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Flood Frequency Analysis of Ghiladhari River, Assam using Gumbel's Extreme Value Distribution Method

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Abstract

The purpose of this research entails performing flood frequency analyses of the Ghiladhari Basin through using Gumbel's extreme value distribution, which is a probability distribution often used model flow rate. Estimating peak flood discharge given a particular return is a requirement for planning, designing, and managing hydraulic infrastructure such as spillways, crossings, bridges, dams, artificial or natural barrages and so on. The approach utilized to simulate the yearly peak flow of the lower Ghiladhari Basin from 1976 to 2020 was obtained from the Brahmaputra Flood Control Board and taken into account for the flood frequency assessment. The regression analysis equation R2 yields a value of 0.867, indicating that Gumbel's distribution is adequate for estimating flow of the river. From the Gumbel's distribution return period T of 200 years, 100 years, 75 years and 50 years; The expected estimated discharge obtained are 194.35 m^3/sec, 176.58 m^3/sec, 169.19m^3/sec and 158.76 m^3/sec respectively. These assessments are useful in order to build major hydraulic structures for strategic planning and management purpose and disaster mitigation in the area.

Keywords: peak flood, Flood frequency analysis, Gumbel's distribution, Ghiladhari Basin

Introduction

Floods are the most frequent natural hazard or destructive event of nature worldwide

(Sathe et al., 2012) that is commonly accompanied with gully erosion, bank line shifting, sand deposition, and riverbank siltation. A flood is a large overflow of water from a stream that breaches its river bank due to heavy precipitation or due to huge amount of water discharged from the upper catchment areas (Chakravartty, 2018). Over the period of time, the human life, assets, and natural resources are all negatively impacted by this aggressive geomorphological agent such as devastating infrastructures, drowning agricultural fields and even countless inhabitants are gone homeless (Mujere, 2011). Floods are also considered as the major natural disaster that responsible for the highest proportion of financial loss compared to other events (Baskar and Baskar, 2009). As a result, it is essential to investigate and analyze flood to protect the region with the measures like structural or non-structural (Ward, 1978).

To know and understand the nature, frequency, and magnitude of the high level water discharge of any river, flood frequency analysis (FFA) is considered one of the most important statistical techniques used in the field of fluvial geomorphology (Kumar, 2019 ; Gogoi and Patnaik, 2023).

Flood estimation is a crucial component of hydrological planning and management for slot management and protection measures including irrigation hydropower and projects to control flooding (Sonowal and Thakuriah, 2019). One of the most common methods used to relate the magnitude of extreme river flow phenomenon to their frequency of occurrence with the help of probability distribution functions i.e. flood frequency analysis (Moges and Taye, 2019). Flood frequency analysis approaches were previously demonstrated to correlate the intensity of flooding with associated occurrence rate (Hosking and Wallis, 1997).

Using recorded yearly peak flow discharge data, flood frequency assessment methods are employed to identify statistical estimates such as mean, standard deviation, skewness, and recurrence interval. The frequency distribution functions of the recurrence interval or exceedance probability is also obtained using the same data, and this information is again utilized to construct a potential probability statement for future flows of varying magnitude. Due to the shortage of suitable data, O'Connell (1868) proposed to establish the correlation with both discharge and area as parabolic using a value of 0.5 for exponent.Fuller (1914) determined by calculating flood events of varying returns by employing probability distributions in the flood estimation technique and evaluating a long track record of daily outflow and peak discharge at an exponent of 0.8. Using a logarithmic probability graph and a three-parameter distribution, Hazel (1921) examined the tendency of the coefficient of skewness to increase in value as the amount of terms in the series increased. To illustrate flood frequency analysis, Foster proposed the Log Pearson type ll distribution in 1924.Gumbel (1941) introduced the extreme value type l distribution of flood frequency analysis and used the extreme value concept. The opportunity of potential high flood occurrences can be predicted by correlating the size of extreme events with associated frequency of occurrence using specific probability distribution function (Chow et. al, 1988). The utmost type of occurrences can be estimated using Gumbel's extreme value technique. According to hydrologists, it is challenging to estimate efflux accurately with only a small amount of significant overflow, rainfall, and waterway stage records.

