Peak Discharge Analyses for Flood Management in Lower Gandak Basin

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Abstract

Flood is flow of large volume of water which is not possible to be accommodated in the preexisting channels created by the river in a fluvial system. It happens and exists for a short span of time. It occurs so because of heavy rain or snow melt water available for flow. Final, it results into spillover/overtops of water from its banks and further lead to occupy a large area in the plain. Since the Gandak Plain is heavily populated and widespread human activities are observed in the plain, spreading of water over the large area is affected adversely. It is believed that the flooding is good for replenishment of soil fertility but the transport of sand particles from the Himalayan Gandak River is the negation of this concept. It is more harmful than good. Ultimately, flood in the Bihar Gandak Plain is a curse for the land and people. It is disastrous and creates numerous types of hardship to the people. Not only that it is, sometimes, the reason for complete collapse of economy, destruction of houses and infrastructures, loss of life and property including human and cattle, and making the life miserable for all the biotic life of the area. In short, it causes widespread disaster. The flood is not only a natural one, but it is aggravated due to the interaction of human beings with its surroundings in the catchment area of any particular river basin. Therefore, this paper highlights different methods by which the flood discharge is estimated based on empirical data. Estimation of the flood discharge is helpful in designing different engineering structures to be taken up in the basin. The dealt methods here are Gumbel's extreme value distribution method, log-normal method, Ven Te Chow's method, Pearson type III method, and Foster type III method.

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Introduction

Flood is very common in the plain, but it is an intricate phenomenon. It is very difficult to define flood which may be acceptable to everyone. Different people consider it differently. According to hydrologists, when precipitation is greater than the drainage capacity, it is flooded. For engineers, it is the runoff which is not controlled in spite of greater efforts. For farmers, it is the water which is greater than the need of the crops. When there is interference in the communication, damage to residences, disruptions in the normal day-to-day life of people due to water, it is called a flood by general people inhabiting the area concerned. Geographers consider all the above-mentioned events to be a condition of a flood.

Flooding is a natural process in the fluvial system in which the available water for flow is greater than the carrying capacity of the channel. Most of the time, the water to discharge is supplied by the heavy down pouring rain in a shorter span or quick snow melt or combination of both. These phenomena are associated with supplying greater amount of water which has finally to be carried away by the channel. The channel has its own capacity to accommodate the water and discharge the same to downstream. Once the supply is greater and the capacity is lesser, flooding is bound to happen. Therefore, a flood is a condition in which excessively high discharge of water is spread over a comparatively flat area leading to temporary submergence. Flood is defined as 'a relatively high flow which overtakes the natural channel provided for runoff' by Ven Te Chow (1956). Ward (1978) defined the same as 'a body of water which rises to overflow land which is not normally submerged.' In other words, it may be stated that the level at which the river channel overflows its banks and submerges the surrounding area is referred as flood situation (Mutreja 1986; Subramanya 1988). Rostvedt (1968) defines flood as 'any high stream flow which overtops natural or artificial banks of a stream.'

Flood is an event which may be caused at different scales and by different mechanisms. Flooding may be caused by excess availability of water due to different reasons discharged through the river. It is generally called a riverine flooding. The little additional available water may be a reason to create flood in an urban area where the drainage is clogged. The draining is not possible in a quicker way, and hence, it is termed as urban flood or flood caused by drainage congestion. In the mountainous region, sometimes floods are also caused due to mudflow in huge quantity along the slope. Subsidence of land near larger water body is also a reason of flooding. When seismic waves are propagating during earthquake through unconsolidated and saturated soils, they allow the soil particles move freely. It leads to fissure eruption on the surface. Through these fissures, subsurface water is propelled and reaches to the surface. This type of flooding was caused during January 15, 1934, Nepal–Bihar earthquake (GSI 1939). Soil liquefaction study was conducted by Nepal–Bihar earthquake on August 21, 1988, by Mukerjee and Lavania (1998). Whether it is mudflow or subsidence or liquefaction, all are clubbed together to call the flood caused by ground surface failure. Coastal areas are also subjected to flooding by ocean waves particularly during cyclonic storm or at the time of tsunami and are referred as coastal flood.

Since the present study is concerned with the Gandak River, here the emphasis is on riverine flood.

With respect to Gandak River, the flood is caused mainly by torrential rain in the upper catchment during monsoon season associated with quick snow melt in the higher altitude due to high temperature during June to September. Floods are recurrent features in the adjoining areas of high discharge carrying rivers all over the world. Where the flood inundate, a large-scale after effects are observed like soil erosion, land degradation, crop damage, shelter collapse, loss of life and property, spread of waterborne various diseases, hunger, epidemics, and other related hardships. These sort of problems are directly associated with the Gandak River basin. These are some of the examples of disaster caused by flood. Flood is a recurrent feature in the Gandak River basin. It happens several times in a year during monsoon months. There may be several peak flows of the river, and every time, it causes the flood to happen.

