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Frequency Analysis of Annual One Day Maximum Rainfall at Amman Zarqa Basin, Jordan

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Abstract

Water management and design of irrigation and drainage projects are based on extreme values rather than on average values. Annual daily maximum rainfall corresponding to return periods varying from 2 to 100 years is used by design engineers and hydrologists for economic planning, and design of minor and major hydraulic structures. This research aims at performing frequency analysis of annual daily maximum rainfall in Amman-Zarqa Basin (AZB) which is an important basin in Jordan. Daily rainfall data at 22 stations distributed in Amman-Zarqa Basin with long time series (more than 40 years) were used for this purpose. For each station, the annual 1- day maximum rainfall data were extracted. Daily maximum values have then been statistically analyzed by RAINBOW software using two probability distribution functions, namely: Linear and log normal distributions. The goodness of fit for the selected distributions is tested using the Chi-square and the Kolmogorov–Simrnov tests at three significant levels (α=5%, 10% and 20%). The results of the goodness of fit indicate that the Log normal distribution provides a good fit to the rainfall data in the basin. Frequency analysis is then conducted to extract the magnitude of 1 day annual maximum rainfall corresponding to 2, 5, 10, 25, 50 and 100 yr return periods for the 22 stations in AZB. Analysis of rainfall regime would enhance the management of water to prevent floods and droughts as well as an effective design of drainage structures especially in relation to their required hydraulic capacity.

Keywords: Amman-Zarqa Basin, Extreme Events, Frequency Analysis, Probability Distribution, RAINBOW Software, Return Period

1. Introduction

The pattern and amount of rainfall are among the most important factors that govern the design of hydraulic structures. However, studies of yearly and seasonal precipitation on global and local scales reveal that the total rainfall is highly variable over many regions of the world (Houghton et al. 1996). The variability depends on the climate and the length of the considered period. Because of the strong temporal rainfall variability, the design and management of drainage and irrigation structures are not based on the long-term rainfall average but on particular rainfall depth that can be expected for a specific probability or return period. This event is usually termed the design rainfall event. The determination of design rainfall event is usually the first step in hydrologic design projects. Design rainfall event can only be obtained by thorough analysis of historical rainfall data. Although the required length of the time series depends on the temporal variability in precipitation, a period of 30 years and over is normally considered satisfactory.

The most common approach for determining design storm events is frequency analysis (Snedecor and Cochran 1980; WMO 1981, 1983 and 1990; Haan 2002). Frequency analysis is used to estimate the probability of occurrence of future events. Different methods of frequency analysis are available. Among those are interval method, ranking method, and applying theoretical frequency distribution (Oosterbaan R.J. 1988R).

The probability of occurrence is often made in terms of return periods and their corresponding event magnitudes. The return period is the period expressed in number of years in which the annual observation is expected to return. The return period represents the reasonable design criteria that should be chosen by the designer, in consultation with the owner, following established hydrologic practice. Table 1 presents typical return periods generally encountered in hydraulic structure design. The selection of return period for design purposes is related to the damage caused by the excess or the shortage of rainfall, the risk one wants to accept and the lifetime of the project.

Many researchers have analyzed heavy and extreme precipitation to predict design rainfall depths for selected return period as the appropriate selection of these events in the design avoids considerable damage and loss of life worldwide each year (Yang et. al 2010; Bhakar et al., 2006; Huff and Angel 1992; Cannarozzo et. al. 1995; Mansell M.G. 1997; Fowler and Kilsb 2003; Brunetti et al. 2001; Kunkel et al. 1999). However in Jordan, few studies were mainly carried out about this topic. In the present paper, frequency analysis of annual daily maximum rainfall data for 22 stations in Amman Zarqa basin (AZB) has been carried out to be used by design engineers and hydrologists for the economic planning and design of hydraulic structures within this basin.

Table 1. Frequencies of Minor Structure Designs (Viessman and Lewis, 2003)

Type of Minor Structure	Return Period, yr	Frequency
Highway Cross road drainage		
0-400 ADT	10	01
400-1700 ADT	10-25	0.1-0.04
1700-5000 ADT	25	0.04
5000^{+} ADT	50	0.2
Airfield	5	0.2
Railroads	25-50	0.04-0.02
Storm drainage	2-10	0.5-0.02
Levees	2-50	0.5-0.02
Drainage ditches	5-50	0.2-0.02

2. Study Area

Amman-Zarqa basin (AZB) is a vital basin in Jordan. It is located north-west of Jordan. The basin drains approximately 4710 square kilometer, 468 square kilometer of which is in Syria. This basin is the most densely populated area in Jordan, it comprises around 65% of the country's population, and 80% of its industries, in addition to intensive agricultural activities (Hammouri and El-Naqa 2007). The climate in the basin is classified as semiarid where rainfall precipitates mostly in the winter season, while the summer season is extensively dry.

