JOURNAL OF FLOOD ENGINEERING
Vol. 9 No. 1 (January-June, 2018)

PRECIPITATION AND DISCHARGE PATTERN ANALYSIS: A CASE STUDY OF BAGMATI RIVER BASIN, NEPAL

Yam Prasad Dhital[1], Rijan Bhakta Kayastha[1] and Saeid Eslamian[2]
[1]*Department of Environmental Science and Engineering, Kathmandu University, Dhulikhel*
[2]*Department of Water, Isfahan University of Technology, Isfahan, 8415683111, Iran*

ABSTRACT: Bagmati River Basin lies in central Nepal and the river originates from the north of Kathmandu at Shivapuri at an altitude of 2690 m inside the Mahabharat Range. Precipitation and discharge pattern analysis of Bagmati River Basin is carried out in this study. All data from 10 climatological stations and three discharge gauging stations are used to analyze the future rainfall trend and estimated peak values of flood in the Bagmati River. Weibull's, California and Hazen's formulae are applied for the rainfall plotting position in frequency analysis and future rainfalls in 2, 5, 10, 25, 50 and 100 return periods using log-scale were estimated. Among all of the climatological stations, Kakani station receives the highest rainfall amount 4345 mm with 100 years return period. Gumbel's Distribution, Log Pearson Type III Distribution and Log–Normal Distribution are used to calculate the peak flood value in 2, 5, 10, 25, 50, 100, 200 and 1000 years. The calculated peak flood value is found to be 18482 cumecs with the return period of 100 years at Pandheradobhan discharge station. Till to date the recorded peak discharge of the Bagmati River was 16000 cumecs on 21 July 1993 at the same station which can be regarded as a 100 years flood in the river. Mean peak flood value is computed as 15872 cumecs in Panderadobhan with compared to the mean highest annual rainfall 4258 mm in Kakani in 100 years return period. The slope of flood frequency curve was greater than those for rainfall frequency curve for the highest value stations. This could show the impact of catchment characteristics on the variability in outflows of the basin.

Keywords: Precipitation, Discharge, Bagmati River Basin, Frequency analysis, Distribution.

1. INTRODUCTION

Precipitation varies place to place due to altitudinal variation, monsoon path and topography. Chure and Mahabharat ranges receive more rainfall than Terai and Himalayan region receives less rainfall in comparison to the other belts of the country. Rainfall occurs due to southeast monsoon which lasts between the months of June to September. In winter season, precipitation is caused by the weather system originating in the Mediterranean region. In general, Nepal receives about 1500 mm rainfall in a year. About 70 to 90 % of the rainfall occurs during the monsoon months in Nepal and the rest of the month are almost dry (Nayava *et al.*, 2009). The 24-hour rainfall of 540 mm at Tistung on 20 July 1993 broke all the previous records in Nepal; hourly peak of the event was 70 mm (Marahatta and Bhusal, 2009). Eslamian and Feizi (2007) applied *L*-Moments for maximum monthly rainfall analysis for an arid region in Iran. The results were promising in comparison with the traditional methods.

Discharge in river increases from Pre-monsoon period to monsoon period and remains high up to post monsoon period. Altogether, there are four major basins in Nepal; Koshi, Narayani, Karnali and Mahakali River systems, however the Bagmati River basin is not included. The Karnali, the Narayani and the Koshi are major snow and glacier fed rivers in Nepal, besides the Mahakali which borders Nepal and India in the west. Mean peak discharge from Koshi, Narayani and Karnali river basin are 8324 cumecs (Chatara-Kothu), 9686 cumecs (Narayanghat) and 9201 cumecs (Chisapani), respectively based on the data published by the Department of Hydrology and Meteorology (DHM, 2008). All the river systems of Nepal are the tributaries to the Ganga draining ultimately drains to the Bay of Bengal. The major tributaries generally flow towards south or southeast direction (Sharma and Adhikari, 2006). The aim of this study is comparison of discharge with rainfall frequency trends for Bagmati River basin, Nepal.

