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FREQUENCY ANALYSIS OF ANNUAL MAXIMUM DAILY RAINFALL IN WADI ALAQIQ, SAUDI ARABIA

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Abstract: In arid regions the rainfall is highly variable temporally and spatially. Statistical frequency analyses help to extract design rainfall intensity for different return periods. Wadi Alaqiq catchment at Madinah region in the Kingdom of Saudi Arabia is selected to estimate the frequency of the daily rainfall, where there are two rainfall stations (Madinah and BirMashi) with more than 40-year annual maximum daily rainfall magnitudes. Several probability distribution functions are tested through goodness-of-fit (GOF). Anderson-Darling (AD) test is applied to select the best statistical distribution and L-moments method is applied for parameters estimation. The generalized logistic and generalized extreme value PDFs are the best for this arid region data for both stations. The findings are useful for application of flood frequency analysis in arid region with similar conditions of hydrological systems. In the mean-time, the climate change effects have been explained through the innovative trend analysis.

Keywords: *Statistical frequency, annual maximum daily rainfall, goodness of fit tests, probability density function, climate change effects, Wadi Alaqiq.*

1.0 Introduction

Major floods caused by extreme rainfall events have impacted the urban communities in different parts of the Kingdom of Saudi Arabia (KSA) including Madinah City region. Extreme rainfall depth can be considered as the most important input in rainfall-runoff modeling for flood design purposes at different return periods that exceed the length of historical rainfall records especially in arid regions. Rainfall analyses are very significant studies in any hydrological and water resources assessment in addition to planning leading for operation and maintenance aspects.

The main data requirement for flood analysis is the rainfall magnitudes and their frequency aspects. Statistical frequency analysis techniques can be used to adapt the most suitable probability distribution function (PDF) by the application to the annual maximum annual rainfall amounts (Fahad *et al*., 2014, 2016; Subyani *et al*., 2010; Subyani and Al-Ahmadi, 2011; Rakhecha *et al*., 1994; Haddad *et al*., 2011; Ayesha *et al*., 2013). The theoretical PDF provides information about the risk assessment and future possible extreme event predictions of the rainfall pattern.

Ayesha *et al.* (2013) studied the selection of PDF for at-site flood frequency analysis in Australia. They investigated fifteen different PDFs based on the annual maximum flood data set. Haddad *et al.* (2010) presented a regional rainfall frequency analysis using L-moments through index method coupled with generalized least square regression for several rainfall stations in Australia. Subyani and Al-Ahmadi (2011) presented annual maximum daily rainfall studies for over 30-year data on Gumbel extreme value PDF for a set of selected return periods in Madinah region, Saudi Arabia.

The main purpose of this study is to identify the most representative PDFs for two major station in the northwestern part of the KSA, each with more than 40-year annual maximum daily rainfall records. These data are evaluated for meaningful information derivation by using several PDF approaches for a set of return periods. However, the climate change effects have been explained through the trend analysis for both station.

Three parameters PDFs are used commonly for rainfall analyses, among which is the Generalized Extreme value (GEV), Generalized Logistic (GLO), Generalized Pareto (GPA), Gumbel (GUM), Log Normal (LN3), Log Pearson (LP3), and Pearson Type III (PE3) for annual maximum daily rainfall data at Wadi Alaqiq in Madinah. Anderson-Darling (AD) test is applied to select the best PDF on the basis of Goodness-of-fit (GOF) test and L-moments method for parameters estimation.

2.0 Study Area

The Madinah Province is located in northwestern part of the KSA (Fig. 1), where the Holy Madinah City is located and it is the fourth most populated region within the KSA. This City is about 160 km inland from the Red Sea coast and approximately 420 km to north of Jeddah, where the city is at an elevation of 620 m above the mean sea level (a.m.s.l). Graphically, it is arid region desert covered with wadis, mountains, rocky and scatted residential areas.

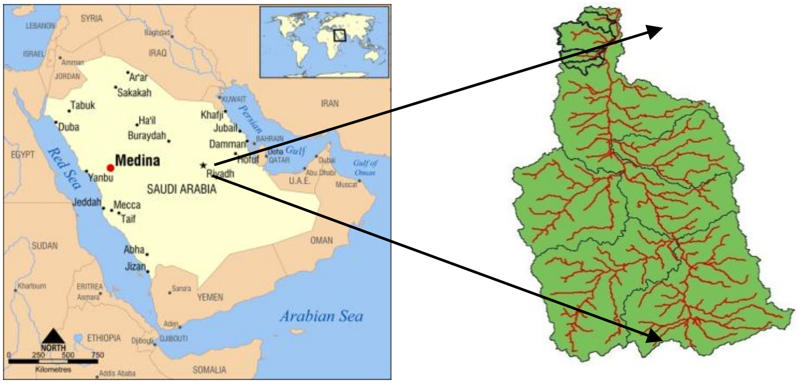


Figure 1: The study area at Wadi Alaqiq, Madinah, Saudi Arabia

3.0 Climate and Rainfall Trend of The Region

The study area receives annual rainfall between 2.5 mm to 212 mm with an average of 62 mm (Taibah University Research and Consulting Institute, 2011). Only 2% to 4% of the rainfall infiltrates and percolates into the saturated zones (Italconsult, 1978; Gutub *et al*., 2003), which is comparable with other arid and semi-arid regions. The annual minimum temperatures range from 7.1^{o}C to 11.5 ^{o}C whereas the annual maximum temperatures vary from 42.4^{o}C to 46.1^{o}C.