Based on data availability, twenty two stations distributed within the AZB were selected (Figure 1). Daily rainfall values for each rain gauge station were compiled from databases that are maintained by the Jordanian Meteorological Department (JMD) and Ministry of Water and Irrigation in Jordan (MWI). The selected stations have long term records that exceed 40 years. Table 2 presents the names, and the length of the record for the selected rain gage stations

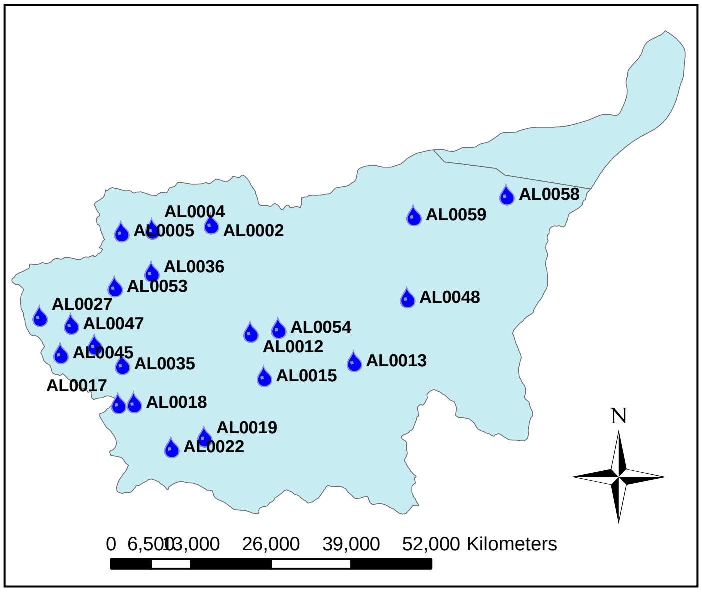

Figure 1. Map of Amman-Zarqa Basin area showing the locations of the selected stations used to derive the rainfall frequencies

Table 2. Selected station in AZB and data availability for each station

Station ID	Station Name	Data range	Station ID	Station Name	Data range
AL0002	Midwar	1950-2009	AL0027	Subihi	1962-2009
AL0004	Jarash	1942-2009	AL0028	Rumeimin	1962-2009
AL0005	Kitta	1937-2009	AL0035	K.H. nursery Evaporation Station (Baq'a)	1963-2009
AL0010	Deir Alla Agricultural Station	1953- 2009	AL0036	Prince Feisal Nursery	1963-2009
AL0012	Sukhna	1950-2010	AL0045	Um Jauza	1967-2009
AL0013	Nawasif	1961-2009	AL0047	Sihan	1967-2009
AL0015	Zarqa	1937-2009	AL0048	Khaldiya	1967-2009
AL0017	Sweilih	1942-2009	AL0053	King Talal dam	1969-2010
AL0018	Jubeiha	1937-2009	AL0054	Hashimiya	1968-2009
AL0019	Amman Airport	1937-2010	AL0058	Sabha and Subhiyeh	1967-2010
AL0022	Amman Hussein College	1950-2009	AL0059	Um el Jumal Evaporation Station	1967-2009

3. Data Analysis

The design and management of irrigation and flood control systems should be based on particular rainfall depths that can be expected for a specific probability or return period. These rainfall depths can only be obtained by frequency analysis which involves thorough analysis of long time series historic rainfall data.

The first step in frequency analysis is to extract the annual maximum values of precipitation from historical precipitation records for a selected duration which is 1day in this study. For each selected station within AZB, the maximum values of annual daily precipitation are tabulated in order to carry out frequency analysis using the software package RAINBOW (Raes et al. 2006; Raes et al. 1996). Table 3 presents an example extracted annual daily maximum precipitation for station AL0002.