Study area

The Ghiladhari River originated from eastern Himalayan ranges of Aka hills of Arunachal Pradesh in East Kameng district of Arunachal Pradesh. The basin extends from 26^0 40’ N to $25^0$57’ N latitude and from $92^0$55’E longitude to $93^0$10’ longitude with a basin area of 458 sq.km out of which 407 sq.km area falls in plains of Biswanath and Sonitpur district of Assam and therest in hills of Arunachal Pradesh (Figure 1). A section of the sub-basin area is occupied by the Papam reserve forest, which is a dense mixed vegetation of evergreen and semi-deciduous forests. The climate is subtropical, with high relative humidity, moderate temperatures, and significant rainfall during the summer season, which triggers flooding. The river travels throughout the Himalayan siwalik zone as well as the Brahmaputra alluvial plains. It is a meandering river in the alluvial plain that switches course from the earlier Mara Ghiladhari route to the current course. Despite the small size of the river, a destructive flood occurs during in the monsoon season. This kind of flood characteristics draws attention to the significance of flood frequency investigations in the Ghiladhari Basin.

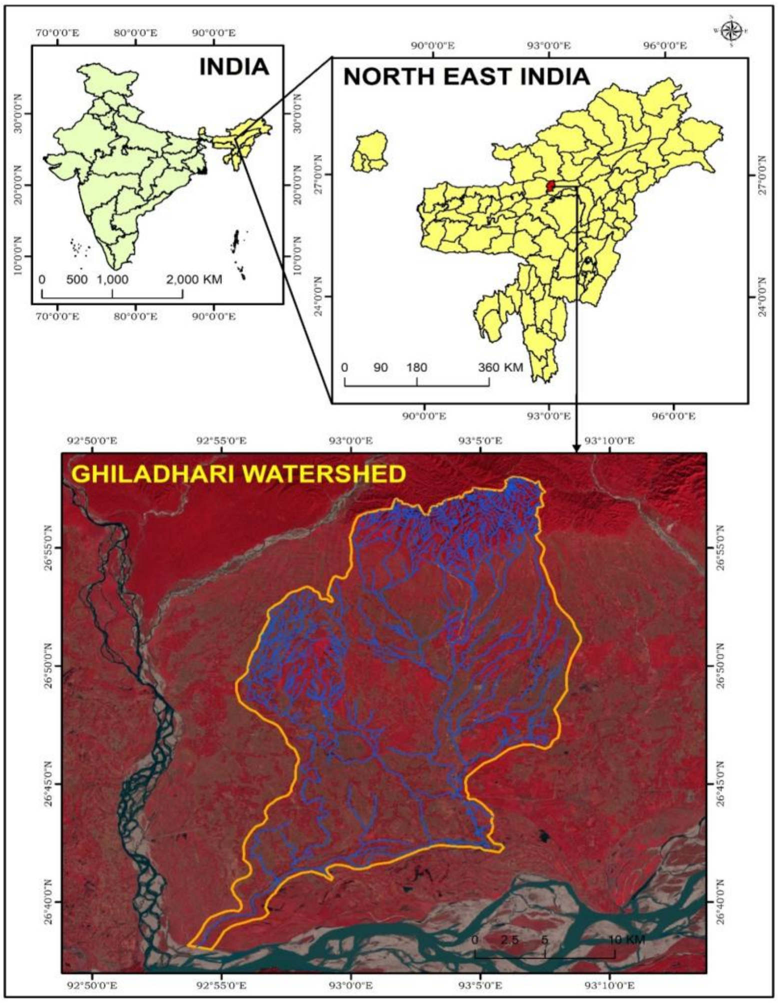

Figure 1: Location Map of the study area

Gumbel proposed the extreme value distribution in 1941, which has since become a commonly employed probability distribution model for extreme values in hydrological and atmospheric investigations. It aids in the forecasting peak flood levels, the amount of precipitation, the maximum sustained winds speed, etc. Gumbel asserts that a flood is the heaviest of the 365 regular flows as well as the yearly sequence of flood flows is a recurrence of the highest values of discharge. Gumbel additionally stated in his hypothesis of extreme events that the chance of an incident occurring is equals or exceeds than a value of X_o. To distinguish the designed inundation, the parameter known as recurrence interval 'T' is typically applied. The equation for plotting position is,

