Natural Resources Conservation and Research (2018) Volume 1
doi:10.24294/nrcr.v1i4.683

A New Method for Estimating Flood Peak Discharge and Extreme Rainfall: Case Study for Firat Basin

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ABSTRACT

The commonly-used design parameter for hydraulic structures is the annual maximum instantaneous streamflow recorded by conventional gauging stations. Increased hydroclimatic variability in recent years and the resultant flooding raise questions concerning the flood risk estimations from the short flow records in Turkey. The method described in this study has been selected according to the likely estimates for the peak flow values at different return periods for the gauged basins. Hence, estimation of the peak flow values for regions with poor or rich discharge datasets could be implemented. In theory, this developed method may be used to estimate the peak flow values at any point on a river network, and not only at basin outlets. In this research, a case study has been conducted on Firat basin, on which the largest dams in Turkey have been built, by employing a novel approach for developing a new method that calculates the peak flood flows and extreme rainfall. The results demonstrate that the approach is sound and can be employed in prediction of peak rainfall and flow parameters in river basins.

***Keywords*:** Extreme Rainfalls; Goodness-of-fit Test; New Estimation Method; Peak Discharge

1. Introduction

From time immemorial, investigations have been made into the probability of occurrence of river floods. Based on that knowledge, river-engineering works have been designed and flood protection measures have been taken. Yet, the data available are insufficient to draw firm conclusions on future effectiveness of these interventions. The more reliable the discharge data from the past, the smaller the risk of failure of the design conditions for flood protection measures. The estimation of the probability of occurrence of peak floods is open to improvement. To that end, other estimation-methods will be used, the data series will be extended and different methods of data processing will be used.

Peak discharge information is required to determine the dam design and appropriate size water conveyance systems such as natural channels, diversion canals, bridge openings etc. The accurate prediction of stream flows is essential to planning of our water resource systems. This paper addresses the practical satate of the art of techniques to perdict flood peaks and their associated frequency of occurence. Statistical relationships will be investigated as means for predicting the peak discharges.

The statistical graphical or analytical methods of flood flow estimation seem to be well established in literature, Gumbel (1958), Chow (1964), Benson (1968), Yevjevich (1972), Haan (1977). Generally, a graphical method by plotting annual peak flow on a log-normal probability paper using the Weibull plotting position formula, or an analytical method using the log Pearson type distributions is recommended.

Rossi *et al*. (1984) describe the theoretical considerations to obtain a parent flood distribution that closely represents the real flood experience, existing of annual flood series of Italian river basins.

Keim and Faiers (1996) explored heavy rainfall distributions by season and the associated differences in seasonal quantile estimates for selected recurrence intervals in Louisiana, as a result of the findings of other investigators.

Adamowski (2000) considers the currently used parametric analysis of 'annual maximum' flood series. They reveal unimodal and multi modal probability density functions for floods in two Canadian Provinces Ontario and

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Quebec.

Adamowski (2000) considers the currently used parametric analysis of ‘annual maximum’ flood series. They reveal unimodal and multi modal probability density functions for floods in two Canadian Provinces Ontario and Quebec.

Nonparametric frequency analysis has been introduced as an alternative method. This method also revealed unimodal and multimodal ‘annual maximum’ and ‘peak over threshold’ flood probability density function shapes in both Provinces.

Luxemburg, W.M.J. *et al.* (2002) analysis the statistical properties of flood runoff of North Asian rivers under conditions of climate change.

Bakker and Luxemburg (2005) consider the problem of heterogeneous distributions of floods, as research in the area of frequency analysis has been rather limited on this item, although several investigators confess that the assumption of homogeneity of flood distributions may not be valid. Therefore, the estimates of probabilities of exceedance are often very unreliable. The heterogeneity of the series of annual maximum runoffs can be explained by the fact that different extreme floods are caused by different mechanisms (ice-melt, rains, cyclones, etc.).

Mantje, *et al.* (2007) try to identify the different homogeneous subsets in a heterogeneous distribution (although the latter is often regarded as homogeneous in flood frequency analysis).