RAINBOW software is specially designed to test the homogeneity of data sets, and carry out frequency analysis to obtain an estimate of rainfall depths for selected probabilities or return periods required for the design (Raes and Leuven 2004). It allows selection of different probability distribution. and evaluating the goodness of fit of the selected probability function by graphical methods (Probability plot and a Histogram of the data). In addition, RAINBOW offers statistical tests for investigating whether data follow a certain distribution (Chi-square and the Kolmogorov-Smirnov test).

Table 3. Example extracted 1-day annual maximum rainfall

Year	Max daily Rainfall (mm)	Year	Max daily Rainfall (mm)	Year	Max daily Rainfall (mm)	Year	Max daily Rainfall (mm)
1950	31.8	1965	46	1980	49	1995	15
1951	40	1966	51.5	1981	12	1996	26
1952	36	1967	9	1982	35	1997	55
1953	45.5	1968	28	1983	47.5	1998	38.5
1954	16.5	1969	20	1984	29	1999	38
1955	42	1970	22.5	1985	20	2000	25
1956	26	1971	22	1986	37.3	2001	49.5
1957	38	1972	19.1	1987	36	2002	0
1958	20	1973	35	1988	48	2003	42
1959	20	1974	35.7	1989	33	2004	77
1960	27	1975	25	1990	25.1	2005	57
1961	28.1	1976	37	1991	35	2006	37
1962	67.8	1977	40.5	1992	17	2007	24
1963	32.6	1978	29.2	1993	19	2008	98
1964	62.4	1979	32.6	1994	27	2009	79.5

There is an infinite number of valid probability distributions (Chin 2013). In this work, two commonly used probability distribution functions, namely: normal distribution (Haan 2002), and log normal distribution (Aitchison and Brown 1957; Crow and Shimizu 1988; Evans et al. 1993) are applied in frequency analysis.

A common application of probability theory in water resources engineering involves the assignment of an exceedance probability, P_e, of the design event. The average number of years between exceedances is called the return period, T. The probability of exceedance and return period is estimated by Weibull method (Weibull 1939) since it is theoretically better sound. Weibull estimates the probability of exceedance or non –exceedance as (Chin 2013):

$$P_e = \frac{m}{n+1} \tag{1}$$

Where r is the rank number and n is the number of observations.

The return period T in years is related to the annual exceedance probability by (Chin 2013):

$$T = \frac{1}{P_e} \tag{2}$$

The two distributional assumptions used in this work were tested using two goodness of fit tests; the ch-squre (χ^2), and the Kolmogorov–Simrnov (K-S) tests. The two goodness of fit were conducted at three different significance levels (α= 5%, 10% and 20%).

In general, the Chi-square test compares how well theoretical distribution fits the empirical distribution (PDF). The Chi-square test statistics is of the form (Montgomery and Runger 2003):

$$\chi^2 = \sum \frac{(observed - \exp ected)^2}{\exp ected} \tag{3}$$

If the computed test statistics is large, then the observed and expected values are not close and the model is a poor fit to the data, otherwise it is a good fit. A good fit leads to the acceptance of Ho whereas a poor fit leads to its rejection.

The Kolmogorov –Smirnov (K-S) test is used to decide if a sample comes from a hypothesized continuous PDF. It is based on the largest vertical difference between the theoretical and empirical CDF. The Kolmogorov – Smirnov (K-S) test statistics is defined as (Chakravart et al. 1967):

$$D = \max_{1 \le i \le N}\left(F(X_i) - \frac{i-1}{N}, \frac{i}{N} - F(X_i) \right) \tag{4}$$

Where F is the theoretical cumulative distribution of the distribution being tested which must be a continuous distribution, and Xi is a random sample, i= 1.2. …., n.

4. Results

4.1 Basic Statistics

For the 22 stations, basic statistics namely: mean, median and standard deviation for daily rainfall data are carried out. Results are reported in Table 4. The mean daily rainfall varied between 3.95 mm (station AL0059) and 15.4 mm (station AL0005). The average rainfall can be used to characterize the historic daily rainfall data in each station but cannot be blindly used to estimate design rainfall depths that can be expected with a specific probability or return period.

The results also reveal that value of the mean is larger than the median value, and the frequency distribution shows a positive skew.

Table 4. Statistical parameters of annual 1 day rainfall data in 22 rainfall stations in AZB.