Two daily rainfall stations are located in the lower part of Wadi Alaqiq catchment, which are Madinah station with hourly records and BirMashi station records have daily magnitudes (Fig. 2). Both stations were established in 1968. The Madinah station has more than 45 years of records while BirMashi has 44 years. Fig. 2 also shows the Theissen polygon for Wadi Alaqiq catchment based on several additional surrounding rainfall stations (Madinah -M001, BirMashi -M103, Faqir -J109, Mosaijeed-J118, Molaileh-M108, Sowaydrah and Sowirqiah).

The effective portion of the four rainfall stations within Wadi Alaqiq is shown in Fig. 2. The M001 station represents 6.22% of the area, whereas stations MJ118, J109 and M103 have 5.91%, 30.96% and 56.72% covers, respectively. BirMashi and Madinah stations contribute significant rainfalls for flood event at lower parts of Wadi Alaqiq, even without rainfall occurrences at Faqir and Mosaijeed. In the same figure, the polygon shows that the two rainfall stations (Sowaydrah and Molaileh) have no influence on Wadi Alaqiq catchment, while Sowirqiah station has the very minimum influence (less than 0.25 %).

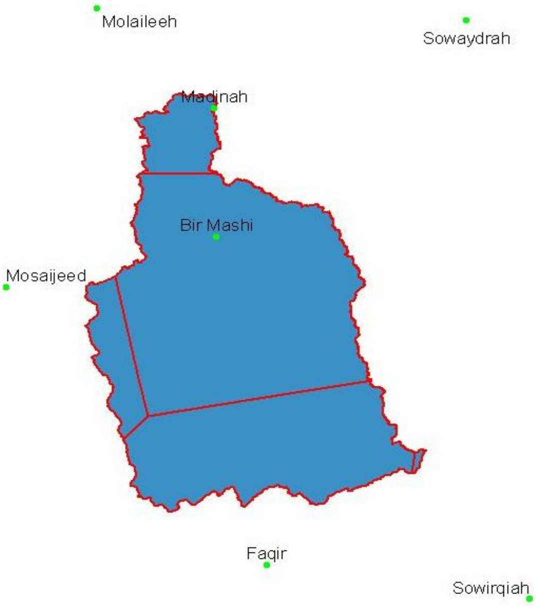


Figure 2: Thiessen polygon for rainfall distribution of Wadi Alaqiq

3.1 Rainfall Trends

Rainfall information is used to indicate the rainfall distribution over Wadi Alaqiq basin. For this purpose, two stations are considered, namely Madinah (M001) and BirMashi (M103). Figure 3(a) and Figure 3(b) show the maximum daily rainfall from 1980 until 2005 at two stations. In Figure 3(a) the two highest daily rainfall magnitudes are around 85.2 mm and 89.6 mm. The rainfall amounts at Madinah station are within the rainfall depth experienced recently in Jeddah City on the 26 November 2009, as 96 mm with its major flood damages**.** Meanwhile, in Figure 3(b) the three highest daily rainfall amounts are 49.5 mm, 45 mm and 57 mm. The comparison between these figures for the same year, say 1993, shows that Figure 3(a) has the highest daily rainfall at 85.2 mm, while Figure 3(b) provides 22 mm rainfall only. One of the reasons for difference is due to the fact that these rainfall stations are far apart from each other at approximately more than 33 km and also they have different climatological environments.

The Madinah City has experienced different degrees of flooding events. Table 1 shows daily storm events at selected stations around Wadi Alaqiq, namely Madinah, BirMashi, Faqir and Mosaijeed. The highest peak daily records took place in March 1993 with consequent flood event in the wadi catchment. Events in 1982, 1993 and 2005 are recorded for floods around Wadi Alaqiq in the Madinah City area with combined effects of rainfall records at Madinah and BirMashi stations.

