all values smaller or greater than the random variable. Different types of statistical distributions and PDFs can be fitted to historical data. Termed rainfall frequency analysis, graphical or analytical methods can be used (Katz *et al.*, 2002).

The plotting position begins by first arranging rainfall data, usually the maximum annual event, in either an ascending or descending order. Next, the data is assigned a plotting position where the number is assigned to the highest (lowest) value, followed by the second highest (lowest) value. This can be performed with the use of specially-prepared probability papers for some PDFs. Several formulae have been developed to estimate plotting positions. Equations for the plotting position (q_i) are generally be written as,

$$q_i = (i\text{-}a)/n+1\text{-}2a \qquad 4$$

where i represents the rank, n is the number of observations, and a is a suggested parameter for different formulas.

In this study, the Weibull plotting position was used to determine the annual maximum daily rainfall for different meteorological stations in the study area. Annual maximum daily series were constructed and ranked in descending order of magnitude. Given the number of record years, the exceedence probability, P, of the rainfall events rank, i, can be estimated by the plotting position formula as (Subramanya, 1994; and Maidment, 1993)

$$P = \frac{i}{n+1} \qquad 5$$

The return period T_r is related to the probability of exceedence by

$$T_r = n + 1/i \qquad 6$$

Analytical Method

The analytical procedure of rainfall frequency analysis consisted of selecting the appropriate theoretical pdf that represented the observed rank of the rainfall events. Certain theoretical pdfs may fit the sample data better with certain statistical parameters such as the mean and standard deviation. The two parameters of the selected pdf were estimated from observed data using some common statistical estimation methods such as the method of moments and maximum likelihood. The parameter estimations were used in the theoretical pdf expressions to estimate the probability of rainfall event occurrence. From the plotting position formula and experience, one can select the most appropriate theoretical pdf for the analysis.

Computation of rainfall expectation given a frequency is typically conducted by utilizing different pdf s. Some common pdfs are Gumbel, log-normal, Pearson type III, Log Pearson type III, and Gamma. The choice of model to use is often based on convenience because a method for determining the best fitting pdf is lacking. A goodness of fit test is used involving the whole range of the pdf. Usually the valid interest is in the upper tail of the distribution, where the researchers are concerned with larger values (extreme events). The Rainfall Frequency Atlas, also known as TP-40 (Hershfield, 1961), provides an extended rainfall frequency study for the United States from approximately 4000 stations. The Gumbel pdf was used to generate point rainfall frequency maps for durations ranging from 30 min to 24 h and return periods from 1 to 100 years.

Gupta (1970) studied model selection in frequency analysis of hydrological data by fitting peak flow rates to ten different pdfs. The goodness of fit was checked by computing the coefficient of determination, which rated Gumbel's method as best. Islam and Kumar (2003) developed Hydro Program for frequency analysis of one day maximum rainfall data. With this method, they discovered that the Gumbel pdf is most suitable for estimating one day maximum rainfall. In this study, Log Pearson type III, and Gumbel pdfs were used to model the maximum daily rainfall for different stations in western Saudi Arabia.

Log Pearson Type III

The Log Pearson type III frequency curve is characterized by three parameters. The mean represents the average ordinate, the standard deviation indicates the slope of the line on PDF paper, and the skew coefficient depicts the degree of curvature. However, this technique is based mainly on the use of log-transformed data and, therefore, the following equations are used (Viesman and Lewis, 1996; Wanielista *et al.,*1997 and Saf, 2005):

Mean: $$\overline{\log x} = \frac{\sum \log x}{n} \qquad 7$$

Standard Deviation: $$\sigma_{\log x} = \sqrt{\sum \left(\log x - \overline{\log x}\right)^2 / (n-1)} \qquad 8$$

Skew Cefficient: $$G = n \sum \left(\log x - \overline{\log x}\right)^3 / (n-1)(n-2)(\sigma \log x)^3 \qquad 9$$

The value of x for any recurrence interval is calculated by,

$$\log x = \overline{\log x} + k\sigma_{\log x} \qquad 10$$

where n is a number yearly records, $\sigma_{\log x}$ is the standard deviation of transforming data, G is the skewness coefficient, $\overline{\log x}$ is the mean of transforming data, and k is a frequency factor that is a function of the recurrence interval (T) and the coefficient of skewness, k= f(G,T). The value of this parameter can be found in previously published tables (Subramanya, 1994). In addition, when the skew is zero, the pdf becomes a two-parameter log-normal pdf.