Station ID	Mean (mm)	Median (mm)	Standard Deviation (mm)
AL0002	7.95	5.00	9.40
AL0004	9.03	5.00	11.59
AL0005	15.40	8.50	18.38
AL0010	6.34	3.20	8.48
AL0012	5.09	2.90	6.67
AL0013	5.96	4.00	6.44
AL0015	4.85	2.50	6.50
AL0017	12.35	6.40	16.43
AL0018	11.46	5.80	15.19
AL0019	5.83	2.50	8.69
AL0022	9.98	4.60	14.38
AL0027	11.71	6.50	15.36
AL0028	10.77	5.45	14.70
AL0035	8.49	4.20	11.43
AL0036	9.54	5.20	11.56
AL0045	13.99	7.10	18.62
AL0047	10.33	5.70	13.09
AL0048	4.74	2.80	5.77
AL0053	7.52	4.45	8.57
AL0054	4.79	3.00	5.59
AL0058	4.68	3.00	5.69
AL0059	3.95	2.50	4.56

4.2 Statistics Test on Goodness of Fit

The goodness of fit for the selected distributions is quantitatively tested by the RAINBOW software using the Chi-square test and the Kolmogorov –Simrnov test. Results are presented in Table 5. Detailed results of the statistical tests for the examined distributions are presented in Annex 1 (Table A.1 and A.2). The statistical comparison by Chi-square test for goodness of fit shows that the log normal distribution gave minimum value of Chi-square for annual 1 day maximum rainfall. Therefore, the hypothesis that the measured rainfall data are from a log normal distribution is accepted at the 10 % significant level. Results of the Kolmogorov-Smirnov test reveal that the log normal distribution can be accepted at a significant level of α=5% at all the selected stations. Hence, log-normal distribution is considered more effective in describing the measured rainfall data. Probability plots for each station are presented in Annex 2 (Figure A.2). The goodness of fit is evaluated graphically by the coefficient of determination (R^2).

Table 5. Results of goodness of fit for the 22 rain gage stations in AZB

Station ID	Linear Transformation		Log-normal Transformation	
	χ^2	(K-S)	χ^2	(K-S)
AL0002	3.83	0.122	2.78	0.067
AL0004	10.52	0.119	3.33	0.071
AL0005	8	0.095	2.67	0.069
AL0010	7.21	0.067	7.21	0.067
AL0012	25.63	0.158	3.66	0.089
AL0013	11.14	0.095	7.44	0.070
AL0015	18.35	0.132	2.47	0.075
AL0017	5.1	0.076	2.3	0.054
AL0018	4.44	0.111	2.34	0.055
AL0019	17.51	0.119	1.08	0.062
AL0022	37.14	0.179	2.37	0.121
AL0027	25.68	0.129	7.25	0.077
AL0028	12.12	0.108	0.97	0.062
AL0035	37.65	0.152	17.94	0.150
AL0036	31.7	0.151	19.86	0.134
AL0045	13.89	0.127	2.92	0.094
AL0047	34.21	0.155	7.69	0.098
AL0048	10.38	0.124	3.7	0.061
AL0053	6.68	0.110	4.7	0.085
AL0054	15.56	0.131	22.02	0.145
AL0058	5.86	0.148	3.04	0.066
AL0059	11.77	0.147	0.8	0.052

4.3 Probability of Exceedance and Return Period

Determination of extreme annual 1-day rainfall depth for selected return periods (2, 5, 10, 25, 50 and 100 yr) on the basis of a frequency analysis for 22 stations in AZB are presented in Table 6. The analysis reveals that a maximum of 71.3 mm in one day is expected to occur in AZB every 2-year (station AL0005). For a return period of 100-yr, the maximum rainfall expected in 1 day in AZB is 172.9 mm (station AL0005).

Table 6: Estimated annual 1-Day maximum rainfall corresponding to different return periods in AZB

