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FLOOD FREQUENCY ANALYSIS FOR KOSI RIVER AT ITS BARRAGE SITE

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ABSTRACT

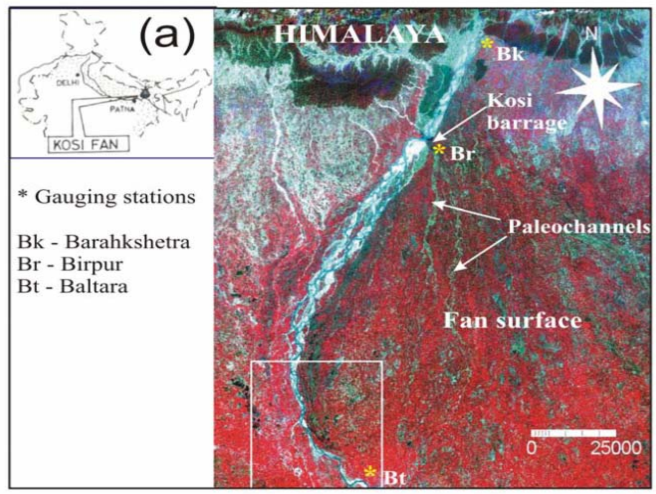
Floods are natural events that have always been an integral part of the geologic history of earth. Human settlements and coactivity have always tended to use flood plains. The Kosi river in north Bihar plains of Eastern India presents a challenge in terms of long and recurring flood hazard. Despite a long history of flood control management in the basin for more than five decades, the river continues to bring a lot of misery through extensive flooding. In the present paper the Log-Pearson Type III distribution, a statistical technique for fitting frequency distribution, has been used to predict the design flood for the river at its barrage site for the discharge data from 1964 to 2008 obtained from WRD, Govt. of Bihar. Apart from this the morphology of the River and the Kosi project have also been described and discussed.

Keywords: *Floods, Kosi river, frequency distribution methods*

INTRODUCTION

Flood and drainage are the two vital interrelated problems of Bihar, a poverty stricken state particularly in North Bihar. The North Bihar plains are drained by some Himalayan rivers and the Ganga being the trunk drain. These rivers are perennial as these are rain as well as snow fed. Important rivers of North Bihar include the Kosi, Gandak, Baghmati, Burhi Gandak, Kamla, Kamla-Balan Mahananda, Kareh and few others. All these rivers have relatively youthful topography and are engaged in channel deepening. They move parallel to the Ganga in the South-east direction and then drain into it. The rainfall in North Bihar is monsoonal in character and its distribution shows wide temporal and spatial variation. Rainfall is confined to few month only and is higher in north-eastern part. This variation in rainfall distribution causes frequent floods in North Bihar, huge losses to crops as large areas are inundated every year. Obviously the principal causes of these recurrent floods are heavy and erratic rainfall and inadequate drainage.

The Kosi River (known as Kaushiki in Sanskrit literature) originates in Tibet at an elevation of 5500 m above MSL by the side of foothills of Mount Everest and traverses through Nepal and India for a distance of about 720 km before joining the river Ganga near Kursela. The river Kosi is the third largest Himalayan River originating from the snowy peaks in the central Himalayas. Its three main tributaries in the Himalayas are the Sun Kosi rising east of Katmandu, the Arun Kosi rising north of Mount Everest in the Tibet and the Tamur Kosi rising west of Mount Kanchanjuna. These three tributaries join at Tribeni in Nepal and the river is known as Kosi thereafter. The river upstream of Tribeni and for about 11 km downstream flows through deep gorge in Himalayas until it enters Gangetic plain at Chatra. From this point, the river runs in a sandy alluvial plain through Nepal terai upto Bhimnagar for a distance of 42 km. Thereafter, it flows through North Bihar and eventually falls into the Ganges near Kursela, the total distance from Bhimnagar to its fall in the Ganges being 260 kms. The rivers Trijuga, Balan, Kamla and Bagmati join river