Literature Review

The shape and size of the basin has a direct bearing on the nature of the flood in the said basin. The basin and its scale in flood peak distribution are studied very suitably by using a log-normal model by Smith (1992). Gupta et al. (1994) used the multi-scaling theory of floods for regional quantile analysis. A very good reporting on flood situation and flood management concerning India and Bangladesh has made by Prasad and Mukherjee (2014). A detail guideline for analyzing extreme floods has been prepared by Ruttan (2004). Subramanya (1988) discussed about the flood estimation using different methods and also deliberated on its control. Different aspects of flood and flooding in the Ganga basin and its tributaries have been studies by Dhar and Nandargi (2002). Rao and Hamed (2000) have studied in detail about the analysis of various methods for estimating the peak discharges. Prasad (2009) has tried to estimate the peak flood for Kosi River at Barahkshetra using 46 years of

peak data. Mutreja (1986) has deliberated much in detail about many methods of peak discharge analysis and estimated the recurrence of probable peak for numerous periods which are yet to come in future. The main purpose of this study is to (a) identify the flood genesis, (b) estimate the peak discharge based on empirical data, and (c) throw light on the grim situation due to flood and the measures to be adopted to minimize the loss in the Gandak Plain of Bihar.

The Study Area

The Gandak River is known as Kali Gandaki in Nepal, but the same river is termed as Narayani in the southern Nepal areas of foothills. It is an antecedent river which means it is older than the Himalayas. It has got its origin from the Tibetan plateau and cuts the Himalayas during its rising periods. It has created the world's deepest gorge 'If one measures the depth of a canyon by the difference between the riverbed and the heights of the highest peaks on either side, the Gorge is the world's deepest'—CWPRS (Central Water and Power Research Station 2012). The Himalayan catchment of the Gandak River encompasses 1025 glaciers and 338 lakes. The Gandak River enters India (Bihar) at Triveni. Here, the river debouches in the plain. Prior to this, the riverbed slope is very steep but further downward, the slope keeps on declining slowly. The greater slope in the upper catchment, crushed rocks due to the Himalayan orogeny, and extensive weathering associated with heavy torrential rain during monsoon months produce enormous sediment. It is carried by the river, but when it reaches at the foothills, the huge deposition is deposited because of the lowered carrying capacity of the river. It has led to the formation of the Gandak mega fan (Geddes 1960; Wells and Dorr 1987; Prakash and Kumar 1991). This mega fan consists of eroded sediments from the upstream and brought and deposited by the Gandak waters. The deposited materials in the plain are loose and unconsolidated, and They get eroded easily further. In the high surge of water in the river, sometimes they

lead to shift the channel by carving out another in the nearby. It happens when the existing channels are chocked by sediment and the water is not channelized quickly. Hence, the channel shift is the evident in both major rivers of north Bihar, the Gandak and the Kosi.

The area under direct study lays downstream to Triveni, particularly after Valmikinagar barrage near Nepal–Bihar border. It is the lower Gandak basin which falls partly in Uttar Pradesh and major portion in north Bihar plain. This area lays between 25° 21′ 23″N to 27° 26′ 54″N latitudes and 83° 49′ 00″E to 85° 15′ 52″E longitudes (Fig. 1). It is a total area of 7370 km^2 out of which 968 km^2 lays in Uttar Pradesh and 6402 km^2 in Bihar. The water rushing from the upper catchment is the main cause for water accumulation and causing flood in the downstream. Therefore, the first para mentioned under the study area is also having great importance in terms of understanding the flood problems. The total length of the embankments along both sides of the Gandak River is 512 km (Baghel 2014). They start from the foothills to downstream through Valmikinagar barrage.

The Gandak River Basin and Its Characteristics

The Gandak basin is a sub-basin, occupying the eastern central place, in the Ganga River basin. The Gandak River gets its origin from Tibetan highlands of Trans-Himalaya from Nhubine Himalaya Glacier at a height of about 6268 m above sea level and confluences with Ganges near Hajipur opposite Patna where the elevation is only 44 m. Along its journey, it covers a distance of about 630 km with a total basin area of around 45,035 km^2 out of which about 9540 km^2 is in Indian Territory. Around 10,000 km^2 area (partly in Nepal) lays in the plain and rest is the mountainous catchment in Tibet and Nepal. The ratio of plain and mountain area is 1:4.5 (Fig. 2), a very big one. Rain and melt water from such a large area with very steep slope generates runoff which quickly reaches to the plain. The slope in the plain becomes very low and huge amount of

water along with concentrated sediment have to be drained. Due to this condition, the carrying capacity of the lower channel is reduced drastically. Hence, the spread of water over a large area is the result leading to flooding. The mean annual water flow of the Gandak River at its confluence with the Ganges is about 52,200 million cubic meters (Dhar and Nandargi 2002). The maximum discharge recorded at Triveni (near Bihar–Nepal border) is 12,700 cubic meter per second (cumec) in 1986, and at Lalganj (in Bihar, Vaishali district), it is 15,750 cumec (Rishideo 2011) in 2001.