Gumbel Type I Distribution

The Gumbel or Type I (EV1) pdf is most widely used for extreme values in hydrological and meteorological studies for predicting such factors as flood peak, maximum rainfall, and maximum wind speed. Gumbel defined a flood as the largest event over a 365-day period. The annual series of flood flows constitute a series of flow values, which abide by the following pdf,

$$p = 1 - e^{-e^{-y}} \qquad 11$$

where p is the probability of a given flow being equal or exceeded, y is the reduced variate as a function of probability from ready-made tables. Then,

$$x = \bar{x} + k\sigma_x \qquad 12$$

where $\bar{x}$ is the mean of the data series, σ_x is its standard deviation, and *k*= 0.7797y-0.45.

The statistical analysis of probable maximum precipitation of a specific return period, PMP, can be estimated as,

$$PMP = \bar{p} + K_T\sigma_x \qquad 13$$

where $\bar{p}$ is the mean annual maximum rainfall, σ_x is the standard deviation of the series, and K_T is a frequency factor that depends on the type of PDF used, the number of recorded years (or return periods). K_T can be estimated from published tables. (Wanielista *et al.,* 1997).

Flood events with maximum extremes are called Probable Maximum Floods (pdfs), which is the maximum water flow in a drainage area that would be expected from a PMP event. Calculation of the PMF begins by obtaining an estimate of the PMP. In general, a basin discharge is a function of climatic and watershed characteristics.

In arid regions, where runoff records is typically not available, methods have been applied to estimate the flood volume using the PMF for different return periods and discharges. These estimations require information such as mean annual rainfall, PMP with different return periods, and the runoff coefficient. Eq. (2) can be used to estimate the runoff coefficient, C, for ungauged catchment wadis in the study area and the volume of the streams in these catchments can be estimated accordingly (Şen, 2008).

A total of 20 stations were selected in and around the seven wadis with annual maximum daily rainfall (24 h) data derived from available daily data provided by the Hydrology Division, the Ministry of Water and Electricity. These records cover a period of 35 to 41 years (*i.e.*, 1965-2007). Although not all stations cover this time period, they represent well the different climate conditions within the study area. Figure 4 shows the regional observed annual maximum rainfall over a 24-h period. These data illustrate inconsistency in rainfall storms due to topography and rainfall variation in the study area.

Results and Discussion

Descriptive statistics of annual maximum daily rainfall are shown in Table 1. Records ranged between 9 to 41 years with most of them covering more than 28 years. Overall, there was an abundance of data to consider, especially for an arid region. This table shows that there was large variation in the rainfall distribution with averages ranging from 19 mm at Khulays to 46 mm at Shafa station. The data from Usfan displayed the maximum coefficient of variation and skewness, whereas the data series for Faqair and Barzah exhibited the minimum values. Data from all other stations resided somewhere in between. Such variations are normal in arid region due to different rainfall mechanisms and topographic variations (Şen, 1983; Nouh, 1987; and Subyani, 2004).