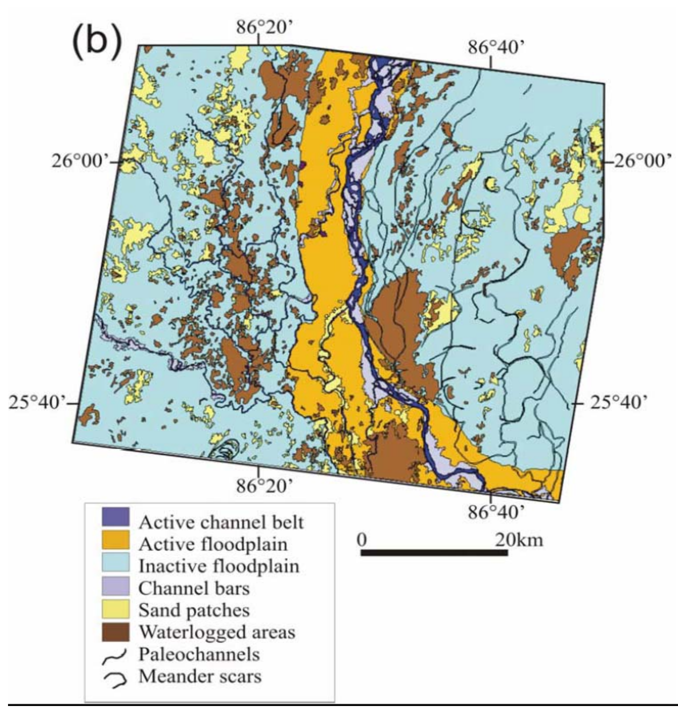


Fig. 1: (a) Location Map of the Kosi Basin with hydrological stations,

(b) Detailed geomorphological map of the area shown in box (a)

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Kosi after entering the plain. Fig.- 1 (After Sinha, et. al, 2005) shows the major geomorphological features in the Kosi plains based on digital mapping from IRS images (LISS III, 7 March, 2002). The braided channel of the Kosi river flows towards SW after debouching into the plains but takes a sharp turn towards SE and then flows parallel to the Ganga in its lowermost reaches before its final confluence with the Ganga. The river is embanked on both sides; the left embankment, running close to the river, is continuous but the right bank is discontinuous particularly in the lower reaches around the confluence with the Ganga.

STUDY AREA

The total catchment area of Kosi River Basin up to Chatra is about 58600 sq. km, and it is divided into Sun Kosi, Arun and Tamur in the proportion of 32%, 58% and 10% respectively. The average rainfall in these catchments varies from 1500 mm to 1250 mm and further decreases by 250 mm in the plain. The average annual runoff measured at Baraksheta is about 53000 million cubic meters (5.3 million Ha m). 81% of this runoff is contributed during June to October. The annual maximum discharge of the river varies from 5,665 m^3/sec (2 lakh cusecs) to 25,910 m^3/sec (9.15 lakh cusecs).

THE RIVER MORPHOLOGY

The course of the river Kosi downstream of the Chatra gorge was subject to frequent changes in the past. The river was notorious for shifting courses and consequent devastation. The history of the river records that between 1731 and 1954, a period of 223 years, the Kosi shifted 113 km from east to west covering 7680 sq. km of land in North Bihar in India and about 1280 sq. km in Nepal by sand deposition as shown in Figure 2. The river below Chatra builds up its plain by dividing its several channels spread over a width varying from 6 to 16 km. The process of shifting of courses of the river and the delta building activities was investigated by Gole and Chitale (1996).

The river Kosi has a steep gradient of about 1.5 m per km in the gorge upstream of Chatra to Bhimnagar, where a barrage has been constructed under the Kosi project; the river has an average flood gradient of 0.873 m per km. In this 42 km reach downstream of the Barrage, the flood slope considerably flattens to 0.445 m per km, in the reach of 29 km from