2. Goodness-of-fit test

It is the work of determining the magnitudes of hydrological variables corresponding to given frequencies or recurrence intervals. Procedures involved in frequency analysis include: (1) collecting a random sample of the interested hydrological variable; (2) finding the best-fit distribution for the sample by a goodness-of-fit (GOF) test or other appropriate methods; and (3) determining the magnitude of the hydrological variable corresponding to a given probability of exceedance using the best-fit distribution. Two GOF tests, namely the chi-square test and the Kolmogorov– Smirnov test, are often used for the selection of probability distributions for hydrological variables (Haan, 2002). Another method of goodness-of-fit test is the method based on ordinary moment-ratio diagrams (D’Agostino and Stephens, 1986).

3. The Scope of the Study

In this study as developed, to yield a satisfactory first estimate of the discharge and corresponding water level at a certain point along the river starting from rainfall forecasts. An improved estimation method for the probability of occurance of flood peak discharges. Improved accuracy of the probability of exceedance estimates of flood peaks as a result of this determination. Identification of the flood properties at rivers that determine further downstream. A method to determine these downstream water levels, their probability of exceedance and accuracy. Operational flood discharge prediction, especially early forecasting, to enhance operational decision making. As the flood event proceeds, the availability of more elaborate data and the use of more sophisticated flood forecasting models may enable more accurate predictions.

In this study, a brand new methodology differing from the distribution analyses has been developed for the estimation of annual maximum instantaneous streamflows as well as the 100, 200, 500, 1000 and 10000-year precipitation depths gauged by meteorological stations, and a correlation has been obtained. Then the values determined by the assistance of this correlation have been compared with the GOF test results.

4. Methodology

If the annual maximum precipitation values measured for river basins are arranged in ascending order as $Q_1<Q_2<Q_3\ldots\ldots<Q_N$, a Q-T variation curve would be obtained as seen in **Figure 1.** For a time period of T years, the T years-recurrence peak-flow Q-T is defined as a value of discharge, which statistically occurs at every T years.

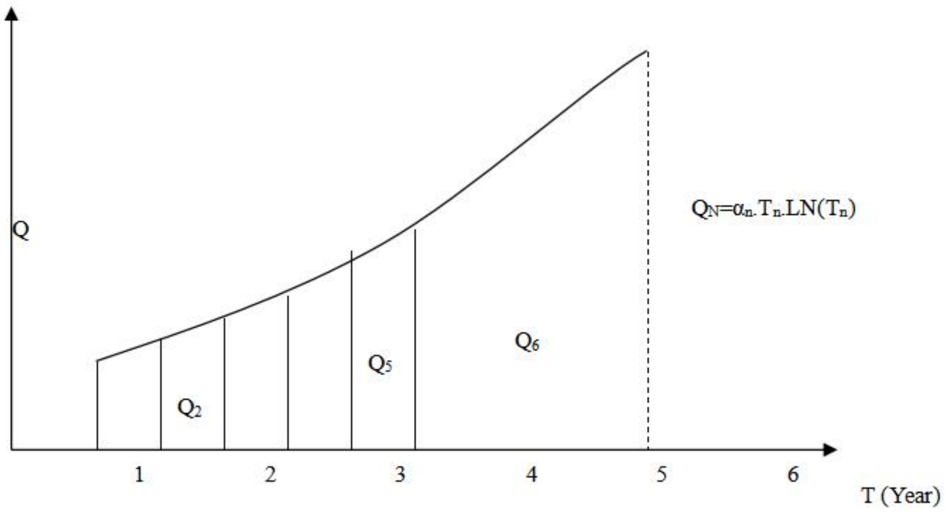

Figure 1; Q-T Variation Curve**.**

For any Q_i in **Figure 1**, the equation below could be asserted:

$Q_i = a_i * T_i * \ln(T_i)$……………………………………………………………………………(1)

The variables employed in the equation above stand for the following:

Q_i = value of the measured streamflow, precipitation depth or similar variable at the i^{th} year

a_i= the coefficient of i^{th} year, T_i= i^{th} year

Consequently, $Q_2=a_2*T_2*\ln(T_2)$ or in short, $Q_2=a_2*2\ln(2)$;

Similarly, equations like $Q_{10}=a_{10}*T_{10}*\ln(T_{10})$ could be stated briefly as $Q_{10}=a_{10}*10\ln(10)$.