$$P = m/N + 1 \quad (1)$$

Where,
m= order number of the events
N= total number of events in the data

The recurrence interval T also calculated as

$$T = 1/P \quad (2)$$

The Gumbel's equation is

$$X_T = \overline{X} + K\,\sigma_{n-1} \quad (3)$$

Where,
$\overline{X}$= mean of sample size
σ_{n-1}= standard deviation of sample size of,

$$N = \sqrt{\sum}\,(X\text{-}X^2)/N\text{-}1 \quad (4)$$

K= frequency factor

Again, the frequency factor K is calculated as,

$$K = Y_T - \overline{Y_n}/\,S_n \quad (5)$$

In which,
Y_T = reduced variant; a function of T and is given by,

$$Y_T = -[\ln.\ln\,(T/\,T\text{-}1)] \quad (6)$$

Y_T =-[0.834 + 2.30 log log (T/ T-1)]
$\overline{Y_n}$= reduced mean; a function of sample size N and is given in table 1
S_n= reduced standard deviation; a function of sample size N and is given in table 2

These equations are used in order to estimate the flood magnitude to a given return period based on total annual flood series.That total annual discharge data of Ghiladhari Basin from 1976 to 2020 were collected from Brahmaputra Flood Control Board Jamuguri Branch and considered for flood frequency analysis using the Gumbel's extreme value distribution. There are various procedure were used to find out the flood frequency and the recurrence interval periods. Based on a total 45-year annual flood series of the Ghiladhari River, these equations are used to determine the flood magnitude corresponding to a given return.The estimated flood-frequency connection will be a straight line if drawn on extreme-value probabilistic graph paper with numeric ordinate.