2. STUDY AREA

The Bagmati River basin lies in central Nepal and covers an area of about 3750 sq. km (Fig. 1). It extends between $26^\circ 42'$ and $27^\circ 50'$ north latitude and $85^\circ 02'$ and $85^\circ 58'$ east longitude. The Bagmati watershed partially includes eight districts: Kathmandu, Lalitpur, Bhaktapur, Makwanpur, Kavre, Sindhuli, Rautahat, and Sarlahi. The Bagmati River begins from the north of Kathmandu at Shivapuri (Bagdwar) at an altitude of 2690 m and drains out of Nepal across the Indian State of Bihar to reach the Ganges.

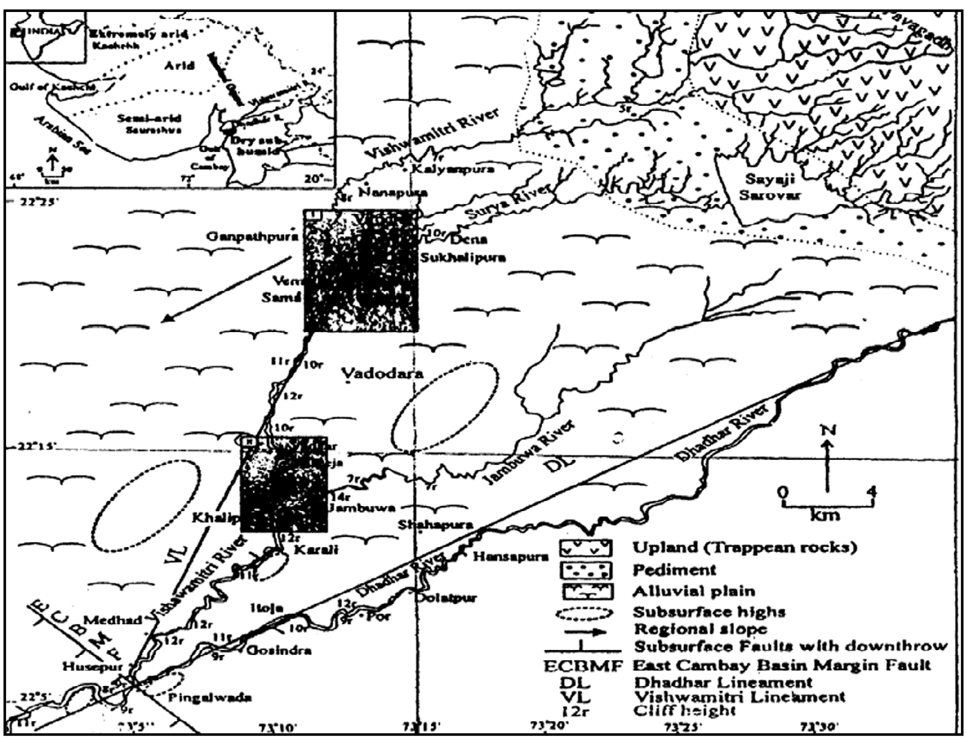

Figure 1: Location Map of Bagmati River Basin

Geologically, the Bagmati River basin can broadly be divided into four units: Terai, Siwaliks, Nawakot Complex and Kathmandu Complex. The Terai consists of Pleistocene to Recent Alluvium deposited by the rivers originating within the Himalayas or beyond. The Siwaliks consists of an alternation of mudstone, sandstone, and conglomerate at varying proportions and textures. The Nawakot Complex consists almost exclusively of low-grade metasediments. The Kathmandu Complex consists of low to high-grade metasediments. Climatically, the Bagmati River basin can be divided into three regions: tropical, warm temperate, and cool temperate. The tropical climate is characteristic of the Terai and Chure Ranges, the warm temperate climate of the lower hills of the Mahabharat Range, and the cool temperate climate of the higher hills of the Mahabharat Range and the midlands.