In these equations, the a_i values for the years of measurement period are obtained by the following relation:

$a_i = Q_i /(T_i.\ln(T_i))$…………………………………………………….………...………………(2)

For instance:

$a_2= Q_2 /(T_2*\ln(T_2))$ or $a_2= Q_2 /(2*\ln(2))$

$a_5= Q_5 /(T_5* \ln(T_5))$ or $a_5= Q_5 /(5*\ln(5))$

$a_n= Q_n /(T_n* \ln(T_n))$ or $a_n= Q_n /(N*\ln(N))$. The graph of the a_i values are as shown in **Figure 2.**

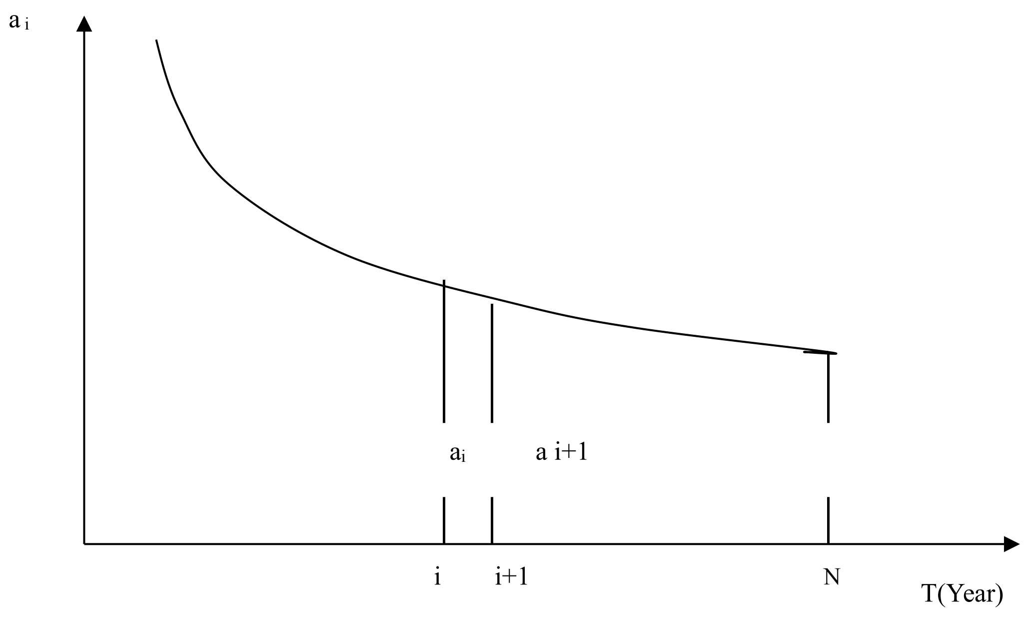

Figure 2; Evolution of a_i values during the period of measurement**.**

The values of a_{50} ,a_{100} ,a_{200} a_{500} ,a_{1000} and a_{10000} which are required for determining the values such as Q_{50}, Q_{100}, Q_{200} ,Q_{500} ,Q_{1000} and Q_{10000} that are beyond the scope of the N-year observation period for which measurements have been taken, could be determined in turn by the assistance of the chart in **Figure 2** as well as the a_{min} values determined from the a_i calculations. The equation below holds between the values of a_i and a_{i+1}:

$a_{(i+1)} = a_i\,(1-1/(i+1))$

Simplifying, $(i+1)*a_{(i+1)} = a_i - 1$ is obtained.