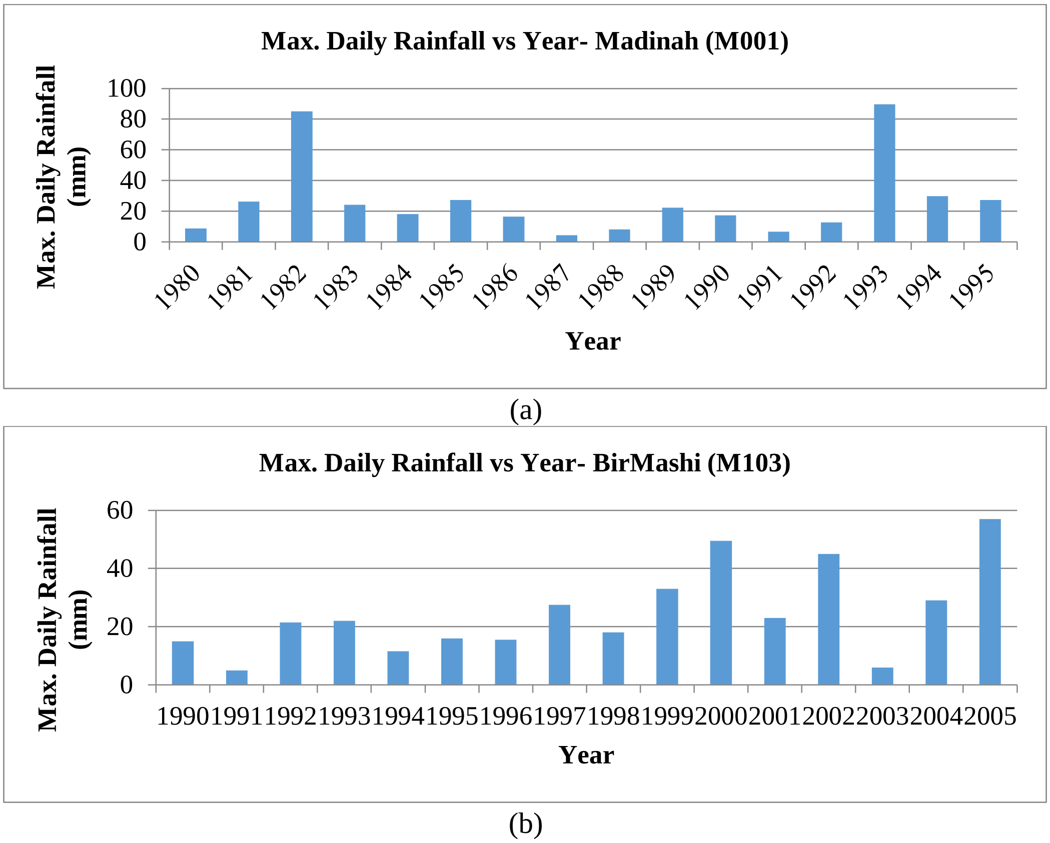


Figure 3: Maximum daily rainfall from 1980 until 2005.

Table 1: Extreme daily storm events at rainfall station around Wadi Alaqiq

Date	Total daily rainfall (mm)			
	Madinah	BirMashi	Faqir	Mosaijeed
11th April 1982**	88.2	19	None	None
20th March 1993**	89.6	22	None	None
17th Nov. 2000**	55	49.5	None	None
29th Nov. 2002	None	45	None	None
21th Jan. 2005**	57.5	57	None	None

*** Flood event (data from Ministry of Water and Electricity (MoWE), Saudi Arabia)*

4.0 Approaches of Annual Maximum Daily Rainfall Analysis

4.1 Statistical Distribution Criteria Based on Anderson-Darling Test

In this study, three-parameter PDFs are used for rainfall analysis, which are the Generalized Extreme value (GEV), Generalized Logistic (GLO), Generalized Pareto (GPA), Gumbel (GUM), Log Normal (LN3), Log Pearson (LP3), and Pearson Type III (PE3). Goodness-of-fit test (GOF) is employed to describe how well the given PDF suits the observed rainfall data sets. On the other hand, Anderson-Darling (A-D) is used for model selection criteria in the rainfall analysis. It can be considered as one of the most powerful methodology in contrast to the other tests (Ahmad *et al*., 1988). Six GOF tests are computed using Easy software (Mathwave, 2013) based on Anderson-Darling test.
L-moments of Hosking (1990) is used as linear combinations of order statistics, where the data have been arranged in ascending order for selection of the best fit PDFs (Kochanek, 2010). The package Lmomco (Asquith *et al*., 2013) is adapted for computing the L-moment parameters for the stations in the Madinah region.

4.1.1 Goodness-of-Fit-Test (GOF)

This test can be used to describe how well the given PDF is suitable for the observed rainfall data sets. The distribution with the smallest values of GOF represents the best fits to the data. *Anderson-Darling (AD)* test can assess whether a given observational data set is drawn from a given PDF. The advantage of AD test is that it gives more weight to the tails than the other GOF tests. This test compares the fit of an empirical cumulative PDF suitability to a theoretical counterpart. It depends only on the sample size, n, of the data sets. The AD test quantity, A, expression can be written as follows.

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1).\left[lnF(X_i) + ln\big(1 - F(X_{n-i+1})\big)\right] \quad (1)$$

Where X_i (I = 1, 2, . . , n) is the data series.

4.1.2. Parameter Estimation Using L-Moments

L-moments method has been used to estimate the parameter of PDFs. In this study, L-moments (Hosking, 1990) is used based on linear combinations of order statistics for data that have been arranged in ascending order. L-moments are analogous to conventional moments, and they are less sensitive to outliers and they calculate the distribution parameters more accurately (Kochanek *et al*., 2010).

4.2 Probability Distribution Function (PDF)

Another method for rainfall analysis by using the PDF, for the generalized extreme value distribution with location μ, scale σ, and shape k ≠ 0 parameters is given as flows.

$$y(x)=\frac{1}{\sigma}\exp\left\{-\left[1+\frac{(x-\mu)}{\sigma}\right]^{-\frac{1}{k}}\right\}\left(1+\frac{(x-\mu)}{\sigma}\right)^{-1-\frac{1}{k}} \tag{2}$$

for

$$1+\frac{(x-\mu)}{\sigma}>0$$

where, k > 0 corresponds to the Type II case, while k < 0 to the Type III case. For k = 0, the Type I case is valid and it can be expressed as,

$$y(x)=\frac{1}{\sigma}\exp\left\{-\exp\left[-\frac{(x-\mu)}{\sigma}\right]-\frac{(x-\mu)}{\sigma}\right\} \tag{3}$$

5.0 Analysis and Discussion

5.1 Statistical Criteria Results

5.1.1 General Description of the Data Sets

Table 2 shows the descriptive statistics of the annual maximum daily rainfall for both Madinah and BirMashi stations, which show relatively high range and variance.