Table 1: Reduced mean$\bar{Y}_n$ in Gumbel's Extreme Value Distribution

N	0	1	2	3	4	5	6	7	8	9
40	0.5436	0.5442	0.5448	0.5453	0.54458	0.5463	0.5468	0.5473	0.5477	0.5481

Table 2: Reduced mean S_n in Gumbel's Extreme Value Distribution

N	0	1	2	3	4	5	6	7	8	9
40	1.1413	1.1436	1.1458	1.148	1.1499	1.1519	1.1538	1.1557	1.1574	1.159

Table 3: Computation Table of Gumbel's Extreme Value Distribution Method

Year	Discharge (in cumec)	Rearranged	*M*	*P = M/N+1*	*T = 1/P*	*T/T-1*	*log (t/t-1)*	*log (t/t-1)*	Y_T	*K*	X_T
1976	57.63	172.83	1	0.0213	47.0000	1.0217	0.0093	-2.0297	3.8394	2.8589	159.1367
1977	21.82	165.08	2	0.0426	23.5000	1.0444	0.0189	-1.7239	3.1353	2.2476	141.1352
1978	34.52	152.13	3	0.0638	15.6667	1.0682	0.0286	-1.5430	2.7188	1.8860	130.4847
1979	57.04	120.26	4	0.0851	11.7500	1.0930	0.0386	-1.4131	2.4197	1.6264	122.8381
1980	56.21	89.33	5	0.1064	9.4000	1.1190	0.0488	-1.3111	2.1850	1.4226	116.8374
1981	80.61	87.89	6	0.1277	7.8333	1.1463	0.0593	-1.2268	1.9909	1.2541	111.8741
1982	46.48	85.09	7	0.1489	6.7143	1.1750	0.0700	-1.1547	1.8247	1.1098	107.6253
1983	81.36	81.36	8	0.1702	5.8750	1.2051	0.0810	-1.0913	1.6789	0.9832	103.8968
1984	70.33	80.61	9	0.1915	5.2222	1.2368	0.0923	-1.0347	1.5485	0.8701	100.5643
1985	54.64	80.05	10	0.2128	4.7000	1.2703	0.1039	-0.9834	1.4303	0.7675	97.5425
1986	41.47	79.57	11	0.2340	4.2727	1.3056	0.1158	-0.9363	1.3219	0.6733	94.7702
1987	56.03	78.75	12	0.2553	3.9167	1.3429	0.1280	-0.8927	1.2215	0.5861	92.2022
1988	74.18	78.37	13	0.2766	3.6154	1.3824	0.1406	-0.8520	1.1277	0.5047	89.8040
1989	56.17	78.21	14	0.2979	3.3571	1.4242	0.1536	-0.8137	1.0395	0.4281	87.5492
1990	152.1	76.89	15	0.3191	3.1333	1.4688	0.1669	-0.7774	0.9560	0.3557	85.4160
1991	165.1	76.22	16	0.3404	2.9375	1.5161	0.1807	-0.7430	0.8767	0.2868	83.3871
1992	120.3	75.64	17	0.3617	2.7647	1.5667	0.1950	-0.7100	0.8008	0.2210	81.4482
1993	172.8	75.06	18	0.3830	2.6111	1.6207	0.2097	-0.6784	0.7280	0.1578	79.5867
1994	45.76	74.64	19	0.4043	2.4737	1.6786	0.2249	-0.6479	0.6579	0.0969	77.7929
1995	87.89	74.18	20	0.4255	2.3500	1.7407	0.2407	-0.6185	0.5900	0.0380	76.0581
1996	89.33	73.65	21	0.4468	2.2381	1.8077	0.2571	-0.5899	0.5242	-0.0192	74.3742
1997	79.57	70.43	22	0.4681	2.1364	1.8800	0.2742	-0.5620	0.4600	-0.0749	72.7340

1998	78.21	70.33	23	0.4894	2.0435	1.9583	0.2919	-0.5348	0.3974	-0.1293	71.1319
1999	80.05	65.65	24	0.5106	1.9583	2.0435	0.3104	-0.5081	0.3360	-0.1826	69.5621
2000	65.13	65.13	25	0.5319	1.8800	2.1364	0.3297	-0.4819	0.2756	-0.2350	68.0193
2001	75.06	63.01	26	0.5532	1.8077	2.2381	0.3499	-0.4561	0.2161	-0.2866	66.4985
2002	78.75	62.77	27	0.5745	1.7407	2.3500	0.3711	-0.4305	0.1573	-0.3377	64.9952
2003	70.43	62.44	28	0.5957	1.6786	2.4737	0.3933	-0.4052	0.0990	-0.3883	63.5046
2004	62.77	61.34	29	0.6170	1.6207	2.6111	0.4168	-0.3800	0.0411	-0.4386	62.0222
2005	59.43	60.04	30	0.6383	1.5667	2.7647	0.4416	-0.3549	-0.0168	-0.4888	60.5431
2006	76.89	59.43	31	0.6596	1.5161	2.9375	0.4680	-0.3298	-0.0747	-0.5391	59.0627
2007	73.65	59.11	32	0.6809	1.4688	3.1333	0.4960	-0.3045	-0.1329	-0.5896	57.5754
2008	61.34	57.63	33	0.7021	1.4242	3.3571	0.5260	-0.2790	-0.1915	-0.6405	56.0758
2009	59.11	57.04	34	0.7234	1.3824	3.6154	0.5582	-0.2532	-0.2509	-0.6921	54.5573
2010	62.44	56.21	35	0.7447	1.3429	3.9167	0.5929	-0.2270	-0.3113	-0.7445	53.0125
2011	78.37	56.17	36	0.7660	1.3056	4.2727	0.6307	-0.2002	-0.3731	-0.7982	51.4329
2012	65.65	56.03	37	0.7872	1.2703	4.7000	0.6721	-0.1726	-0.4367	-0.8534	49.8076
2013	55.52	55.52	38	0.8085	1.2368	5.2222	0.7179	-0.1440	-0.5025	-0.9105	48.1237
2014	63.01	54.64	39	0.8298	1.2051	5.8750	0.7690	-0.1141	-0.5714	-0.9703	46.3638
2015	85.09	52.04	40	0.8511	1.1750	6.7143	0.8270	-0.0825	-0.6441	-1.0334	44.5049
2016	52.04	46.48	41	0.8723	1.1463	7.8334	0.8939	-0.0487	-0.7219	-1.1010	42.5147
2017	75.64	45.76	42	0.8936	1.1190	9.4000	0.9731	-0.0118	-0.8068	-1.1747	40.3448
2018	60.04	41.47	43	0.9149	1.0930	11.7500	1.0700	0.0294	-0.9017	-1.2571	37.9176
2019	74.64	34.52	44	0.9362	1.0682	15.6667	1.1950	0.0774	-1.0122	-1.3529	35.0941
2020	76.22	21.82	45	0.9574	1.0444	23.5000	1.3711	0.1371	-1.1496	-1.4723	31.5795