For instance, concerning the relationship between the 16[th] and 17[th] years;

$17.a_{17}=16.a_{16}$, hence,

$N*a_{min} = 100.a_{100} = 1000.a_{1000} = 10000.a_{10000}$. Therefore, the equation below could be derived since the product of $N*a_{min}$ must be constant:

$Q_T = a_{min}*N*\ln(T)$ ……………………………………………..........................……………(3)

The T-year streamflow as well as any time-dependant variable could be determined by Equation 3.

With N denoting the measurement year, the following streamflow values have been obtained;

$Q_{50} = a_{min}$ .N*ln (50) yields 50-year streamflow

$Q_{100} = a_{min}$ .N*ln (100) yields 100-year streamflow

$Q_{200} = a_{min}$ .N*ln (200) yields 200-year streamflow

$Q_{500} = a_{min}$ .N*ln N(500) yields 500-year streamflow

$Q_{1000} = a_{min}$ .N*ln (1000) yields 1000-year streamflow

$Q_{10000} = a_{min}$ .N*ln (10000) yields 10000-year streamflow

In the equations given above:

a_{min} = The minimum value obtained from the graph of measured values in **Figure 2** or from equation 2 using the a_i calculations. If no observation in excess of the N-year value has been made within the year of measurement, the value of a_{min} is reached at year N as seen in **Figure 2.** However, this situation is encountered rarely. Generally, a_{min} is reached before the N[th] year since some measurements greater than N-year values are observed within a particular observation year. In this case, if we denote the year where a_{min} has been reached as N_{amin}, the product of ($a_{min}*N_{amin}$) stays constant. Therefore, the following equations hold:

$(a_{min}.N_{amin}) = 100.a_{100} = 1000.a_{1000} = 10000.a_{10000}$. Consequently, Equation 3 could be stated in the following form:

$Q_T = a_{min}*N_{amin}*\ln(T)$ ………………..…………………………………………………….(4)

5. Study Case

The study area is situated adjacent to Keban Township, approximately 40 km to the west of Elazig province in eastern Turkey (**Figure 3**). The drainage system is characterized primarily by ephemeral streams of limited widths. The Euphrates is the main river in the study area, flowing from north to south.. The elevation of the region ranges from about 1000 m to over 2500 m. The vegetation comprises of scarce scrub grass and stunted trees. The area has a semi-arid climate characterized by dry summers and cold winters. According to the meteorological data for the period of 1923 to 2010 (Turkish State Meteorological Service, Elazig), the average annual rainfall is 399 mm, with snowfall accounting for more than half of this precipitation. The lowest mean precipitation has been recorded in the months of July and August (6 and 4 mm, respectively), whereas the highest mean precipitation has been recorded in the months of April and May (58 and 60 mm, respectively). The mean annual temperature is 14.8^o C, with July and August being the warmest months, with average temperatures around 28^{0}C, whereas January and February are the coldest months, with temperatures around 3^o C.

Keban dam, which is one of the largest dams in Turkey and the world, was built on the Euphrates river in the Upper Euphrates region. Keban Dam Reservoir spans an area of 67,500 km^2. The construction of the dam had been launched in 1964 and the dam had become operational by 1974. The maximum streamflow values of Euphrates River for a period of N=43 years between 1932 and 1974 (prior to the completion of Keban Dam) as measured by AGI owned by EIE located in Keban have been displayed in **Figure 4** and the streamflow analysis conducted by the new method is given in **Table 1**. Since the construction of Keban Dam has been fully completed in 1975, no streamflow measurements have been carried out after 1975. The obtained values have been given in **Table 2** in addition to the GOF test results of the measured streamflows for 43 years.