Station ID	Maximum 1-Day Rainfall (mm)					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
AL0002	32.4	47.6	58.2	72	82.7	93.6
AL0004	47.4	63.7	74.4	87.7	97.6	107.4
AL0005	71.3	98.2	116.1	138.8	155.8	172.9
AL0010	36.7	48.9	56.8	66.6	73.8	81
AL0012	23.4	33.3	40	48.7	55.3	62
AL0013	21.9	30.1	35.5	42.4	47.6	52.7
AL0015	22.5	33.3	40.8	50.7	58.4	66.2
AL0017	66.9	92.5	109.5	131.1	147.3	163.6
AL0018	63.1	85.4	99.9	118.3	131.8	145.4
AL0019	37.3	51.2	60.5	72.2	80.9	89.7
AL0022	56.4	76.3	89.3	105.6	117.8	129.8
AL0027	59.3	83.7	100.2	121.4	137.4	153.6
AL0028	57.3	78.3	92.3	109.9	123	136.2
AL0035	45.8	60.3	69.6	81.1	89.5	97.8
AL0036	44.4	57.9	66.5	77.2	84.9	92.6
AL0045	66.1	96.2	117	144.2	165	186.3
AL0047	51.8	70.6	82.9	98.5	110.1	121.6
AL0048	20.2	26.5	30.6	35.5	39.2	42.8
AL0053	32.5	41.7	47.4	54.4	59.5	64.5
AL0054	19	29.1	36.3	46	53.6	61.6
AL0058	17.5	27.5	34.9	44.8	52.8	61.1
AL0059	15.2	23.2	29	36.7	42.7	49

5. Conclusion

Frequency analysis of extreme rainfall events has scientific and practical value in the context of basin-scale water resource and flood risk management. In this work, a set of daily rainfall time series for 22 stations across the Amman-Zarqa Basin (AZB) is applied to perform frequency analysis of annual daily maximum rainfall. Two probability distributions namely normal and log normal are applied to estimate one day annual maximum rainfall of various return periods. The two distributions were tested by comparing the Chi-square and Kolmogorov–Simrnov values. Log-normal distribution was found to be the best fit for most of the stations in AZB. The magnitudes of 1 day annual maximum rainfall corresponding to 2 to 100 years return period were estimated using the lognormal distribution.

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Annex 1

Table A.1: Statistical test for normal distribution for the 22 rain gage stations in AZB

Station ID	χ^2	Chi-Square test Results	K-S	(K-S) test Results
AL0002	3.83	Distribution is rejected with CL of 83.7 %	0.122	Distribution can be accepted R^2=0.90
AL0004	10.52	Distribution is rejected with CL of 99.0 %	0.119	Distribution can be accepted R^2=0.90
AL0005	8	Distribution is rejected with CL of 95.2 %	0.095	Distribution can be accepted R^2=0.98
AL0010	7.21	Distribution is rejected with CL of 93.1 %	0.067	Distribution can be accepted R^2=0.98
AL0012	25.63	Distribution is rejected with CL of 99.0 %	0.158	Distribution is rejected with CL of 89.4 % R^2=0.79
AL0013	11.14	Distribution is rejected with CL of 99.0 %	0.095	Distribution can be accepted R^2=0.94
AL0015	18.35	Distribution is rejected with CL of 99.0 %	0.132	Distribution can be accepted R^2=0.93
AL0017	5.1	Distribution is rejected with CL of 91.8 %	0.076	Distribution can be accepted R^2=0.95
AL0018	4.44	Distribution is rejected with CL of 88.6 %	0.111	Distribution can be accepted R^2=0.92
AL0019	17.51	Distribution is rejected with CL of 99.0 %	0.118	Distribution can be accepted R^2=0.87
AL0022	37.14	Distribution is rejected with CL of 99.0 %	0.179	Distribution is rejected with CL of 95.3 % R^2=0.83
AL0027	25.68	Distribution is rejected with CL of 99.0 %	0.128	Distribution can be accepted R^2=0.87
AL0028	12.12	Distribution is rejected with CL of 99.0 %	0.108	Distribution can be accepted R^2=0.95
AL0035	37.65	Distribution is rejected with CL of 99.0 %	0.151	Distribution can be accepted R^2=0.91
AL0036	31.7	Distribution is rejected with CL of 99.0 %	0.151	Distribution can be accepted R^2=0.91
AL0045	13.89	Distribution is rejected with CL of 99.0 %	0.127	Distribution can be accepted R^2=0.88
AL0047	34.21	Distribution is rejected with CL of 99.0 %	0.155	Distribution can be accepted R^2=0.81
AL0048	10.38	Distribution is rejected with CL of 99.0 %	0.124	Distribution can be accepted R^2=0.93
AL0053	6.68	Distribution is rejected with CL of 95.9 %	0.109	Distribution can be accepted R^2=0.97
AL0054	15.56	Distribution is rejected with CL of 99.0 %	0.131	Distribution can be accepted R^2=0.82
AL0058	5.86	Distribution is rejected with CL of 97.9 %	0.148	Distribution can be accepted R^2=0.85
AL0059	11.77	Distribution is rejected with CL of 99.0 %	0.147	Distribution can be accepted R^2=0.88