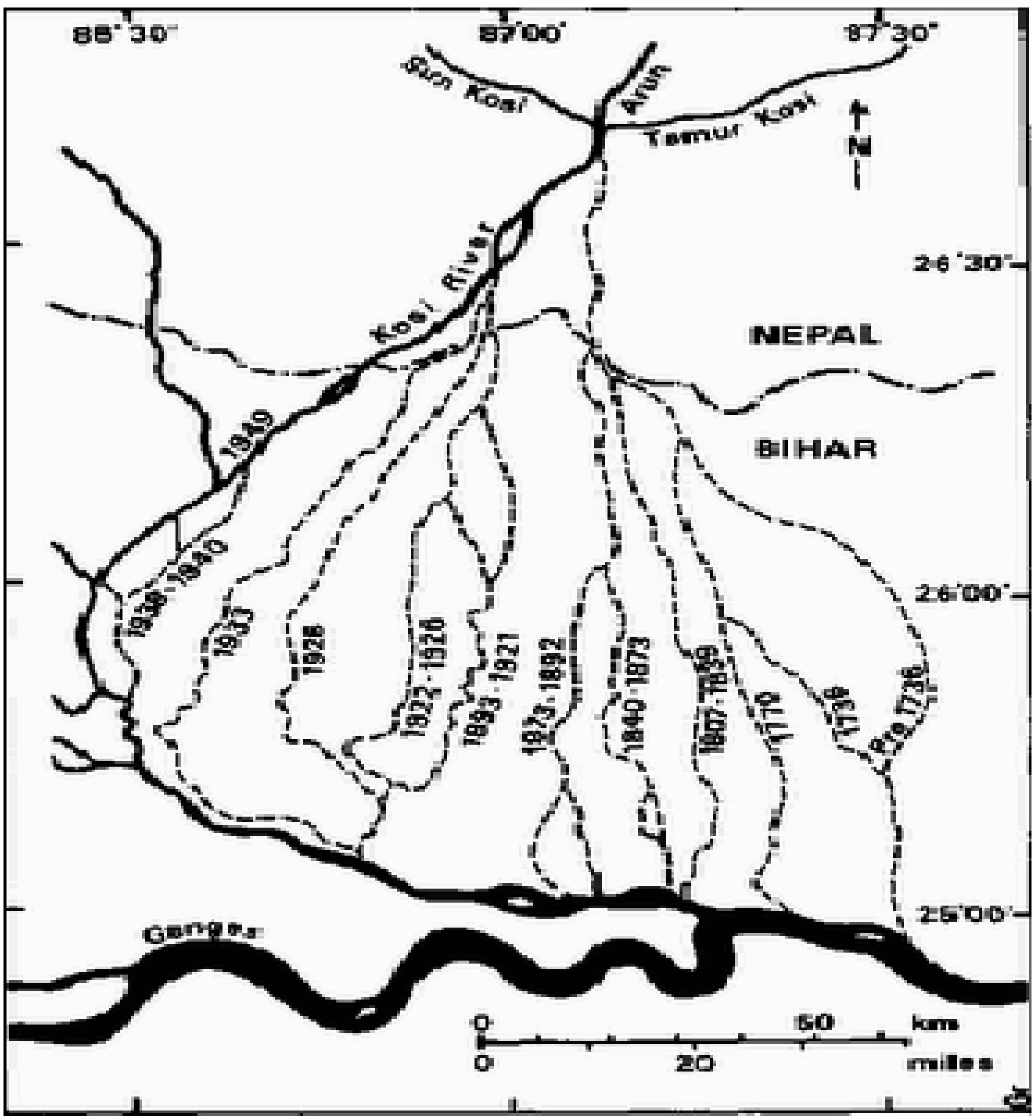

Fig. 2: Shifting courses of the River Kosi

Bhimnagar to Kunauli. The flood slope gradually flattens out in the lower reaches. The flood slope becomes as flat as 0.061 m per km in the outfall reach. These rapid changes in the gradient of slope in a comparatively short distance are one of the major factors attributed to the special characteristics of Kosi (Chitale, 2000). The river bed slopes in different reaches as per pre 1966 data were as follows:

Chatra:	1/570
Hanuman Nagar:	1/2400
Baptiyahi:	1/5200
Kursela:	1/18000

From 15 to 20 km downstream of Hanuman Nagar the river divides in to several channels occupying width as high as 15 km especially due to flattening of slope and deposition of sediment. In the process of delta building the Kosi River has shifted from east to west over a wide area from Mahananda River on east to Balan River on west. As a result of shifting of river course, Kosi River bears destruction and devastation, ruining towns and villages, covering agricultural land with sand, turning wide depressions into marshy lands, ultimately making countryside uninhabited. About 7700 sq. km land in Bihar and 1300 sq. km in Nepal has been turned in to wasteland due to sand deposition during process of shifting.