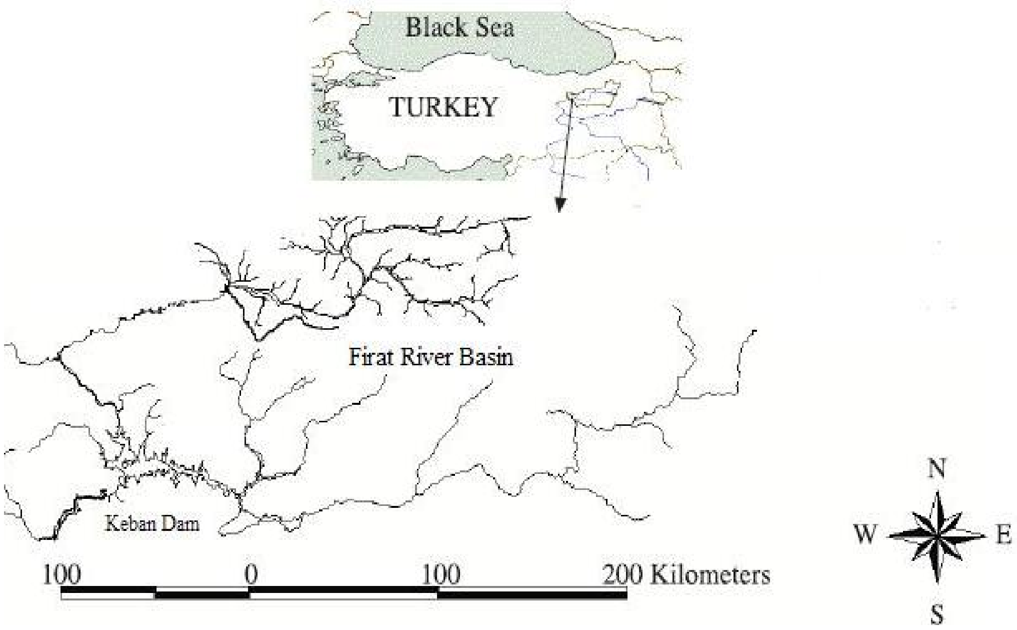

Figure 3; Location of study area.

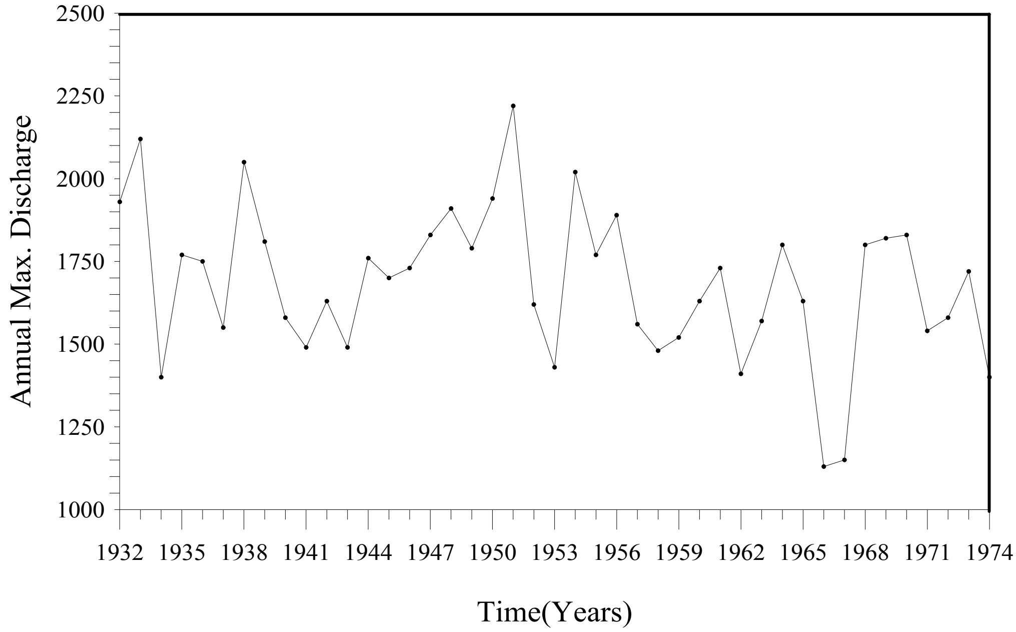

Figure 4; Change of annual maximum discharge for each years.