Department of Hydrology and Meteorology (DHM) has established twenty four rainfall gauging stations within and in the nearby of the catchment area and five discharge gauging stations on the Bagmati River basin. Among all of the rainfall stations, Daman and Manusmara are the highest and lowest altitude stations with elevations 2314 m and 100 m. The annual average and monsoon average rainfall of the catchment area are 1800 mm and 1500 mm, respectively (Bagmati Report, 2005). Sundarijal and Panderadobhan are the highest and lowest altitude discharge gauging stations with elevation 1600 m and 180 m, respectively. Mean peak discharge at Sundarijal and Panderadobhan are 13.8 and 4876 cumecs, respectively based on the data from 1963 to 2006.

3. METHODOLOGY

3.1 Rainfall Frequency Analysis

Rainfall data from 1980 to 2006 (DHM, 1982-2008) are used for the frequency analysis of all climatological stations in the Bagmati River basin. Hazen, California and Weibull's plotting position formulae are used to see the future rainfall estimate of each climatological station. Future rainfall values at 2, 5, 10, 25, 50 and 100 years return period are estimated using log domain. The return period is calculated by(Reddi, 2001):

Weibull's Method, $$T_r = \frac{(n+1)}{m} \tag{1}$$

California Method, $$T_r = \frac{n}{m} \tag{2}$$

Hazen's Method, $$T_r = \frac{2n}{(2m-1)} \tag{3}$$

Where,

T_r : Return period

n : No. of years,

m : Order,

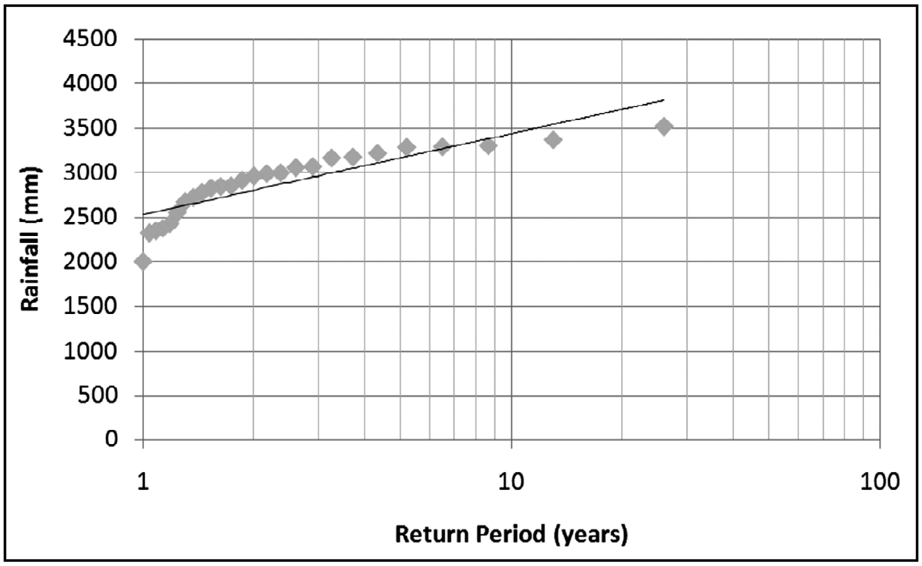

Figure 2: Rainfall Analysis of Kakani with California Method

For frequency analysis, the trend line is set between the annual rainfalls versus return period as shown in the rainfall analysis of Kakani with California method (Fig. 2).

3.2 Discharge Analysis

Discharge data of Gaurighat, Khokana and Panderadobhan (DHM, 2008) gauging stations in the Bagmati River basin are used in the present study to calculate the future peak flood value at 2, 5, 10, 25, 50, 100, 200 and 1000 years return period in the respective gauging stations. Sundarijal and Bhorleni gauging stations are not used due to less magnitude of discharge in Sundarijal and insufficient data in Bhorleni. In order to calculate the magnitudes of extreme floods corresponding to certain recurrence intervals, cumulative distribution function (CDF) is used which is expressed as (Chow et al., 1988):

$$Q_T = \overline{X} + K_T \times SD \tag{4}$$

where,

Q_T : Magnitude of peak flood discharge at T year

$\overline{X}$: Mean of flood discharges for the given years

$S.D.$: Standard deviation of flood discharges

K_T : Frequency factor that depends on the return period (T years) and probability distribution used in the analysis

In the above equation (5), for the calculation of frequency factor (K_T), three standard methods such as Gumbel Distribution, Log Pearson Type III Distribution and Log-Normal Distribution are used in this study.