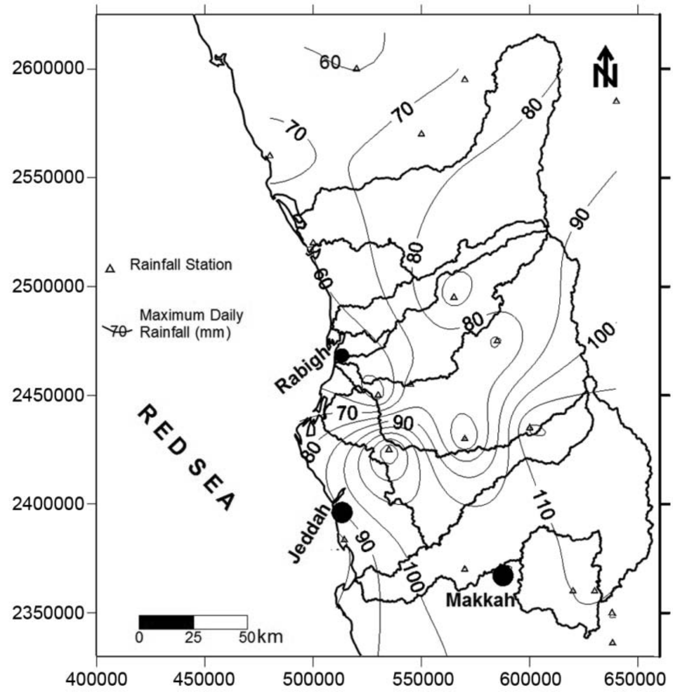

Fig. 4. Study area with observed annual maximum rainfall for 24 h.

Table 1. Statistical parameters of annual maximum 24hr rainfall data.

Station Name	St. ID	No. of Years	Max. (mm)	Min. (mm)	Average	Std. Dev	Coef. of Variation	Coef. of Skewness
Bahrah	1	35	111	1	29.37	21.27	0.72	1.70
Khulays	2	9	43	2	18.61	12.05	0.65	1.04
Faqair	3	39	71	6	31.22	18.14	0.58	0.45
Malbanah	4	39	75	1	30.17	21.48	0.71	0.50
Mastorah	5	39	74	2	20.51	17.36	0.85	1.29
Um Albirak	6	40	60	1	23.59	14.96	0.63	0.77
Makkah	7	14	99	8	38.85	28.81	0.74	0.95
Shabah	8	41	94	1	29.00	20.85	0.72	0.86
Jeddah	9	29	72	1	29.42	18.17	0.62	0.84
Rabigh	10	36	60	1	19.29	16.49	0.86	0.91
Kurr	11	40	110	2	39.09	22.14	0.57	1.23
Mid Scarp	12	40	117	1	45.66	28.91	0.63	0.72
Madrakah	13	41	121	1	33.03	24.96	0.76	1.64
Ain Al Aziziyah	14	36	75	1	22.16	20.67	0.93	1.39
Midhah	15	35	67	1	23.39	15.83	0.68	0.98
Usfan	16	29	140	2	27.92	28.05	1.00	2.47
Barzah	17	30	58	1	23.24	17.28	0.74	0.45
Suwayriqiyah	18	28	86	9	29.38	15.46	0.53	1.95
Shaffa	19	43	115	8	45.70	20.41	0.45	0.66
Taif NW	20	41	98	1	35.35	21.05	0.60	1.92

The annual maximum daily rainfall data from 20 stations in the study area were analyzed, resulting in Log Pearson Type III and Gumbel (EV1) pdfs. A plot of each PDF on log probability paper is shown in Fig. 5. Visual inspection of the graphs reveals that the Gumbel PDF is the best fit in most cases with minimum mean square errors.