The average annual discharge (Q_{av}) of the Kosi at is 2236 m^3/s and the average monsoon discharge (5156 m^3/s) being almost 5 times higher than the non-monsoon discharge (1175 m^3/s). Such large difference between monsoonal and non-monsoonal discharge makes the river vulnerable to flooding as the shallow river sections cannot accommodate the excess discharge (Sinha, et al, 2005).

METHODOLOGY: FLOOD FREQUENCY ANALYSIS

Flood frequency analyses are used to predict design floods for sites along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedence probability. Flood frequency distributions can take on many forms according to the equations used to carry out the statistical analyses. Four of the common forms are:

- **Normal Distribution**
- **Log-Normal Distribution**
- **Gumbel Distribution**
- **Log-Pearson Type III Distribution**

Each distribution can be used to predict design floods; however, there are advantages and disadvantages of each technique. In the present paper only two distributions have been used to predict the probable floods of different recurrent intervals as described below.

Gumbel's Method

Extreme value distribution introduced by Gumbel (1941) is commonly used. It is one of the most widely used probability distribution functions for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc.

Gumbel's Equation for practical use: As we know that the value of the variate X with a return period T is used as $X_T = \overline{X} + K\,\sigma_{n-1}$

Where

σ_{n-1} = Standard deviation of the sample.

$$= \sqrt{\frac{(X-\overline{X})^2}{N-1}}$$

Where

N = Number of Samples

$\overline{X}$ = Mean of the samples

T = Return period

K = Frequency factor expressed as

$$K = \frac{Y_T - Y_n}{S_n}$$

Where $Y_T = -\left[\ln.\ln\frac{T}{T-1}\right]$

Y_n = Reduced mean, a function of sample size N and is arranged in Table-2. For $N \rightarrow \infty$,

$Y_n \rightarrow 0.577$

S_n = Reduced Standard Deviation function of sample size N and is arranged in Table-2.

For $N \rightarrow \infty$, $Y_n \rightarrow 1.2825$

K is also determined by formula given below

$$K = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left(\ln\frac{T}{T-1}\right)\right\} \qquad \text{For N >100}$$

LOG-PEARSON TYPE III DISTRIBUTION

The Log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the design flood for a river at some site. Once the statistical information is calculated for the river site, a frequency distribution can be constructed. The probabilities of floods of various sizes can be extracted from the curve. The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. This technique is the standard technique used by Federal Agencies in the United States. The Log-Pearson Type III distribution tells us the likely values of discharges to expect in the river at various recurrence intervals based on the available historical record. This is helpful when designing structures in or near the river that may be affected by floods. It is also helpful when designing structures to protect against the largest expected event. For this reason, it is customary to perform the flood frequency analysis using the instantaneous peak discharge data. However, the Log-Pearson Type III distribution can be constructed using the maximum values for mean daily discharge data.

In this the variate X is first transformed into logarithmic form (base 10) and the transformed data is then analyzed. If X is the variant of random hydrologic series. Then the series of Z variate

Where $Z = \log_{10} X$

For this Z series, for any return period (T)

$$Z_T = \bar{Z} + K_z \sigma_Z$$

$\bar{Z}$ = Mean of Z values

σ_Z = Standard deviation of Z variate sample

N = Number of Samples

$$\sigma_Z = \sqrt{\frac{\sum (Z - \bar{Z})^2}{N - 1}}$$

This variate K_z

$= f(C_s, T)$

K_z is determined from C_s and T relation table

Where C_s = Coefficient of skew of variate Z

$$= \frac{N \sum (Zi - \bar{Z})^3}{(N-1)(N-2)(\sigma_z)^3}$$

After finding Z_T the corresponding value of X_T is obtained

X_T = Antilog (Z_T) base 10

K_Z is also approximated by KITE (1977) as

$$K_Z = W - \frac{(2.515517 + 0.802853W + 0.0328W^2)}{(1 + 1.432788W + 0.189269W^2 + 0.001308W^3)}$$

Where $W = [\log (1/P^2)]^{1/2}$

$P = 1/T$ & $O < P \leq 0.5$

It is assumed that Maximum of the Maximum value of PMP calculated at each rain gauge stations will be the PMP for whole basin.