Source: Brahmaputra Flood control Board and computed by the researcher

Gumbel's frequency distribution approach has been employed to perform the inundation data analysis. From 1976 through 2020, the total yearly flow was evaluated in descending order *(X)* and designated with a serial numbers ranging from 1 to 45. The effluent amount was utilized to determine the ranking *(M).* The maximum discharge value, 172.83 m3/s, was designated the very first (1) rank, and the smallest flow value, 21.82 m3/s, was designated the lowest rank (45). The return period (*T*) was estimated using equation (eq. 2), and (X_T) was determined by utilizing equation (eq.3). The mean (*X*) and standard deviation (*σ-1*) of the total yearly outflow are computed to conclude the X_T.As per the formula (5), the 'K' value of the study was determined.The variant Y_T is determined.S_n and Y_n are fixed values obtained from the Gumbel's distribution table (table 1 & 2) in the *'K'* value calculation.The variant 'Y_T' value was calculated by employing the equation (eq. 6) by using specified return period '*T*'the calculated data was then used to estimate the flood frequency for this research area by using the formula

$$X_T = \bar{X} + K\, \sigma_{n-1}$$

Results and discussions:

The flood frequency analysis was performed utilizing annual flow data recorded from the Ghiladhari River at the Biswanath Ghat road gauzing site from 1976 to 2020.The maximum flood discharge of 172.8 m^3/sec was recorded in 1993. The second and third largest flood discharge were recorded 165.08 and 152.13 in the year of 1991 and 1990 respectively.While lowest flood flow 21.82 m^3/sec was recorded 1977. The 45 years mean flood record is 74.94 m^3/sec. The estimated standard deviation is 29.45, as well as the trend line equation (R^2) is 0.867. According to the linear regression equation, the pattern is compact and acceptable for forecasting probable floods in the catchment.The estimated flood discharge of coming 200 years, 100 years, 50 years and 10 years are 194.35 m^3/sec, 176.58 m^3/sec, 158.76 m^3/sec and 116.61 m^3/sec respectively.A semi-logarithmic paper diagram displaying each of the measured and projected maximum discharge data for the Ghiladhari River is displayed in Figure 4 and 5.