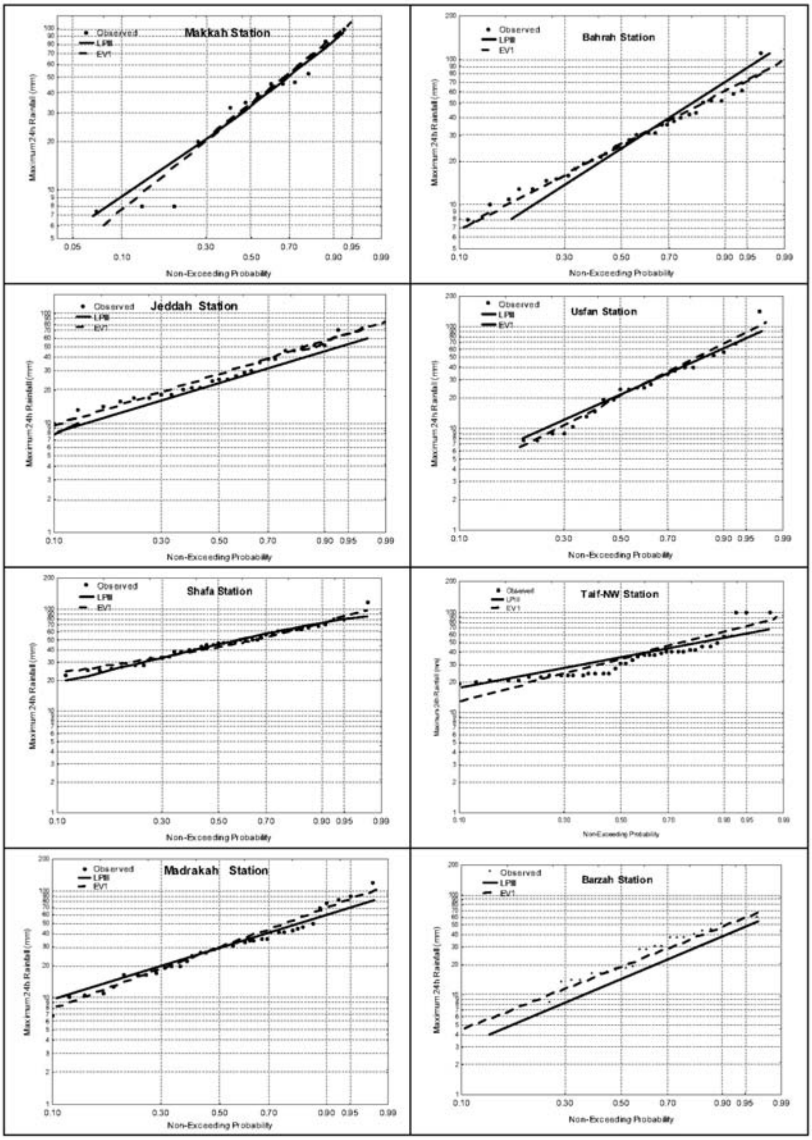

Fig. 5. Annual maximum daily rainfall probability for study area stations.

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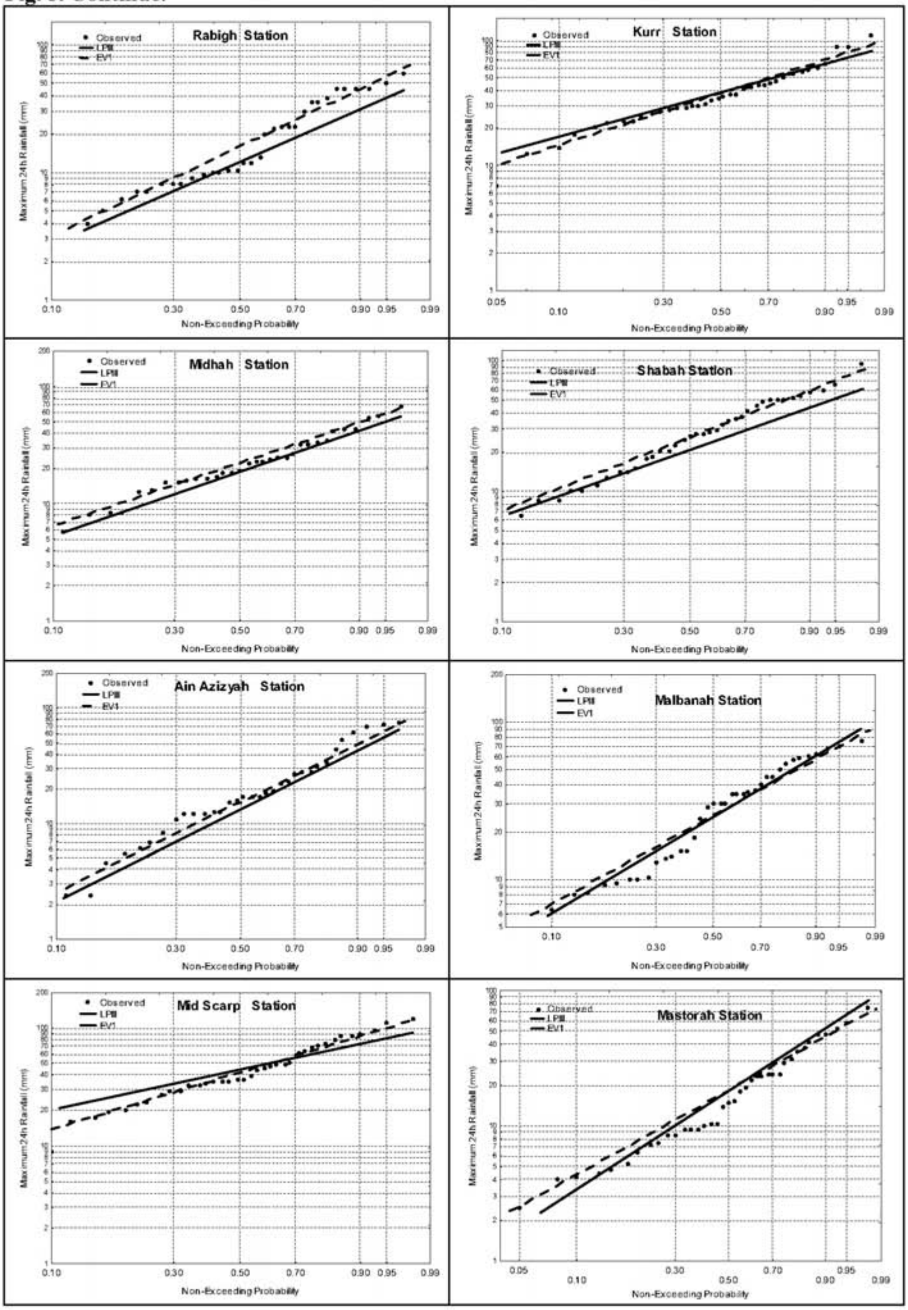