Table 2: Descriptive statistics of Madinah and BirMashi maximum daily rainfall data

	Madinah	*BirMashi*		*Madinah*	*BirMashi*
Sample Size	45	44	Min	1.3	1.5
Range	88.3	64.5	Percentile 5%	2.53	4.5
Mean	22.51	22.94	Percentile 10%	3.82	8
Variance	363.72	198.92	25% (Q1)	9.5	14
Std. Deviation	19.07	14.10	50% (Median)	17.3	20.75
Coef. of Variation	0.847	0.6147	75% (Q3)	27.8	26.88
Std. Error	2.843	2.126	Percentile 90%	48.16	48
Skewness	1.954	1.261	Percentile 95%	76.89	55.13
Excess Kurtosis	4.619	1.516	Max	89.6	66

5.1.2. L-Moment Computations

The package Lmomco (Asquith, 2013) is used for computing the L-moment parameters for both Madinah and BirMashi stations and the results are shown in Table 3. The L-CV value for BirMashi shows high variability, whereas for Madinah station, it has very high variability. For the L-Skew the Madinah station shows larger skewness than BirMashi.

Table 3: L-moments parameter for Madinah and BirMashi stations (max. daily rainfall)

	Madinah	*BirMashi*
L1 (Mean)	22.5067	22.9432
L2 (L-Scale)	9.5263	7.4813
L3	2.8671	1.8437
L4	2.3109	1.7236
L5	1.7388	0.4762
L-CV (t)	0.4233	0.3261
t3 (L-Skew)	0.30097	0.2464
t4 (L-Kurt)	0.24258	0.2304
t5	0.18253	0.0636

5.1.3. Goodness of Fit tests (GOF)

The GOF tests are computed using Easy software (Mathwave, 2013). Table 4 shows for Madinah and BirMashi results of GOF tests for each PDF in descending order based on the Anderson-Darling (AD) test. The lower the value the better is the PDF. For both Madinah and BirMashi stations, AD test gave comparable results for the PDFs. The best four PDFs for both rainfall stations are GLO, GEV, PE5, and LN3. However, GEV is considered as one of the best PDF and it generates lower errors from AD test. GEV is applied to both Madinah and BirMashi stations as shown in Table 4. Both stations gave very similar results, however in general, the GLO distribution performs the best and the second is the GEV.

Table 5 provides prediction of maximum daily rainfall for different return periods based on GEV distribution for the study area. The rainfall depths at different return periods are applied for rainfall-runoff simulation of flood frequency analysis.

Table 4: Goodness of fit tests for Madinah and BirMashi maximum daily rainfall

Distribution	*Madinah*		*BirMashi*	
	Statistic	*Rank*	*Statistic*	*Rank*
Gen. Logistic (GLO)	0.29516	1	0.30533	1
Gen. Extreme Value (GEV)	0.31036	2	0.38403	2
Pearson 5 (3P)	0.35395	3	0.4124	3
Lognormal (3P)	0.38105	4	0.44398	4
Log-Pearson 3	0.42526	5	4.9462	8
Lognormal	0.76176	6	0.88479	6
Gumbel Max	0.85298	7	0.53724	5
Pearson 5	2.1834	8	2.5393	7
Gen. Pareto	11.925	9	15.127	9

Table 5: Prediction of maximum daily rainfall for different return periods based on GEV distribution

Return Period	*M001*	*M103*
/ ARI (year)	*Madinah*	*BirMashi*
5	32.81	31.88
10	44.8	40.82
25	62.67	53.28
50	78.22	63.44
100	95.91	74.39
200	116.09	86.21

5.2 Probability Density Function (PDF)

The annual maximum rainfall amounts are treated with the most suitable PDF so as to identify the future predictions for probable rainfall amounts. For this purpose, Matlab software is used and the following steps show the application of the methodology.At station M001 (see Figure 4), it is obvious that the annual rainfall amounts comply by the Gamma PDF with the shape and scale parameters as α = 1.5512 mm and β = 14.4490 mm, respectively. The fit of observed data scatter with this Gamma PDF is very well for low and medium rainfall amounts, but for others although there are deviations, they follow again the general trend of this PDF. In the preperation of this figure the following steps are necessary.

i) Sort the available annual rainfall data values in an ascending order from the smallest to the greatest,

ii) Determine the number of available annual rainfall data n,

iii) In the ordered data, the rank is denoted by m, where the smallest (greatest) annual rainfall amount has the least rank as m = 1 (m = n). Others will have ranks in between,

iv) First, the empirical probabilities must be attached to each one of the ordered data according to the rank, m, corresponding probability, P_m, as follows,

$$P_m = \frac{m}{n+1} \tag{4}$$

v) Hence, there are two sequences as the ordered data and corresponding empirical probability series. Their plots by stars appear in the form of scatter points as in Figures 4 and 5..