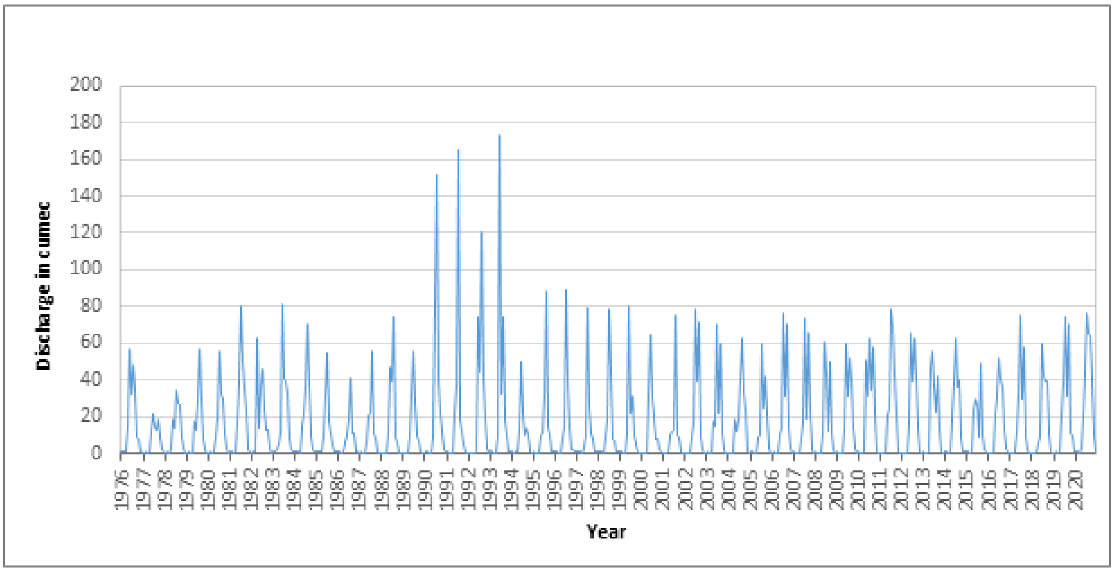

Figure 2: Annual pattern of average water discharge in Ghiladhari River at N.H. 52 crossing gauge-discharge-site during 1967-2020

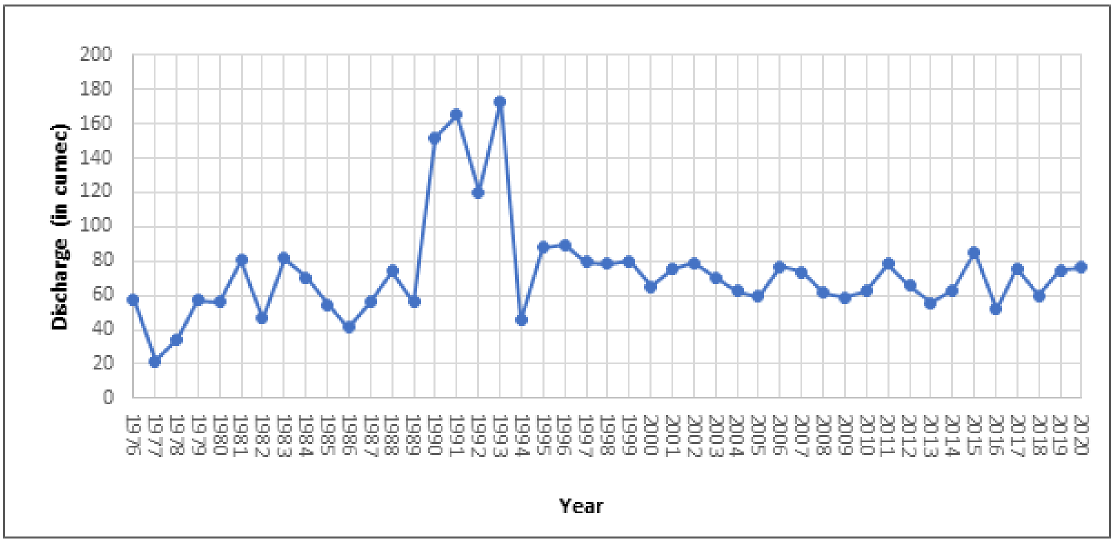

Figure 3: Trend of Annual Peak Discharge in Ghiladhari River (1976-2020)