Fig. 5. Annual maximum daily rainfall probability for study area stations.

Table 2 shows the prediction for a 24-h period along with 2-, 3-, 5-, 10-, 25-, 50-, 100-, and 200-yr return periods, for the best fitting Gumbel pdf. With high return periods such as 100- and 200-yr, the Gumbel PDF overestimated the prediction and did not fit well in the higher probability ranges compared to the maximum real data, especially with short term records (*e.g.,* the Khulays and Makkah stations). In most cases, the 50-yr return period had the best prediction, making it useful for project design applications.

Table 2. Prediction (mm) for Gumbel pdf for selected return periods (in years) based on 24-hr duration data.

Station ID	Probability							
	0.995	0.99	0.98	0.96	0.9	0.8	0.667	0.5
	Return Period (y)							
	200	100	50	25	10	5	3	2
1	108.8	97.2	85.5	73.8	57.9	45.4	35.5	26.5
2	82.0	72.9	63.7	54.4	41.9	31.9	24.1	17.0
4	108.9	97.4	85.8	74.2	58.5	46.0	36.2	27.3
5	84.1	74.8	65.5	56.1	43.4	33.3	25.3	18.1
7	166.1	147.6	129.0	110.3	85.1	65.2	49.3	35.0
8	104.9	93.8	82.6	71.4	56.3	44.3	34.8	26.2
9	98.9	88.7	78.5	68.3	54.4	43.5	34.8	27.0
10	80.5	71.5	62.6	53.5	41.3	31.6	24.0	17.1
13	123.5	110.2	96.9	83.6	65.5	51.2	39.9	29.7
14	99.0	87.7	76.5	65.1	49.8	37.7	28.0	19.3
15	23.7	26.4	26.6	23.9	15.5	6.6	3.7	6.5
16	136.6	120.7	104.8	88.7	67.1	49.9	36.3	24.1
17	89.7	80.0	70.2	60.4	47.2	36.7	28.4	20.9
19	121.5	110.4	99.3	88.1	72.9	60.9	51.4	42.9
20	111.3	100.2	89.0	77.8	62.6	50.6	41.1	32.5
11	119.9	108.1	96.2	84.2	68.1	55.4	45.2	36.1
12	151.1	135.7	120.2	104.6	83.5	66.9	53.7	41.7
6	77.5	69.6	61.7	53.7	43.0	34.4	27.7	21.6
3	97.7	88.0	78.2	68.4	55.1	44.6	36.3	28.8
18	89.7	80.9	72.1	63.1	51.1	41.6	34.1	27.3