3.2.1 Gumbel's Distribution

For Gumbel's extreme value distribution, the frequency factor is calculated by:

$$K_t = \frac{(Y_t - Y_n)}{S_n} \tag{5}$$

where,

Y_t : Reduced variate [Y_t = –ln {ln (T_r / (T_r – 1)}]

Y_n : Mean of the reduced variate

S_n : Standard deviation of the reduced variate

3.2.2 Log Pearson Type III Distribution

In case of Log Pearson Type III distribution, *T*-year peak flood discharge is obtained with the following steps:

(a) The flood series are logarithmically transformed with base 10, log(x)

(b) Coefficient of skewness (g) is calculated along with the mean and standard deviation of the transformed series:

$$g = \frac{n\sum[y_i - \bar{y}]^3}{(n-1)(n-2)s_y^{\,3}} \tag{6}$$

where,

n : No. of years,

y_i : Log(x)

$\bar{y}$: Mean

s_y : Standard deviation

(c) K_t, the frequency factor for this distribution, is a function of return period and the coefficient of skewness. Values of K_t for various return periods are available in the text books such as Applied Hydrology (Chow et al., 1988).

3.2.3 Log-Normal Distribution

It is to be noted that when the coefficient of skewness is zero, the log Pearson Type III distribution reduces to Log-normal distribution. Then, the value of peak discharges for the required return periods are calculated.

4. RESULTS AND DISCUSSIONS

4.1 Rainfall Frequency Analysis

The estimated values of rainfall in 2, 5, 10, 25, 50 and 100-year return periods by Weibull's, California and Hazen's methods are shown in Table 1. Highest rainfall value is obtained from California method and the least rainfall value is obtained from Hazen's method in all of the return periods for all climatological stations. Station no.1029 (Khumaltar), 1030 (Kathmandu Airport), 1039 (Panipokhari) are found as rainfall magnitudes 1500 mm to 2500 mm, station no. 905 (Daman), 1022 (Godavari), 1043 (Nagarkot), 1071 (Budhanilkhantha), 1118 (Manusmara) are found as rainfall magnitudes 2500 mm to 3500 mm and station no.1007 (Kakani), 1107 (Sindhulighadi) are found as rainfall magnitudes 3500 mm to 4500 mm. Among three methods, Hazen's method is more appropriate for the calculation of maximum rainfall at any desired recurrence intervals because it gives two times greater value of recurrence interval than that obtained by using Weibull's or California formula and the estimated rainfall value from Hazen method is quite closer to the observed value of each station.

Table 1
Calculated Rainfall for Different Return Periods with Weibull's, California and Hazen's Methods

Station no.	*Return periods*	*Rainfall (mm)*		
		Weibull	*California*	*Hazen*
905 (Daman)	2	1639	1657	1636
	5	2058	2076	1995
	10	2375	2393	2266
	25	2794	2812	2624
	50	3111	3129	2895
	100	3428	3446	3167
1007 (Kakani)	2	2786	2801	2785
	5	3147	3162	3092
	10	3421	3436	3325
	25	3783	3798	3633
	50	4056	4071	3866
	100	4330	4345	4098
1022 (Godavari)	2	1784	1797	1782
	5	2076	2089	2034
	10	2296	2309	2225
	25	2588	2600	2477
	50	2808	2821	2667
	100	3028	3041	2858
1029 (Khumaltar)	2	1145	1152	1143
	5	1343	1350	1313
	10	1493	1500	1441
	25	1691	1698	1610
	50	1841	1848	1738
	100	1990	1998	1866