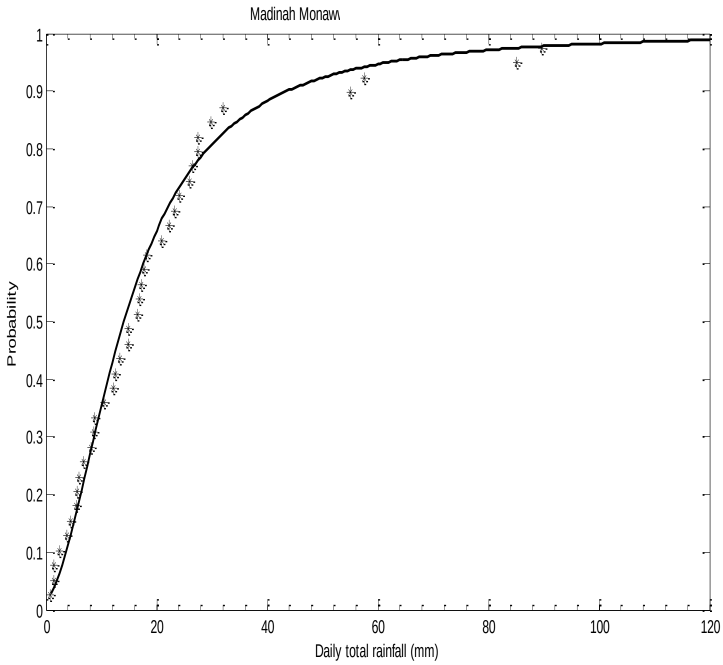


Figure 4: Probability vs. daily rainfall at Madinah station (M001)

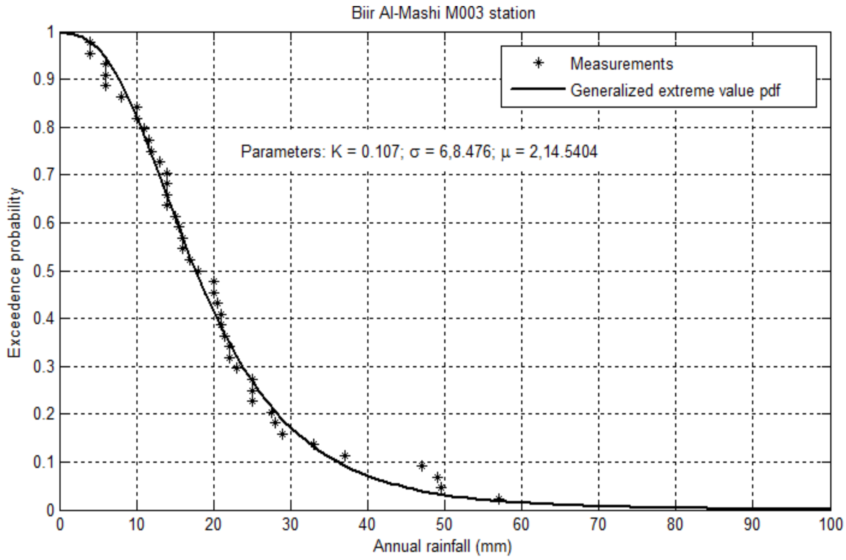


Figure 5: Generalized extreme value for Bir Mashi station

One can notice that the scatter points has a regular decrease as the annual data values increase. This means that the extreme events will have less probability of occurrence whereas low and medium rainfall events have greater probability of occurrences,

vi) After the previous empirical work steps it is now time to try and find the best fitting theoretical PDF to the scatter points. After several trials, herein, theoretical Gamma PDF has been fitted to the scatter points through Matlab software,

vii) First the valid parameters of the given annual data are calculated through the software, as parameter=gamfit(data) statement. Here “data” implies annual rainfall values for station M001. This software yields the parameters as stated in the figure and earlier as α = 1.5512 mm and β = 14.4490 mm,

viii) The empirical scatter data figure has the annual rainfall change range from 0 to 100 mm, and therefore, accordingly the Matlab software is defined as the horizontal axis variable as x=0:001:100; which means that for the theoretical calculations the software will start from 0 and each time the software will increase for the next calculation value with increment 0.001 until reaching the maximum value of 100 mm,

ix) The theoretical Gamma PDF values, y, are calculated again in the Matlab software by the following statement, which includes previously calculated parameters as, y = gamcdf(x, 1.5512,14.4490). Hence, there are y values corresponding to x values. The 1-y values are the theoretical Gamma probabilities and their plot appears as a continuous line in the same figure.

x) In order to calculate risk amounts it is first necessary to select a set of design durations (design period), which are adopted as 5-yer, 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year (see Table 5.5). The corresponding probabilities to these set of selected design periods are 1/5 = 0.200, 1/10 = 0.100, 1/25 = 0.040, 1/50 = 0.050, 1/100 = 0.010, 1/250 = 0.004, and 1/500 = 0.002.

xi) The theoretical annual precipitation values that correspond to these probabilities, p, can be obtained from the Matlab software. AnnualPrecipitation = gaminv(p, 1.5512,14.4490).

Hence, the rainfall amounts are given in Table 6, accordingly. Similar to what have been explained for station M001, one can apply the same procedure to the other station, M003. The results are given in Table 6 and Figure 5, which expose different values (higher) of rainfall over return period according to formulation based on generalized extreme value PDF. This is due to the analysis based on daily annual maximum series at Madinah station (M001) and BirMashi station (M003).

Table 6: Results for probability and return period vs. rainfall at Madinah station

Probability (Risk)	*Return period*	*Rainfall (mm)*
0.20	5	29.25
0.10	10	43.60
0.04	25	68.68
0.02	50	94.08
0.01	100	126.99
0.004	250	186.06

Table 7 and Figure 6 indicate the return periods with corresponding risk levels and the rainfall amounts obtained from the generalized extreme value (GEV) PDF.