Table A.2: Statistical test for Log-normal distribution for the 22 rain gage stations in AZB

Station ID	χ^2	Chi-Square test Results	K-S	(K-S) test Results
AL0002	2.78	Distribution can be accepted	0.067	Distribution can be accepted R^2=0.99
AL0004	3.33	Distribution can be accepted	0.071	Distribution can be accepted R^2=0.97
AL0005	2.67	Distribution can be accepted	0.069	Distribution can be accepted R^2=0.96
AL0010	7.21	Distribution is rejected with CL of 93.1 %	0.067	Distribution can be accepted R^2= 0.98
AL0012	3.66	Distribution is rejected with CL of 82.3 %	0.089	Distribution can be accepted R^2= 0.97
AL0013	7.44	Distribution is rejected with CL of 93.8 %	0.070	Distribution can be accepted R^2= 0.99
AL0015	2.47	Distribution can be accepted	0.075	Distribution can be accepted R^2=0.99
AL0017	2.3	Distribution can be accepted	0.054	Distribution can be accepted R^2=0.99
AL0018	2.34	Distribution can be accepted	0.055	Distribution can be accepted R^2=0.99
AL0019	1.08	Distribution can be accepted	0.062	Distribution can be accepted R^2=0.98
AL0022	2.37	Distribution can be accepted	0.121	Distribution can be accepted R^2=0.95
AL0027	7.25	Distribution is rejected with CL of 93.2 %	0.077	Distribution can be accepted R^2=0.98
AL0028	0.97	Distribution can be accepted	0.062	Distribution can be accepted R^2=0.99
AL0035	17.94	Distribution is rejected with CL of 99.0 %	0.150	Distribution can be accepted R^2=0.96
AL0036	19.86	Distribution is rejected with CL of 99.0 %	0.134	Distribution can be accepted R^2=0.96
AL0045	2.92	Distribution can be accepted	0.094	Distribution can be accepted R^2=0.96
AL0047	7.69	Distribution is rejected with CL of 97.1 %	0.098	Distribution can be accepted R^2=0.95
AL0048	3.7	Distribution can be accepted	0.061	Distribution can be accepted R^2=0.99
AL0053	4.7	Distribution is rejected with CL of 90.3 %	0.085	Distribution can be accepted R^2=0.97
AL0054	22.02	Distribution is rejected with CL of 99.0 %	0.145	Distribution can be accepted R^2=0.94
AL0058	3.04	Distribution is rejected with CL of 91.4 %	0.066	Distribution can be accepted R^2=0.98
AL0059	0.8	Distribution can be accepted	0.052	Distribution can be accepted R^2=0.99