The Gandak River and its many tributaries are getting their origins at high altitudes in the Himalayas from glaciers. There are numerous springs from where the water is channelized to the streams, and hence, the Gandak is a perennial river. Huge amount of sediment is produced from the upper Himalayan catchment and deposited in the plain areas. Since the deposited sediment is loose and unconsolidated, the bed is very much unstable. Meandering is routine affair of the river in the plain. Dam construction is possible only in the mountainous region in Nepal and hence, the reservoir may be there. There is no such scope in the plain to do for flood control. It all depends upon the understanding between two nations as it is a trans-boundary river. It is a well-known fact that the answer of the flood is not laying the plain, but it is has its genesis in the upper catchment. It is possible through the overall land and all human activity management in the upper reach of the river. Most of the time flood becomes uncontrollable not because of the excess of water, but it is the excess of sediment charge from the river water. If the sediment coming from the running water is regulated/controlled/trapped in the initial stage, the flood may easily be regulated as well. Therefore, the international territorial extent of the upper catchment is one of the prime reasons of the failure of the land and human activity management. In fact, the integrated approach is the need of the hour not only for the benefit for India but for the benefit of Nepal as well. Both of the country would harvest the benefit by sharing and caring the need of each other.
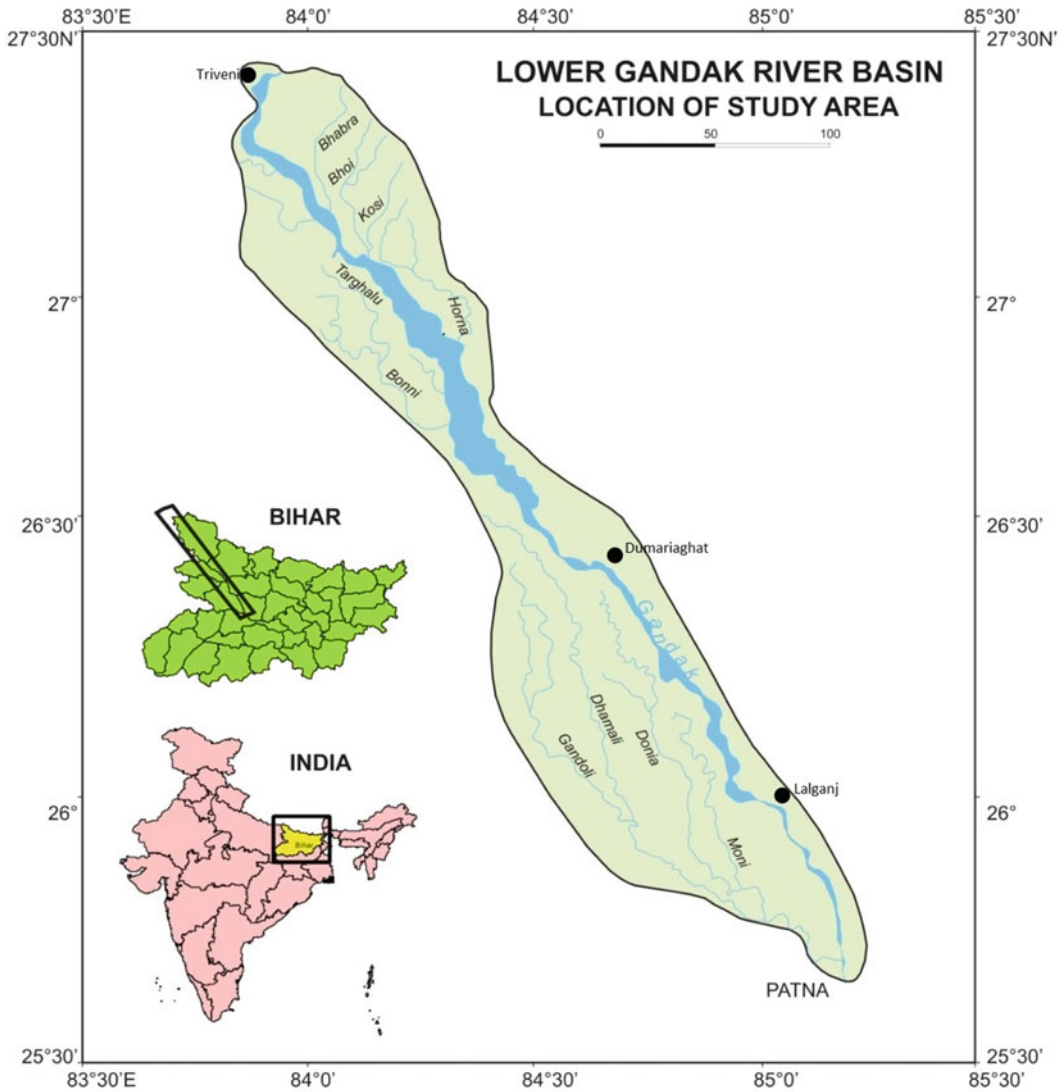
Fig. 1 Lower Gandak River basin