Table 7: Results for Probability and return period vs. rainfall at BirMashi station

Return period	*Risk (%)*	*Rainfall (mm)*
2	0.50	17.71
5	0.20	28.34
10	0.10	36.12
25	0.04	46.90
50	0.02	55.64
100	0.01	64.99
250	0.004	78.43

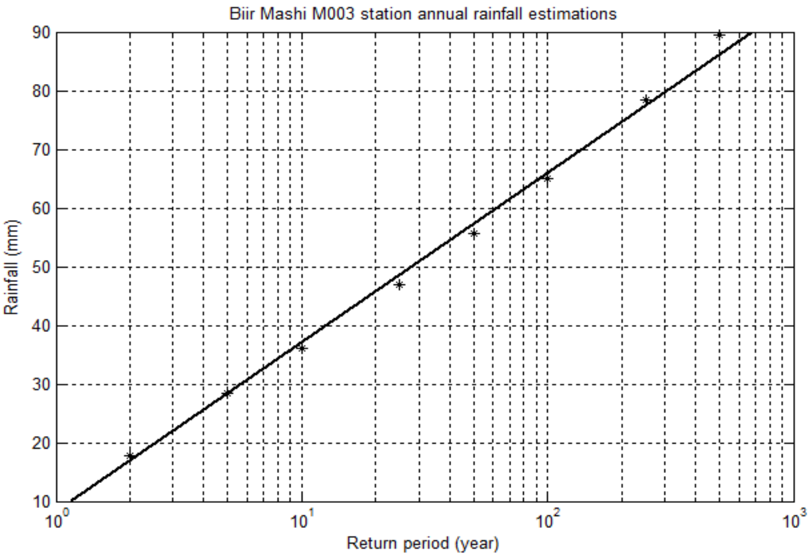


Figure 6: BirMashi station annual rainfall estimation

It is obvious that the relationship between the return period, R, in year and the corresponding rainfall amounts, r, in mm appears as a straight-line on semi-logarithmic paper. After some simple calculations the mathematical function of this relationship can be obtained as follows.

$$R = 0.4e^{0.894r} \quad \text{or} \quad r = 11.18.\log\left(\frac{R}{0.4}\right) \qquad (5)$$

5.2.1. Trend Analysis

The rainfall records are not necessary only for risk calculations, intensity-duration-frequency curve construction, statistical parameter determinations, but also to see whether there are possible trends or climate change effects in the past records. For this purpose, Mann-Kendall trend analysis has been employed in the literature frequently, but this approach does not provide embedden internal trends so far as the “low”, “medium” and “high” rainfall amounts are concerned. This technique gives a global trend without any internal partial variations and the trend is considered as a linear increase or decrease within the whole duration of past records.

Two commonly used trend tests are Mann-Kendall (Mann, 1945; Kendall, 1975) test and Spearman's Rho test to the data set (Sen, 1978). In many hydrological studies, these two non-parametric rank-based statistical tests are used for detecting monotonic trends in time series data. The power of these tests has not been well documented.

Several studies indicate that the most widely used method for detecting trend is the non-parametric MK trend test. The MK rank statistic is considered the most appropriate (Goossens and Berger, 1986) for the analysis of trends in climatological time series or for the detection of a climatic discontinuity. Mann in 1945 originally derived the test and Kendall in 1975 subsequently derived the test statistic commonly known as the Kendall's tau statistic. It was found to be an excellent tool for trend detection in different applications (Lettenmaier *et al*., 1994; Burn and Hag-Elnur, 2002).

Most trend-detection studies using the MK test have assumed that sample data are serially independent, even though certain hydrological time series such as water quality series and annual mean and annual minimum stream flows may frequently display statistically significant serial correlation (Yue and Wang, 2002). Furthermore, von Storch (1995) documented that the existence of positive serial correlation increases the probability that the MK test detects trend when no trend exists. However, an innovative trend analysis has been proposed to literature by Şen (2012, 2014).

The application of this methodology is explained below prior to its application to the rainfall stations in the study area, namely, M001 and M103.The basic idea rests on the fact that if two time series are identical to each other, their plot against each other shows scatter of points along 1:1 (45^o) line on the Cartesian coordinate system as in Figure 7a. There are 25 data points, which come from a non-normal probability distribution function. Whatever the time series are, whether trend free or with monotonic trends, all of them falls on the 1:1 line when plotted against itself. There is no distinction whether time series are non-normally distributed, having small sample lengths or serial correlations. One important conclusion in the plot of Figure 7a is that data values sort themselves in ascending (or descending) order along the 1:1 line. This idea will also be used in the trend identification procedure proposed in this paper.

The same 25 data points are added increasing and decreasing trends separately and then they are ordered and plotted against the original (trend free) time series, which is also sorted in ascending order. The results are in Figures 7b and 7c, respectively, for increasing and decreasing trends. It is obvious that in the case of increasing (decreasing) monotonic trend, scatter of the points falls above (below) the 1:1 line. Any trial with non-normal, small sample and serially correlated time series, similar scatter diagrams are obtained for increasing and decreasing trends.

The next question for the basis of the methodology proposed in this paper is how could one identify the existing trend in a given time series with respect to the idea of 1:1 line. The answer appears as plot of the first half of the time series against the second half according to the abovementioned idea. In Figures 5.8a and 5.8b, the same time series as in Figures 7b and 7c are used, this time by considering two-halves and the sorting procedure. It becomes obvious that monotone increasing (decreasing) trend in the given time series fall above (below) the 1:1 line. This idea can be used in any engineering hydro-meteorological or hydro-climatic time series trend identifications.