By applying estimates of PMP values from the suitable PDF (herein Gumbel model), we determined the PMP estimates for a 50-year return period, which demonstrate an increase from the southeast to northwest (*i.e.,* from 100 to 50 mm) (Fig. 6). Likewise, the PMP estimates for a 100-year return period indicated an increase from the southeast to northwest of the study area (*i.e*., from 120 to 60 mm) (Fig. 7). These figures can help in the future planning of different engineering structures.

Due to rainfall variability over the basins and the morphology of the study area, the mean annual rainfall (Fig. 4) was calculated from between two successive isohyets and multiplied by the area between the isohyets, as shown in column 3 of Table 3. For example, Wadi Fatimah has a watershed area of 5085 km^2. The percentage of the area between two successive isohyets (168 mm) was approximately 66% (0.66 × 5085 = 3356 km^2). Hence, the partial rainfall volume in this specific area was about 563,824,800 m^3 as shown in column 4 (Table 3). The total rainfall volume (V_A) in million cubic meters is shown in column 5 (Table 3). Finally, runoff volume (V_R) in million cubic meters was a product of the runoff coefficient and the total rainfall volume (V_AxC).

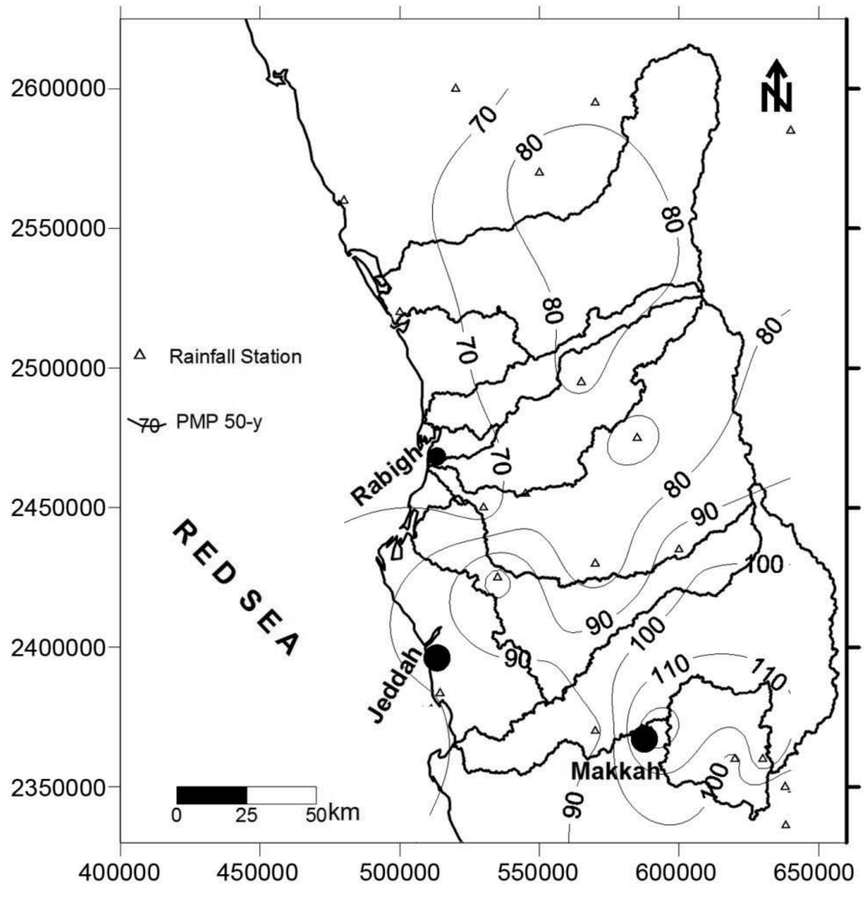

Fig. 6. Probable maximum rainfall of 24h for 50 years return period.