Table Contd…

Station no.	*Return periods*	*Rainfall (mm)*		
		Weibull	*California*	*Hazen*
1030 (Kathmandu Airport)	2	1411	1419	1410
	5	1634	1642	1600
	10	1802	1810	1744
	25	2025	2033	1934
	50	2193	2201	2078
	100	2362	2370	2222
1039 (Panipokhari)	2	1540	1555	1539
	5	1780	1795	1738
	10	1962	1977	1889
	25	2202	2217	2088
	50	2384	2398	2239
	100	2565	2580	2390
1043 (Nagarkot)	2	1749	1764	1748
	5	2091	2106	2037
	10	2350	2365	2256
	25	2692	2707	2545
	50	2951	2966	2763
	100	3210	3225	2982
1071 (Budhanil Khantha)	2	1984	2000	1981
	5	2229	2244	2182
	10	2414	2429	2334
	25	2658	2673	2535
	50	2843	2858	2687
	100	3027	3043	2839
1107 (Sindhulighadi)	2	2628	2661	2622
	5	3014	3048	2928
	10	3307	3340	3159
	25	3694	3727	3466
	50	3987	4020	3697
	100	4280	4313	3929
1118 (Manusmara)	2	1421	1447	1417
	5	1880	1906	1802
	10	2226	2252	2094
	25	2684	2710	2480
	50	3031	3057	2771
	100	3377	3403	3063

4.2 Discharge Analysis

The calculated value of peak flood in 2, 5, 10, 25, 50, 100, 200 and 1000-year return periods by Gumbel, Log Pearson and Log Normal distribution are shown on Table 2 and frequency curves are plotted and also shown on Figures 3, 4 and 5. The highest value at Gaurighat gauging station (station no. 530) was 108 cumecs on 23 July 2002 which belongs to Gumbel's 25 years flood, Log Pearson 100 years flood and Log Normal below 50 years flood. The highest value at Khokana gauging station (station no. 550.05) was 942 cumecs on 22 July 2002, following 938 cumecs on 20 July 1993 which belongs to approximately 25 years flood for Log Pearson and below 25 years for both Gumbel and Log Normal Distributions. Highest value at Panderadobhan Gauging station (Station no. 589) was 16000 cumecs on 21 July 1993 which belongs to approximately 100 years flood for Gumbel, below 100 years for Log Pearson and below 1000 years for Log Normal Distribution. The highest peak stage at Panderadobhan was found as 7.10 m in 4th July 2009, the corresponding maximum instantaneous discharge was found as 3380 m^3/s, which is less than two year's calculated values for all of the three distributions. Gumbel's distribution is better than the other distributions because the calculated values are more reasonable and significant in comparison with the observed value.

Frequency analysis of higher rainfall stations Daman (Station no. 905), Sindhuligadhi (Station no.1107) and Kakani (Station no.1007) with highest discharge station Panderadobhan (Station no.589) is shown in Figure 6. Mean estimated rainfall values in 2, 5, 10, 25, 50 and 100 years are compared with the mean discharge values of respective return periods. The result seems that when the annual rainfall occurs 3347 mm in Daman, 4174 mm in Sindhulighadhi, 4258 mm in Kakani, the corresponding discharge will be 15872 cumecs in Panderadobhan in 100 years return period.

Table 2
Discharges in Cumecs with Gumbel, Log Pearson Type 3 and Log Normal Distributions

Station no.	*Return periods*	*Discharge in cumecs*		
		Gumbel	*Log Pearson Type 3*	*Log Normal*
530 (Gaurighat)	2	52.650	53.840	52.190
	5	74.510	71.830	71.460
	10	88.990	82.160	84.210
	25	107.28	93.660	100.31
	50	120.85	101.29	112.32
	100	134.31	108.25	124.32
	200	147.73	114.61	136.47
	1000	178.82	127.80	165.33

Table Contd…

Station no.	*Return periods*	*Discharge in cumecs*		
		Gumbel	*Log Pearson Type 3*	*Log Normal*
550.05 (Khokana)	2	412.06	401.58	386.53
	5	685.33	633.90	629.15
	10	866.25	787.96	811.55
	25	1094.8	978.88	1064.5
	50	1264.4	1116.9	1268.5
	100	1432.8	1250.3	1484.7
	200	1600.5	1381.1	1715.8
	1000	1989.0	1680.4	2310.0
589 (Panderadobhan)	2	4386.3	3913.5	4283.7
	5	7635.6	6018.1	6332.5
	10	9786.8	7981.0	7767.5
	25	12505	11289	9656.9
	50	14521	14498	11115
	100	16523	18482	12611
	200	18517	23441	14163
	1000	23137	40146	17980