Year	Max. Discharge	Sequential data	a_i	T(Time) N=43	$Q_T=a_{min}.N_{amin}.LN(T)$
1951	2220	1630	27.20	20	1653,716
1952	1620	1700	26.58	21	1680,649
1953	1430	1720	25.29	22	1706,33
1954	2020	1730	23.98	23	1730,868
1955	1770	1730	22.68	24	1754,362
1956	1890	1750	21.74	25	1776,897
1957	1560	1760	20.77	26	1798,547
1958	1480	1770	19.89	27	1819,381
1959	1520	1770	18.97	28	1839,457
1960	1630	1790	18.33	29	1858,828
1961	1730	1800	17.64	30	1877,543
1962	1410	1800	16.90	31	1895,643
1963	1570	1810	16.32	32	1913,169
1964	1800	1820	15.77	33	1930,156
1965	1630	1830	15.26	34	1946,636
1966	1130	1830	14.70	35	1962,637
1967	1150	1890	14.65	36	1978,188
1968	1800	1910	14.29	37	1993,313
1969	1820	1930	13.96	38	2008,035
1970	1830	1940	13.57	39	2022,374
1971	1540	2020	13.68	40	2036,35
1972	1580	2050	13.46	41	2049,981
1973	1720	2120	13.50	42	2063,283
1974	1400	2220	13.72	43	2076,273
Q_{50}	-	-	-	50	2159,531
Q_{100}	-	-	-	100	2542,164
Q_{200}	-	-	-	200	2924,798
Q_{500}	-	-	-	500	3430,613
Q_{1000}	-	-	-	1000	3813,247
Q_{10000}	-	-	-	10000	5084,329
Q_{20000}	-	-	-	20000	5466,963

Table 1. Streamflow analysis conducted by the new method

Method Name	**Q_{50}**	**Q_{100}**	**Q_{200}**	**Q_{500}**	**Q_{1000}**	**Q_{10000}**
Present study	2159	2542	2924	3430	3813	5084
F.Life(3P)	2152	2214	2272	2341	2390	2535
L.Loj(3P)	2187	2277	2367	2485	2574	2869
Burr	2152	2226	2298	2394	2468	2719
John.SU	2151	2218	2281	2360	2419	2605
Chi-Squre	2155	2218	2276	2346	2395	2541
Error	2171	2243	2310	2393	2452	2631
Lojistik	2180	2269	2357	2474	2562	2855
Gum max.	2282	2408	2533	2698	2822	3226
Log.Loj	2310	2453	2604	2816	2987	3635
Gam.(3P)	2172	2242	2306	2385	2441	2610
Ge.Gam.	2150	2271	2342	2430	2493	2686
Freched	2536	2770	3025	3397	3709	4964
Rayleigh	3762	4081	4378	4741	4999	5772

Table 2. Other methods and present study results for Q_T

The frequency analysis of the maximum streamflows belonging to Euphrates river:

$N=43$, $Q_{avg}=1,685.6$ m^3/s, $\sigma=230$, $C_s=-0.126$

GOF(Goodness-of-Fit) Test

a) Kolmogorov - Smirnov

1. Fatiqul Life (3P), 2. Log Logistic (3P), 3. Burr 4. Johnson SU 5. Chi Squared (2P).

b) Anderson-Darling

1.Burr, 2. Johnson SU, 3. Log Logistic (3P), 4.Error, 5. Log Logistic

c) Chi-Squared

1. Gumbel max, 2. Log Logistic, 3. Gamma (3P), 4. Gen. Gamma 5. Log. Logistic(3P)

In **Table 3**, the analysis of the total rainfall for the 79-year period between 1928 and 2006 has been given and a correlation has been empirically developed to predict the annual rainfall depth h_t according to the results of this methodology. This correlation is given in Equation 5.