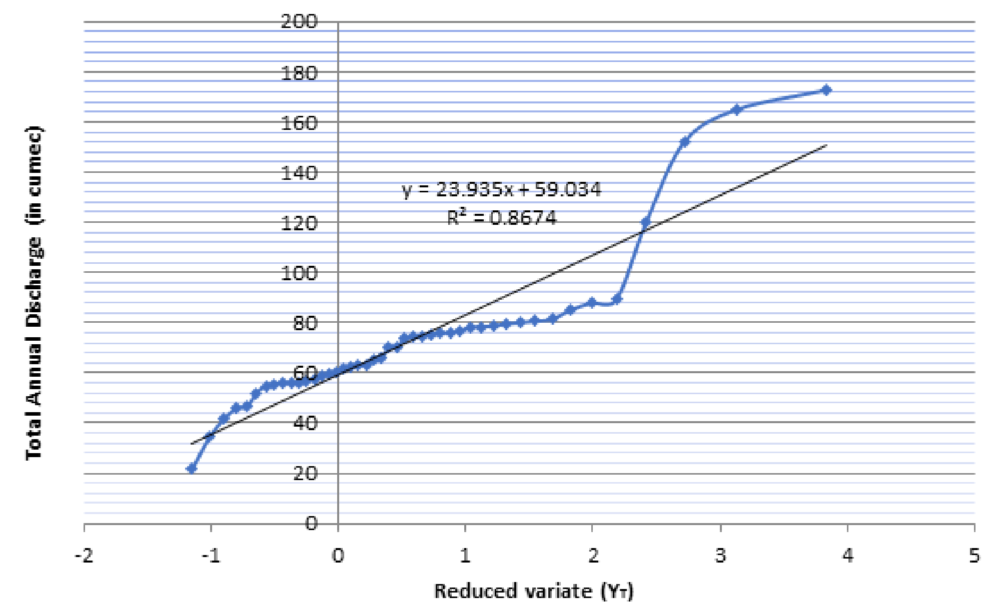

Figure 4: Plot of Reduced Variant v/s Total Annual Discharge for Ghiladhari River

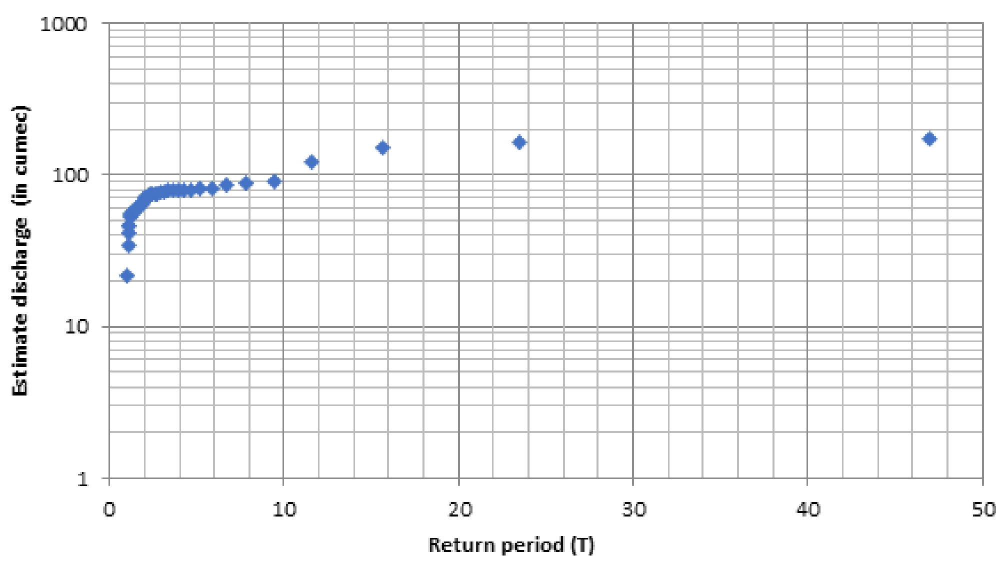

Figure 5: Flood Frequency Analysis by Gumbel's Extreme Value Distribution Method

Table 3: Estimation of Peak Discharge using Gumbel's Extreme Value Distribution

Return Period (T) (Years)	Peak Discharge *(YT)* (in cumec)	Frequency Factor (K)	Estimated flood *(XT)* (in cumec)
2	0.366512921	-0.156078722	68.54152472
5	1.499939987	0.827884353	97.4643287
10	2.250367327	1.479353527	116.6137416
15	2.673752092	1.846906929	127.4176785
25	3.198534261	2.302486554	140.8090755
50	3.901938658	2.913133656	158.7585565
75	4.310784111	3.268065032	169.1914791
100	4.600149227	3.519271835	176.5755012
200	5.295812143	4.123198318	194.3274349