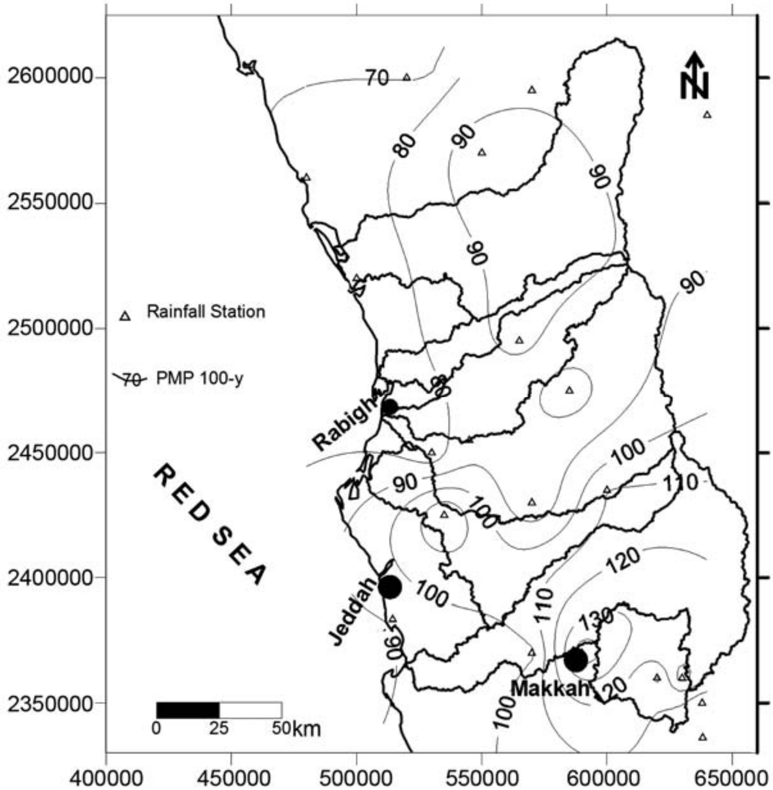

Fig. 7. Probable maximum rainfall of 24h for 100 years return period.

From this table, it is obvious that the Fatimah basin receives the highest volume of rainfall (752.5×10^6 m^3) and runoff (35.4×10^6 m^3). Rabigh, which received a rainfall and runoff volume of 476.0×10^6 m^3 and 21.8×10^6 m^3, respectively, was the second-ranked basin.

To estimate the PMF, the observed runoff volume produced from the probable maximum 24-h rainfall is shown in Table 4. This table also lists the PMF and PMP calculations for a 50 and 100-yr return period. Figure 8 shows the comparison between observed 50-yr and 100-yr return periods for PMF estimations. Some basins exhibited similar results in the observed 50-yr and 100-yr return periods (*i.e.,* Fatimah, Jeddah, and Thamrah). Other basins, however, displayed slight differences in PMF values due to rainfall variability and the availability of short-term records.

Table 3. Mean annual runoff volume in study area basins.

Basin	Area (A, km^2)	Effective Mean Annual Rainfall, P (mm)* Effective Area(%)	Partial Rainfall Volume (10^{6}m^3)	Total Rainfall Volume (V_A, 10^{6}m^3)	Mean Runoff Coefficient (C)	Runoff Volume (V_R, 10^6 m^3)
Na'man	1543	153*1	202.5	202.5	0.0717	14.7
Fatimah	5085	168*0.66 116*0.33	563.8 194.6	758.5	0.0467	35.4
Jeddah	1360	80*0.4 75*0.4 62*0.2	43.5 40.8 16.9	101.2	0.075	7.6
Usfan	2830	115*0.5 88*0.2 75*0.3	162.7 49.8 63.7	276.2	0.0576	15.9
Khulays	5170	116*0.3 88*0.4 75*0.3	179.9 182.0 116.3	478.2	0.046	22.2
Qudaid	2280	88*0.2 75*0.2 62*0.6	40.1 34.2 84.8	159.1	0.062	9.9
Thamrah	1015	88*0.3 75*0.3 62*0.4	26.8 22.8 25.2	74.8	0.083	6.2
Rabigh	5360	116*0.4 88*0.2 62*0.4	248.7 94.3 132.9	476.0	0.046	21.8