RESULTS AND DISCUSSION

Floods are natural phenomenon and they play a vital role in maintaining the river form and overbank flows should be expected with a reasonable degree of regularity (Leopold and Maddock, 1955). It is the very mechanics of river formation which demands that highest discharges would not be confined within the channel and overbank flooding will occur. The risk from flooding becomes greater because of the increase in population pressure as more and more floodplain is occupied thereby necessitating the efforts to reduce the flood risk to be stepped up. However, it is very rarely possible to provide complete protection against floods, and therefore, all flood management programmes have to be designed in such a way that it does not give a false sense of security to the people living in the region, as is normally the case in India. Any flood management plan has to conform to local conditions and has to be cost-effective apart from minimizing the adverse effects of flood control measures such as modifications in river sections, waterlogging and increased development in floodplains to avoid greater damages during flooding.

Table1: Results shown by Gumbel's Method

Year	Discharge (Cumecs)	Discharge (000' Cumecs) (X)	Mean Discharge (000' Cumecs) $\bar{X}$	$(x - \bar{x})$	$(x - \bar{x})^2$
1964	281946	281.946	344.1454	-62.1994	3868.771
1965	239309	239.309	344.1454	-104.836	10990.68
1966	391042	391.042	344.1454	46.89656	2199.287
1967	316094	316.094	344.1454	-28.0514	786.8835
1968	788200	788.200	344.1454	444.0546	197184.4
1969	315020	315.020	344.1454	-29.1254	848.2915
1970	450400	450.400	344.1454	106.2546	11290.03
1971	418100	418.100	344.1454	73.95456	5469.276
1972	347579	347.579	344.1454	3.433556	11.7893
1973	401935	401.935	344.1454	57.78956	3339.633
1974	387818	387.818	344.1454	43.67256	1907.292
1975	331474	331.474	344.1454	-12.6714	160.5655
1976	291183	291.183	344.1454	-52.9624	2805.021
1977	279286	279.286	344.1454	-64.8594	4206.748
1978	340065	340.065	344.1454	-4.08044	16.65003
1979	406813	406.813	344.1454	62.66756	3927.223

1980	291410	291.410	344.1454	-52.7354	2781.027
1981	264116	264.116	344.1454	-80.0294	6404.712
1982	208365	208.365	344.1454	-135.78	18436.33
1983	286684	286.684	344.1454	-57.4614	3301.818
1984	501787	501.787	344.1454	157.6416	24850.86
1985	334320	334.320	344.1454	-9.82544	96.53936
1986	282963	282.963	344.1454	-61.1824	3743.292
1987	523771	523.771	344.1454	179.6256	32265.34
1988	400190	400.190	344.1454	56.04456	3140.992
1989	472413	472.413	344.1454	128.2676	16452.57
1990	400675	400.675	344.1454	56.52956	3195.591
1991	361009	361.009	344.1454	16.86356	284.3795
1992	291586	291.586	344.1454	-52.5594	2762.495
1993	317382	317.382	344.1454	-26.7634	716.282
1994	252012	252.012	344.1454	-92.1334	8488.572
1995	245414	245.414	344.1454	-98.7314	9747.898
1996	331229	331.229	344.1454	-12.9164	166.8345
1997	284868	284.868	344.1454	-59.2774	3513.815
1998	311629	311.629	344.1454	-32.5164	1057.319
1999	380358	380.358	344.1454	36.21256	1311.349
2000	324119	324.119	344.1454	-20.0264	401.0585
2001	262996	262.996	344.1454	-81.1494	6585.232
2002	386910	386.910	344.1454	42.76456	1828.807
2003	389970	389.970	344.1454	45.82456	2099.89
2004	398669	398.669	344.1454	54.52356	2972.818
2005	286373	286.373	344.1454	-57.7724	3337.655
2006	191948	191.948	344.1454	-152.197	23164.06
2007	281973	281.973	344.1454	-62.1724	3865.413
2008	235142	235.142	344.1454	-109.003	11881.75
		15486.55			**447867.3**