Year	Daily max. rainfall	Sequential data	a_i	T(Time), N=43	$h_T=a_{min}.N_{amin}.LN(T)$
1980	22,1	34,2	0,162528	53	37,15717
1981	18,2	34,3	0,159235	54	37,3321
1982	25,1	34,3	0,155624	55	37,50383
1983	22,8	34,8	0,154379	56	37,67246
1984	20	34,9	0,15144	57	37,83811
1985	38,2	35	0,148616	58	38,00087
1986	29,7	35,7	0,148395	59	38,16086
1987	46,1	36	0,146544	60	38,31815
1988	18	37,2	0,148347	61	38,47285
1989	21,7	37,3	0,14577	62	38,62503
1990	29,7	38,1	0,145967	63	38,77477
1991	30,3	38,2	0,143518	64	38,92216
1992	35,7	38,5	0,141891	65	39,06726
1993	17,6	39,8	0,143933	66	39,21014
1994	61,6	40,3	0,143053	67	39,35088
1995	34,8	41,9	0,14603	68	39,48953
1996	33,5	42,8	0,146498	69	39,62616
1997	28	46,1	0,155013	70	39,76082
1998	20,1	46,2	0,152651	71	39,89357
1999	32	47,9	0,15556	72	40,02446
2000	33,5	48	0,153255	73	40,15355
2001	20,9	48,3	0,151648	74	40,28088
2002	27,2	49,9	0,154102	75	40,40651
2003	48	50,1	0,152217	76	40,53047
2004	33,1	58,2	0,174005	77	40,65281
2005	39,8	61,6	0,181271	78	40,77357
2006	27,7	80,4	0,232918	79	40,89279
h_{50}	-	-	-	50	36,61184
h_{100}	-	-	-	100	43,09887
h_{200}	-	-	-	200	49,58589
h_{500}	-	-	-	500	58,16127
h_{1000}	-	-	-	1000	64,6483
h_{10000}	-	-	-	10000	86,19773
h_{20000}	-	-	-	20000	92,68476

Table 3. Analysis of the total rainfall

The frequency analysis of maximum daily precipitation for Elazığ Province is as follows:

N=79, h_{avg}=31.56 mm, σ =11.45, C_s=1.348

Total annual precipitation for Elazığ Province could be given by the following equation:

h_t =127,79.$T^{-0,011}$.ln(T)……………………………………………………………………(5)

GOF(Goodness-of-Fit) Test

a)Kolmogorov- Smirnov

1.Beta, 2.Gamma (3P), 3. Fatiq. Life (3P) 4. Gen. Gamma(4P) 5. Gen. Gamma

b) Anderson-Darling

1.Burr(4P), 2. Burr, 3. Dagum, 4. Log Logistic, 5. P5 (3P)

c) Chi-Squared

1.Cauchy, 2. Weibul, 3.Gen. Gamma, 4. Logistic, 5. Gamma

The results obtained by the other existing methods and the results of this study are given in Table 4 together. As seen in Table 4, the distributions of Burr, Burr (4P), Dagum, Log. Logistic P5 (3P) and Cauchy that have been obtained from the GOF test have not yielded satisfactory results. The other distributions, namely Rayleigh (2P), Gamma, Weibul (3P), Kumaraswamy, Logistic, Nakagami and Erlang have produced the closest results to the new method. In **Figure 5**, the other methods that have produced the closest results to those obtained in this study have been compared with each other.

Method Name	h_{50}	h_{100}	h_{200}	h_{500}	h_{1000}	h_{10000}	h_{20000}
Present Study	36,6	43.1	49,5	58.1	64,6	86.2	92.6
Beta	57	62	66,7	72	76	89	93.7
Gamma(3P)	59	64	69	75	79	99	98.5
F.Life (3P)	59,6	65	70	77	82	99	104
Ge.Gam.4P	60	65	70,5	77	82,5	99,4	104
Gen.Gamma	58	62	66	72	76	88	92
Burr(4P)	61	68	76	89	99,5	144,5	161
Burr	62	70	79	93	105	158	178
Dagum	62	72	82	97	111	172	196
Log.Loj	63	72	83	99	114	179	206
P5(3P)	60	66	72	81	87	110	118
Cauchy	Not suitable						
Rayleigh	58	62	66	71	74	84	86.6
Gamma	59	64	68	75	79	92	96.5
Weibull(3P)	58	62	66.5	71	75	85	88
Kumaraswamy	58	62	66	71	74	84.8	87.6
Lojistik	56	60	65	71	75	89	94
Nakagami	61	65	70	75	78	89.5	92.5
Erlang	56	60	65	71	75	88	92