Annex 2

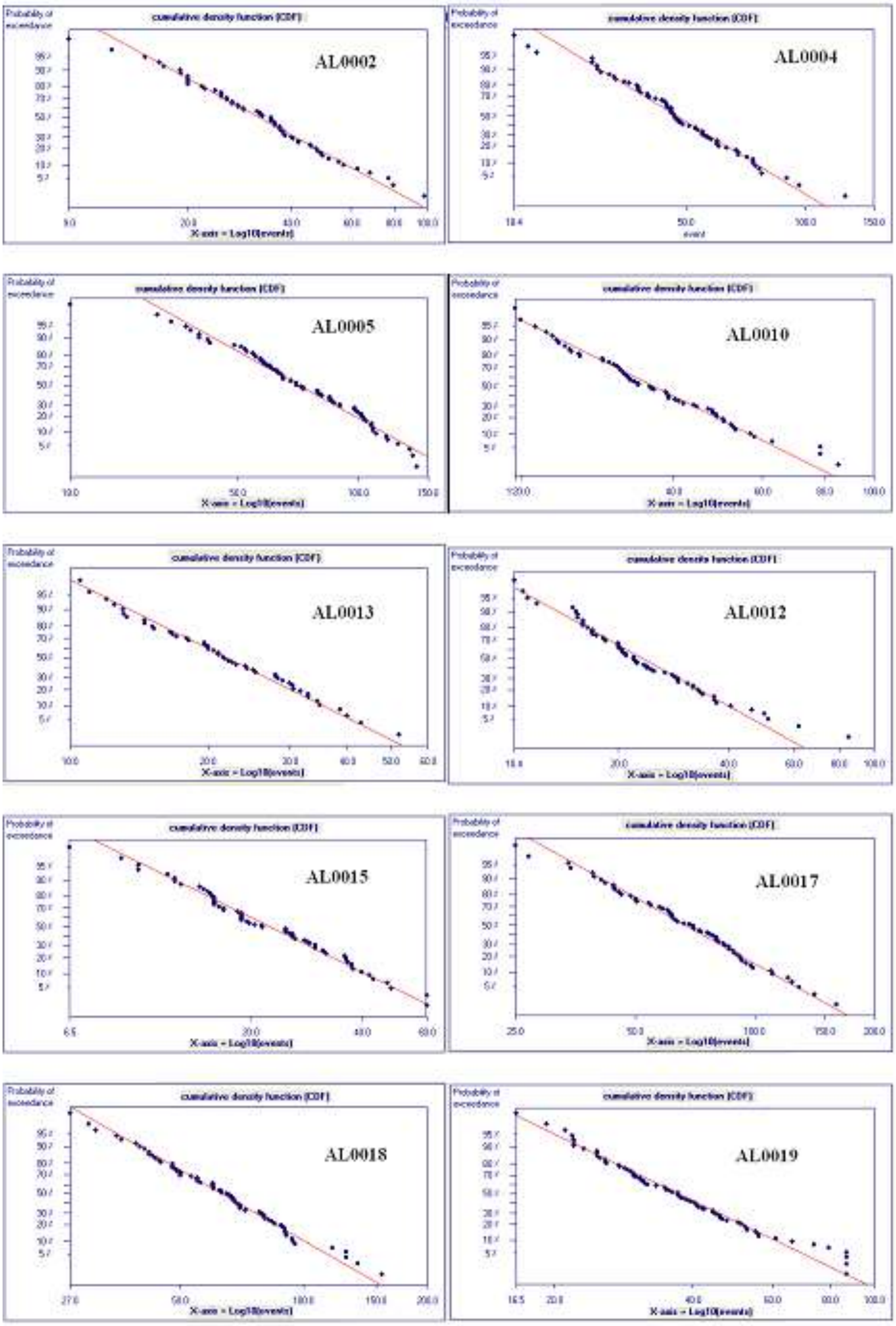

Figure A.1: Probability plot (CDF) for selected stations AL002-AL0019 in AZB.