Source: computed by the researcher

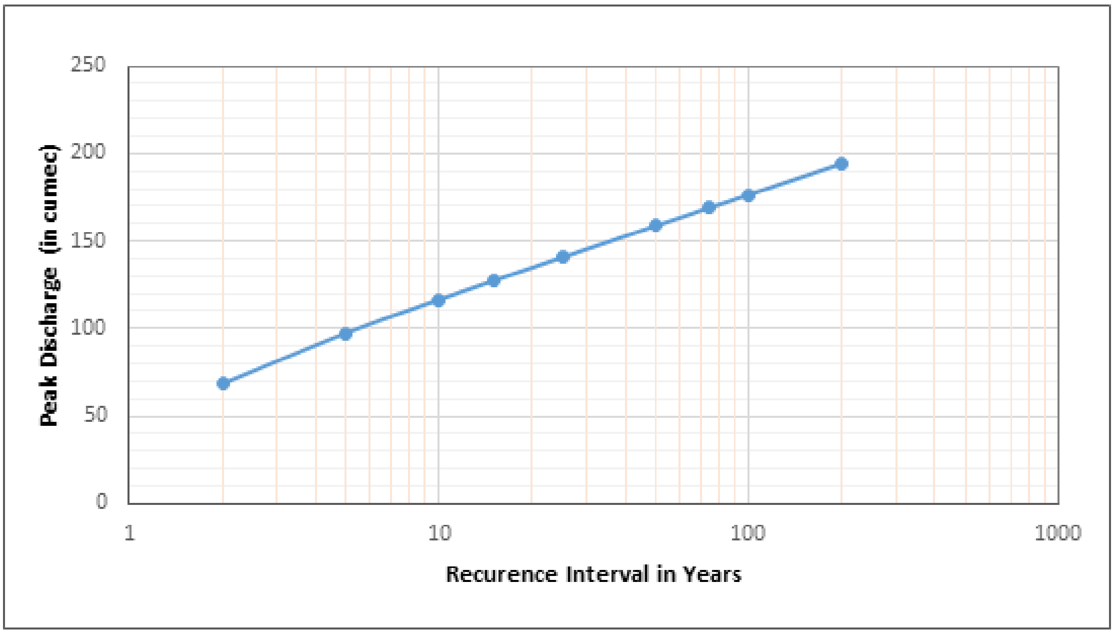

Figure 6: Estimation of flow magnitudes in different return periods using Gumbel's Extreme Value Distribution for the Ghiladhari River (1967-2020)

The flood frequency discharge increases in the downstream part of the river as many small streams and tributaries contribute water to the discharge of the river. It has been observed in the result that the River Basin experience flood each and every year and the Flood Frequency Analyse computed using Gumbel's extreme value distribution method shows an increasing movement in the peak flood for the return period 2, 5, 10, 25, 50, 100 and 200 years.

Conclusion

According to the flood data of the last 45 years shows the maximum occurrence of flood was recorded in the years of 1990 to 1993 and minimum in the year of 1977-78 in the Ghiladhari Basin.The computed and observed records are found to be well fitted to Gumbel's Extreme Value Distribution Function. Therefore, the Gumbel's extreme value distribution method has the necessary reliability for extrapolating Ghiladhari River flow estimation.These attributes that are mentioned above indicates that the estimation of flood nearly accurate and further can be utilize in designing of significant Hydraulic Structure, Bridges and Reaches, Concrete Gravity Dam, Weir, Barrages, Guide bank, irrigation and planning purpose and conservation of part of Kaziranga National Park and Pabhoi Reserve Forest. However the extreme value model will give reasonable estimation of flood discharge for any desire return period without any instrumentation, expensive and time consuming field work. That also help to adopt emergency evacuation in advance during flood warning period which may save thousands of lives from upcoming havoc.

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