On the other hand, it is also possible to have time series with half plots similar to Figure 8 as in Figure 9, where there are scatter of points on both sides of 1:1 line. In Figure 9a low (high) values are more (less) in the first half than the next half, whereas in Figure 9b the opposite situation occurs. These cases correspond to non-monotonic trends where within the same time series there are increasing and decreasing trends at different scales even hidden ones.

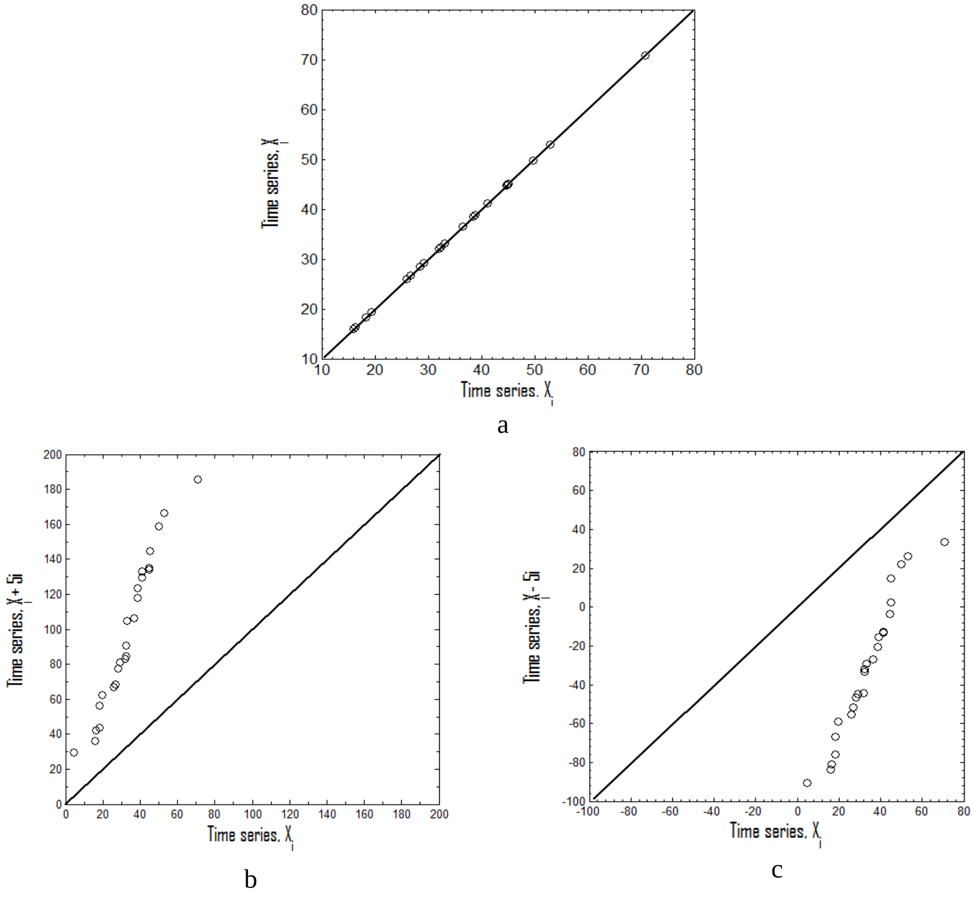
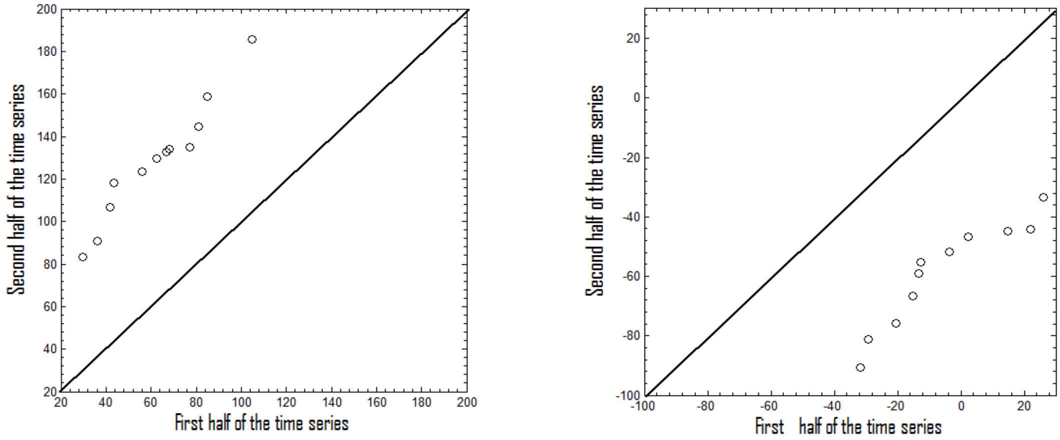
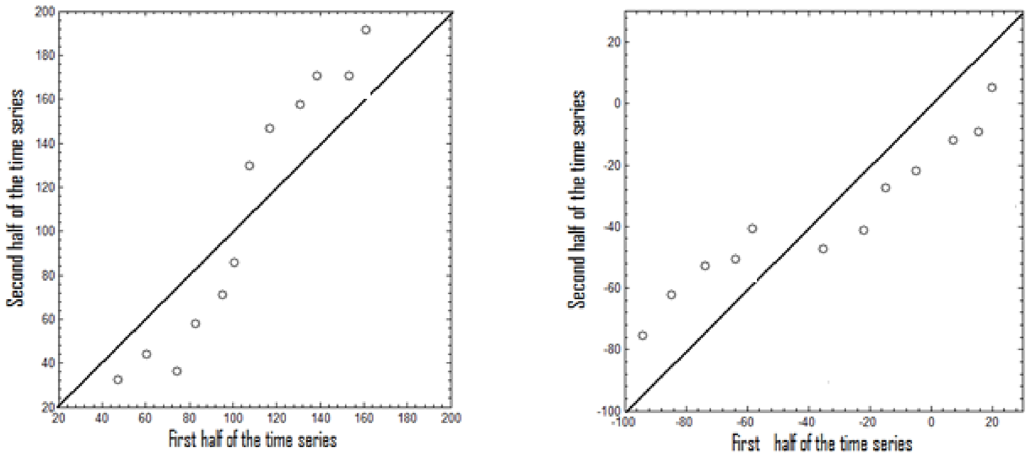