Table 2: Values of Yn, Sn and Y_T for different Return Periods:

T (Years)	Y_T	Yn	Sn
10	2.2504	0.5463	1.1519
25	3.1985	0.5463	1.1519
50	3.9019	0.5463	1.1519
100	4.6001	0.5463	1.1519
200	5.2958	0.5463	1.1519

Table 3: Results shown by Log-Pearson Type III Distribution

Year	Discharge (Cumecs) (X)	Z = $\log_{10} X$	$\overline{Z}$ = Mean of $\log_{10} X$	$(Z-\overline{Z})$	$(Z-\overline{Z})^2$	$(Z-\overline{Z})^3$
1964	281946	5.4502	5.521531	-0.0713	0.00508813	-0.00036294
1965	239309	5.3789	5.521531	-0.1426	0.02034363	-0.00290164
1966	391042	5.5922	5.521531	0.0707	0.00499409	0.00035293
1967	316094	5.4998	5.521531	-0.0217	0.00047224	-0.00001026
1968	788200	5.8966	5.521531	0.3751	0.14067667	0.05276344
1969	315020	5.4983	5.521531	-0.0232	0.00053968	-0.00001254
1970	450400	5.6536	5.521531	0.1321	0.01744219	0.00230357
1971	418100	5.6213	5.521531	0.0998	0.00995383	0.00099308
1972	347579	5.5411	5.521531	0.0196	0.00038294	0.00000749

1973	401935	5.6042	5.521531	0.0827	0.00683415	0.00056497
1974	387818	5.5886	5.521531	0.0671	0.00449824	0.00030169
1975	331474	5.5204	5.521531	-0.0011	0.00000128	0.00000000
1976	291183	5.4642	5.521531	-0.0573	0.00328686	-0.00018844
1977	279286	5.4460	5.521531	-0.0755	0.00570495	-0.00043090
1978	340065	5.5316	5.521531	0.0101	0.00010138	0.00000102
1979	406813	5.6094	5.521531	0.0879	0.00772094	0.00067843
1980	291410	5.4645	5.521531	-0.0570	0.00325255	-0.00018550
1981	264116	5.4218	5.521531	-0.0997	0.00994629	-0.00099196
1982	208365	5.3188	5.521531	-0.2027	0.04109990	-0.00833223
1983	286684	5.4574	5.521531	-0.0641	0.00411280	-0.00026376
1984	501787	5.7005	5.521531	0.1790	0.03202986	0.00573235
1985	334320	5.5242	5.521531	0.0027	0.00000712	0.00000002
1986	282963	5.4517	5.521531	-0.0698	0.00487638	-0.00034052
1987	523771	5.7191	5.521531	0.1976	0.03903347	0.00771180
1988	400190	5.6023	5.521531	0.0808	0.00652361	0.00052691
1989	472413	5.6743	5.521531	0.1528	0.02333833	0.00356537
1990	400675	5.6028	5.521531	0.0813	0.00660463	0.00053675
1991	361009	5.5575	5.521531	0.0360	0.00129376	0.00004654
1992	291586	5.4648	5.521531	-0.0567	0.00321842	-0.00018258
1993	317382	5.5016	5.521531	-0.0199	0.00039725	-0.00000792
1994	252012	5.4014	5.521531	-0.1201	0.01443148	-0.00173367
1995	245414	5.3899	5.521531	-0.1316	0.01732675	-0.00228074
1996	331229	5.5201	5.521531	-0.0014	0.00000205	0.00000000
1997	284868	5.4546	5.521531	-0.0669	0.00447977	-0.00029984
1998	311629	5.4936	5.521531	-0.0279	0.00078015	-0.00002179
1999	380358	5.5802	5.521531	0.0587	0.00344204	0.00020194
2000	324119	5.5107	5.521531	-0.0108	0.00011731	-0.00000127
2001	262996	5.4199	5.521531	-0.1016	0.01032888	-0.00104974
2002	386910	5.5876	5.521531	0.0661	0.00436510	0.00028840
2003	389970	5.5910	5.521531	0.0695	0.00482593	0.00033525
2004	398669	5.6006	5.521531	0.0791	0.00625189	0.00049433
2005	286373	5.4569	5.521531	-0.0646	0.00417718	-0.00026998
2006	191948	5.2832	5.521531	-0.2383	0.05680172	-0.01353762
2007	281973	5.4502	5.521531	-0.0713	0.00508813	-0.00036294
2008	235142	5.3713	5.521531	-0.1502	0.02256939	-0.00339062
		248.4689			0.55876336	0.04024689