Table 4. Other methods and present study results for h_t

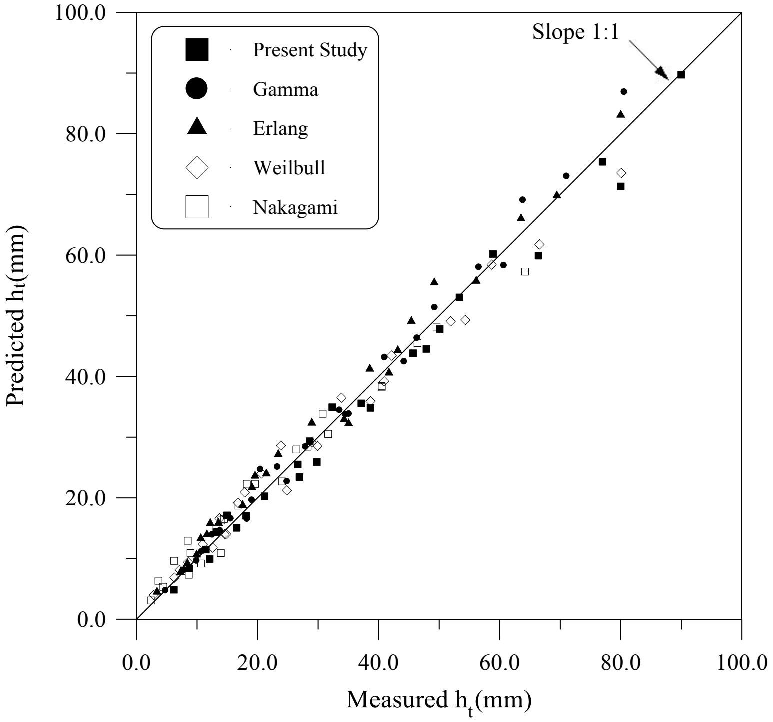

Figure 5; The calculated and measured values for precipitation**.**

The values obtained from this method have been compared with the calculated values using Eq. 5.

6. Conclusion

The goal of this study is to improve the understanding of peak flood discharge and extreme rainfall processes in river catchments. Nevertheless, continued hydrologic, hydraulic, and paleohydrologic research on catchments areas is needed that would contribute towards a broad range of hydrologic research projects and investigations. An improved understanding of basic hydrologic and hydraulic processes will improve the available methods for the assessment of peak flood and extreme rainfall phenomena. These related studies depend on accurate data and hydrologic methods. The improved hydraulic methods can be incorporated into numerical simulation models of surface-water systems and could be useful to improve the analyses of hydrologic processes. The results of this method are also applicable to other rivers. Moreover, empirical correlations predicting the annual rainfall depths in the gauged catchments have been developed.

In time related analyses, since the product $a_i.N_i$ remains approximately constant, the results of the distribution analyses obtained from this method and the GOF tests could be compared and thereby the most convenient results could be determined. Additionally, these results are more practical and reliable than the analyses methods such as MOM and Moment-L. If an observation is conducted for a long enough time and the a curves produce reasonable values, the Q_T and the h_t values of the catchments could be determined with the assistance of a curves. For example, the total rainfall for Elazig could be calculated by the following formula:

$h_t=127.79T^{-0,011}.\ln(T)$.

An extreme rainfall that leads to a flash flood can be approached by a variety of methods. Among others, such methodologies like meteorological analysis, hydrological modeling, hydraulic modeling and analysis, post event campaigns for data retrieving (flood marks, peak flow timing through intervals) can be used to provide additional information for reliable annual peak discharge estimations.

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