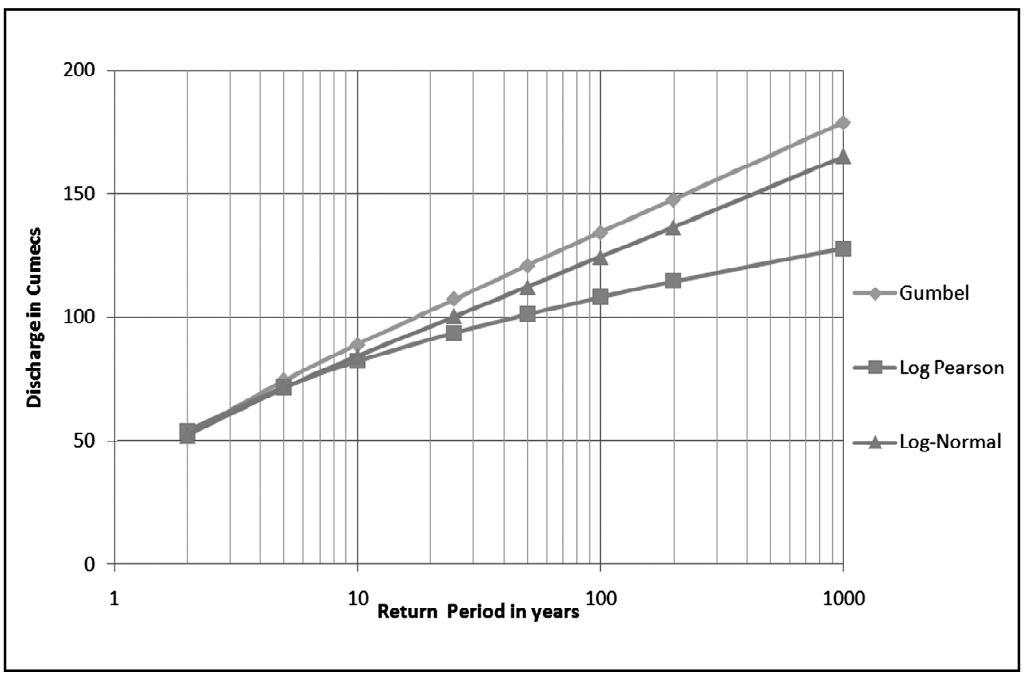

Figure 3: Frequency Analysis of Gaurighat Station

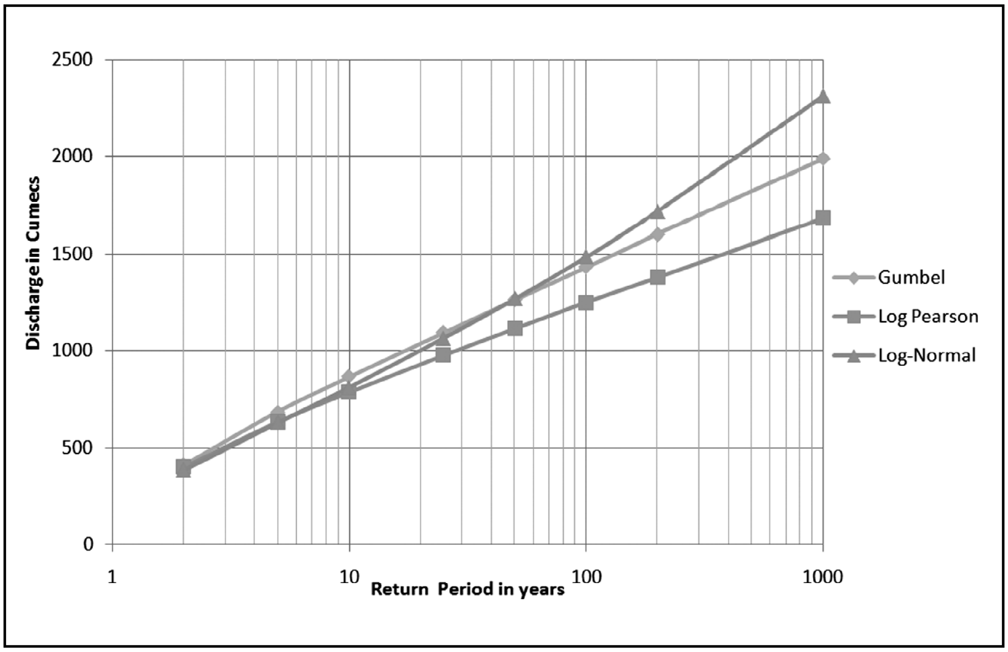

Figure 4: Frequency Analysis of Khokana Station

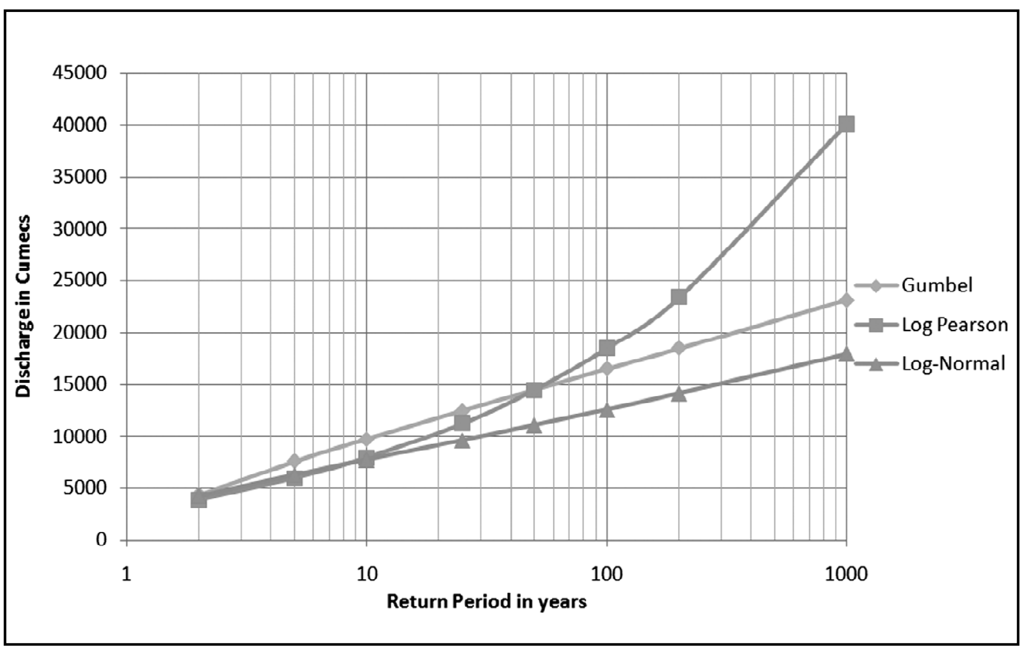

Figure 5: Frequency Analysis of Pandheradobhan Station

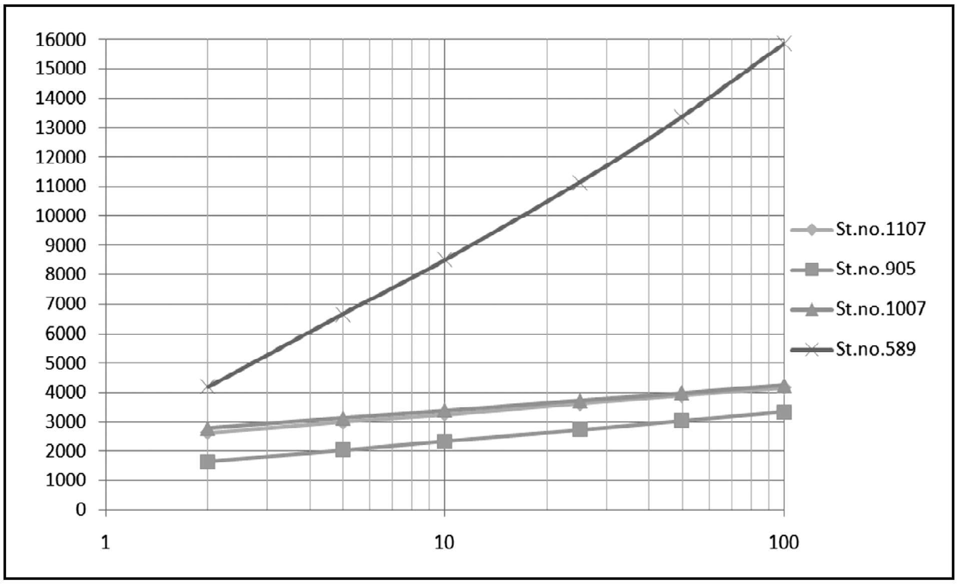

Figure 6: Frequency Analysis of Higher Rainfall Stations with the Highest Discharge Station

5. CONCLUSIONS

Among all of the climatological stations in the Bagmati river basin, Kakani station receives the highest rainfall amount 4345 mm and Khumaltar station receives the least rainfall amount 1866 mm with 100 years return period. Khumaltar and Kathmandu Airport are found to be the less rainfall area while Kakani and Sindhuligadhi are found to be the high rainfall area in comparison.

The calculated highest peak flood values in Gaurighat, Khokana and Panderadobhan discharge stations were found as 124 cumecs, 1484 cumecs and 18482 cumecs, respectively in 100 years return period. The maximum instantaneous discharge was found as 3380 m^3/s in 4^{th} July 