Note: V_A = AP; V_R = V_AC

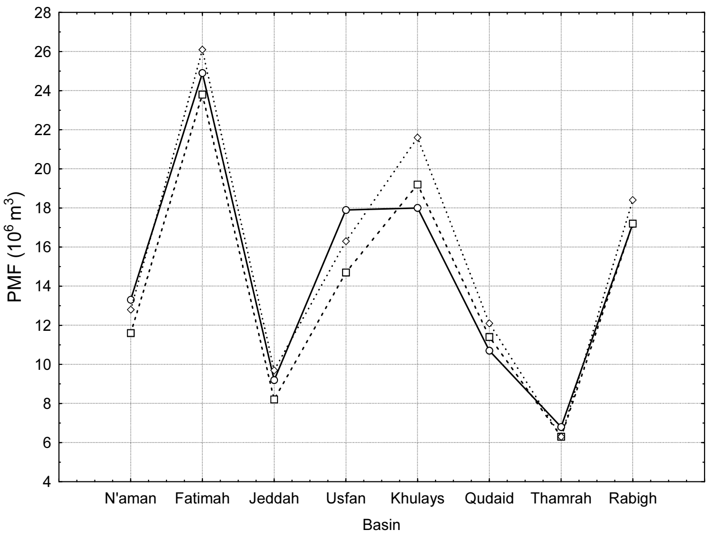

Fig. 8. Comparison of observed and 50-y and 100-y return periods for PMF.

Conclusion

Rainfall in western Saudi Arabia is extremely high and violent, which is typical of any arid region. Thunderstorms of high intensity followed by dry periods are common. Eight major wadis, namely Na'man, Fatimah, Jeddah, Usfan, Khulays, Qudaid, Thamrah and Rabigh, with 20 rainfall stations were selected for studying the maximum rainfall over a 24-h period. Investigation of the rainfall frequency curve was developed using EV1 for the best prediction of 5-, 10-, 50-, and 100-yr return periods. Flooding was investigated indirectly because no records were available for most of the basins in the study area. However, Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) maps were presented for different return periods. The results can be used to plan future water projects and manage flood hazards. A network with more daily rainfall and runoff measurements stations should be established along with flood warning systems at the outlet of all wadis due to potential flash flood hazards.

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تحليل الفيضانات في غرب المملكة العربية السعودية

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المستخلص. تتميز منطقة غرب المملكة العربية السعودية بالجفاف الشديد وتغير كبير في تساقط الأمطار مكانيا وزمانيا. وتحدث الفيضانات بشكل عام بعد فترة قصيرة من تساقط شديد للأمطار لفترة قصيرة، مما يتسبب في كوارث بشرية وإتلاف للمنشآت وخاصة في المناطق المأهولة. وللأسف لا توجد تسجيلات لكمية السيول أو مقدارها في هذه المناطق، ومن تسجيلات الأمطار لعدد عشرين محطة لمدة لا تقل عن ثلاثين عاما موزعة داخل وحول الأحواض الثمانية في منطقة غرب المملكة، تم تحليل القيمة العليا السنوية في اليوم الواحد باستخدام توزيعي بيرسون اللوغاريتمي وتوزيع قمبل وهما الأكثر استخداما ولفترات زمنية مختلفة، أوضحت النتائج أن توزيع قمبل هو الأنسب لنمذجة الأمطار، وكذلك الأنسب للتنبؤ لفترة خمسين عاماً. كذلك تم إنتاج خرائط إقليمية لأعلى قيمة مطرية في منطقة الدراسة، وأعلى قيمة للفيضان في الأحواض. هذه النتائج قد تساعد في التخطيط المستقبلي للمشاريع والمحافظة عليها مستقبلاً بإذن الله.

الكلمات الدالة: أعلى قيمة مطر يومية في السنة، توزيع بيرسون اللوغاريتمي، توزيع قمبل، خرائط أعلى توزيع مطري وفيضانات، غرب المملكة العربية السعودية.