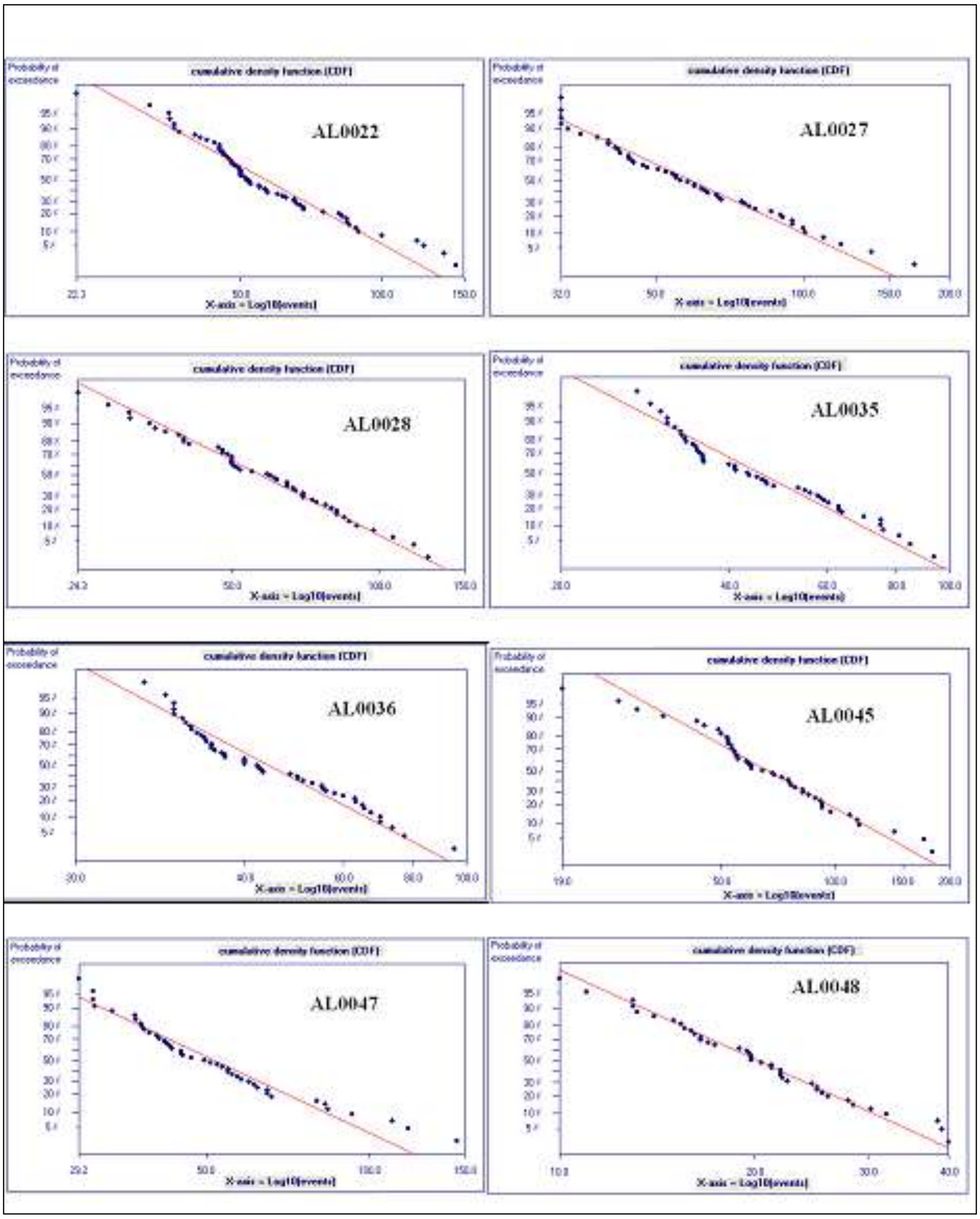

Figure A.2 Probability plot (CDF) for selected stations AL0022-AL0048 in AZB.

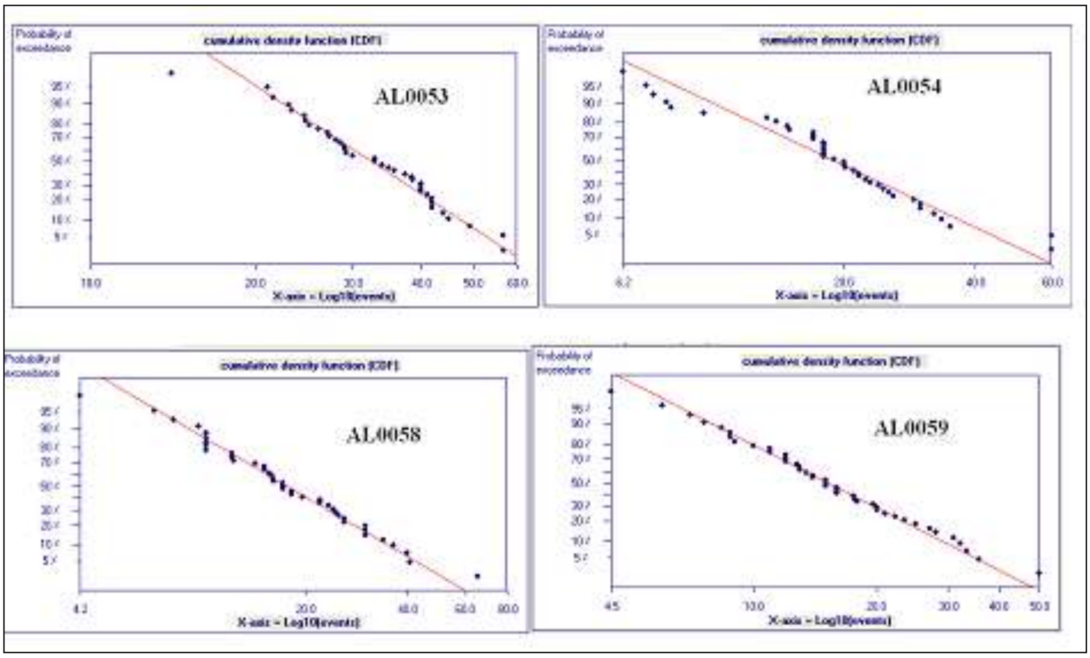

Figure A.3: Probability plot (CDF) for selected stations AL0053-AL0059 in AZB.