2009 which is less than the calculated value of 2 year return period. Mean peak flood value in Panderadobhan is found as 15872 cumecs with the comparison of mean highest annual rainfall 3347 mm in Daman, 4174 mm in Sindhulighadhi and 4258 mm in Kakani in 100 years return period. The slope of flood frequency curve was greater than those for rainfall frequency curve for the stations with the highest amount. This indicates the impact of catchment characteristics on the outflow variability of the basin.

References

[1] Bagmati Report, 2005, "Preparation of Water Induced Hazard Maps of the Bagmati River Basin", **1** (Main Report), 2005, Department of Water Induced Disaster Prevention, Kathmandu, Nepal.

[2] Chow, V.T., Maidment, D.R. and Mays, L.W., 1988. *Applied Hydrology*, McGraw-Hill Book Company, Singapore.

[3] DHM, 1982-2007, *Climatological Records of Nepal*, 1976-2005, Department of Hydrology and Meteorology, Kathmandu, Nepal.

[4] DHM, 2008, *Climatological and Agrometeorolical Records of Nepal*, 2006, Department of Hydrology and Meteorology, Kathmandu, Nepal.

[5] DHM, 2008, *Stream Flow Summary* (1962-2006), Department of Hydrology and Meteorology, Kathmandu, Nepal.

[6] Eslamian, S.S. and Feizi, H., 2007, "Maximum Monthly Rainfall Analysis using L-Moments for an Arid Region in Isfahan Province", Iran, *J. of Applied Meteorology and Climatology*, **46:** 494-503.

[7] Marahatta, S. and Bhusal, J.K., 2009, "Relating Hydrological Extremes with Area-A Case on Extreme Floods in South Central Nepal", *Journal of Hydrology and Meteorology*, **6:** 44-48, Society of Hydrologists and Meteorologists (SOHAM), Nepal.

[8] Nayava, J.L., Singh, R. and Bhatta, M.R., 2009, "Impact of Climate, Climate Change and Modern Technology on Wheat Production in Nepal: A Case Study at Bhairhawa", *Journal of Hydrology and Meteorology*, **6:** 1-14, Society of Hydrologists and Meteorologists (SOHAM) - Nepal.

[9] Reddi, P. J., 2001, *A Text Book of Hydrology*, Laxmi Publications Pvt Ltd, New Delhi, India.

[10] Sharma, K.P. and Adhikari, N.R., 2006, *Hydrological Estimation in Nepal*, Department of Hydrology and Meteorology, Kathmandu, Nepal.