The Flood Frequency Analysis is a direct means of estimation of desired flood or rainfall based upon the available flood flow or rainfall data series of the catchment. The results of the frequency analysis depend upon the length of data. The minimum number of years of record required to obtain satisfactory estimates depend upon the variability of data.

The basis for selection of an appropriate method has to be based on a careful analysis of hydrological data to understand the processes involved and then to extrapolate the changes in the hydraulic regime after applying the flood control measures. The Kosi river in eastern India has defied all flood control measures so far, and therefore, a major policy shift is required for flood management in the region. A proper flood plain zoning and identification of flood risk is essential before planning any further flood control measures. Our hydrological data analysis shows that the Kosi river displays very high discharge variability and difference between monsoonal and non-monsoonal discharges is as high as 5 times. This results in an enormously excess discharge during monsoon months which the river cannot carry in its shallow alluvial channels and overbank flooding occurs.physical and climatological characteristics of the basin. Generally 30 years or more data are required as essential. Smaller length of records is also used when it is unavoidable. However, frequency analysis should not be adapted if the length of records are less than 10 years.

Frequency Analysis is the most reliable in uniform climates from year to year. In such cases, relatively short records give a reliable picture of the frequency distribution. With increasing length of flood or rainfall records, it affords a viable alternative method of flood flow or rainfall estimation in the most cases.

In the present study the result shows that values of Kosi flood discharge for 10 years and 200 years recurrence intervals estimated by Log Pearson type III are more as compared to that by Gumbel's method. Further for 25, 50 and 100 years recurrence intervals the values from Gumbel's method are more as compared to that from Log Pearson type III method. However, for Indian conditions, Log Pearson type III should be used if there is no shortage of data.

CONCLUSION

In the present study the result shows that values of Kosi flood discharge for 10 years and 200 years recurrence intervals estimated by Log Pearson type III are more as compared to that by Gumbel's method. Further for 25, 50 and 100 years recurrence intervals the values from Gumbel's method are more as compared to that from Log Pearson type III method. However, for Indian conditions, Log Pearson type III should be used if there is no shortage of data.

The Kosi river in north Bihar plains, eastern India shows extreme variability in terms of flood magnitude and frequency both spatially as well as temporally. Such efforts should be a part of non-structural measures of flood management to reduce short term and long-term damages and to bring awareness among the scientific community on the potential need of such a study.

The flood embankments cannot prevent the shifting tendency of the river course. Raising of embankments may also be necessary due to rise in water level caused by aggradations. The embankments have to be constructed sufficiently wide with respect to the khadirs of the river Kosi so that the embanked river is able to carry the flood peaks keeping in view of the fact that the earthen embankments cannot stand velocities adjacent to banks exceeding about 1.2 to 1.5 m/s.

Since the floods in Kosi is an international issue, there should be high level summits at regular interval among the Govt. of India, Govt. of Nepal and the state Govt. of Bihar to find out the long lasting solution to this problem. Apart front this people's participation should be ensured in the entire flood related activities. By adopting the above works the floods of Kosi and other rivers of Bihar can be managed to great extent.

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