Figure 7: a) The same time series plot, b) increasing trend, c) decreasing



a b

Figure 8: Time series halves with monotonic trends



a b

Figure 9: Time series halves with non-monotonic trends

In practical applications, a mixture of the all cases explained in this section appears and accordingly the necessary interpretations must be done for better understanding of the time series structure composition.

5.2.2. Application

The application of the previously explained approach has been employed for the annual rainfall sequence in the study area. Figure 10 is the result for the meteorology station M003. One can interpret that the low rainfall occurrences and amounts at this station have increased during the recent years. Although, the medium rainfall events have more or less stable situation, as for the high precipitation amounts there has been always increase in recent years in the high rainfall amounts. One can conclude that in the future higher rainfall expectations are common in this station location.

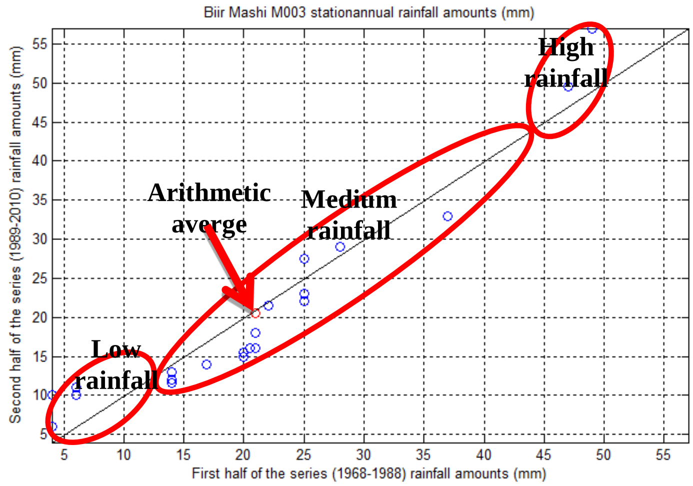


Figure 10: First half of the series (1968-1988) rainfall amounts (mm) at BirMashi station (M003)

It is obvious from this figure that at very low and high rainfall values are epected to show increasing trends in the future, but medium rainfall amounts will have decreasing trends most of the time.

5.3 Comparison of Rainfall Analysis between Different Approaches Using Annual Maximum Daily Rainfall Data

As has been explained above, different PDF approach have been used for the best description of the available rainfall data in the Wadi region but their comparisons are given separately for the two station (M001 and M003) in the Tables 8 and 9.

Also, the result was compared with study by Subyani and Al-Ahmadi, 2011. They studied the maximum annual daily rainfalls of several station including Madinah and BirMashi stations are evaluated and derived using the theoretical Gumbel extreme value (EVI) for different return periods. Rainfall results from Tables 8 and 9 indicate very close and small differences below 50-year return period of both stations. However, 100-year return period has some changes within two stations due to difference approach of rainfall analysis.

Table 8: Madinah station

Prob.	ARI (years)	Subyani & Al-Ahmadi 2011	PDF	GOF criteria
Method		EVI	GEV	GEV
0.9	10	50.5	43.6	44.8
0.96	25	65.0	68.68	62.67
0.98	50	75.7	94.08	78.22
0.99	100	86.4	126.99	95.91

Table 9: BirMashi station

Prob.	ARI (years)	Subyani & Al-Ahmadi 2011	PDF	GOF criteria
Method		EVI	GEV	GEV
0.9	10	36.2	36.12	40.82
0.96	25	44.6	46.90	53.28
0.98	50	50.9	55.64	63.44
0.99	100	57.1	64.99	74.39

6.0 Conclusion

The study evaluated the application of maximum annual rainfall series at Wadi Alaqiq in Madinah based on Madinah and BirMashi station. The rainfall analyses examined probability distribution functions (PDFs) with different goodness-of-fit (GOF) tests including Anderson Darling (AD) test. The GOF tests showed that the generalized logistic (GLO) and generalized extreme value (GEV) PDFs are the two best ones and they are followed by PE3, LN3 PDFs for both stations. However, for three-parameter PDFs, the GEV, is chosen for final analyses and it fits both stations. The findings are useful for application of flood frequency analysis in arid region with similar conditions of hydrological systems. In the mean-time the climate change variability has been also assessed by an innovative trend methodology.

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