Rainfall Distribution

The pattern of precipitation distribution in the upper Gandak River basin of the Himalayan catchment areas is quite distinctive. The entire upper catchment area of the Gandak River basin can very well be divided into four ecological zones on the basis of its elevation. They are Trans-Himalaya, high mountains, hills, and Tarai. The lowest annual average precipitation is observed in the northern zone of the Trans-Himalaya where it is just 55 cm and relatively more in the high Himalayan areas with a precipitation of around 150 cm annually. But the lower altitudinal zone of hills receives the highest annual average rainfall which is about 347 cm. Tarai region experiences a little less rainfall where it just 195 cm. The mean annual precipitation in the upper Himalayan catchment area of the Gandak basin upstream to Triveni is 186 cm (Panthi et al. 2015). The topography and altitude have very important role in the distribution of precipitation in the basin. There is significant

Fig. 2 Gandak River catchment in the mountain and plain
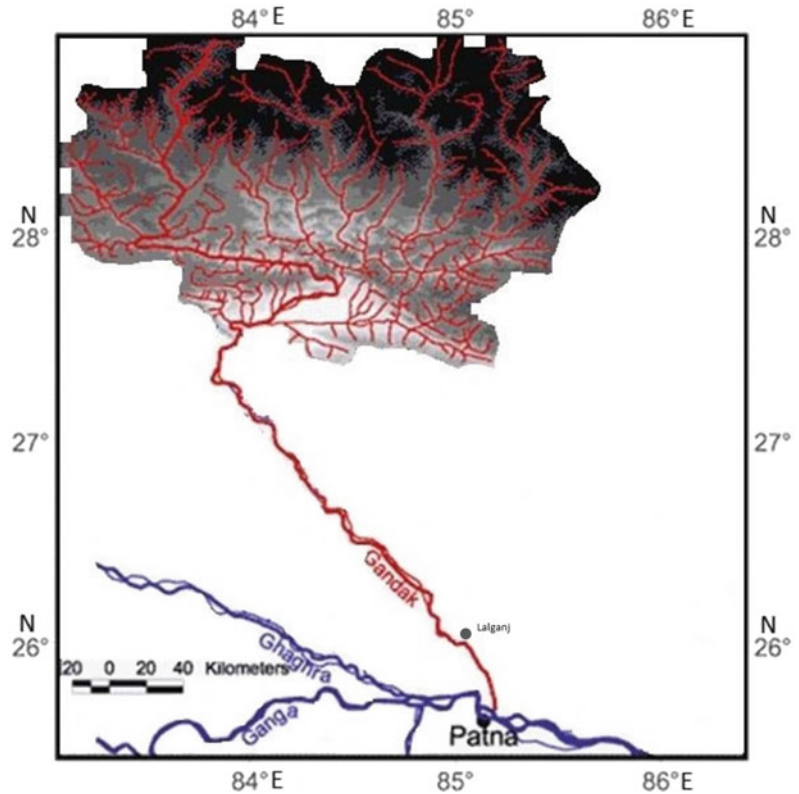
variation in the distribution of precipitation over the seasons as well as subregions mentioned above. Periodic variation of precipitation in the basin is also very distinctive. About 78% of the total annual precipitation in the Gandak River basin is received within four monsoon months (June–September). Remaining 22% rainfall is spread over a period of eight non-monsoon months (October–May).

The mean annual rainfall for the entire river basin in the plain is 120 cm (Ranade et al. 2008). The flood and its havoc are created by the runoff coming from the mountainous catchment where the slope is very steep. Runoff is very swift, and it reaches the lower basin quickly. As stated above, the real solution of the flood in the Gandak Plain is laying in the upper catchment. Hence, the action needs to be taken there to tackle the flood problem.

Data Source and Methodology

The present study is based on secondary data. The data is related to the peak discharge recorded at Lalganj discharge site. The peak discharge is defined as a single maximum recorded discharge within a calendar year. This data has been collected from the Gandak Division of the Ganga Flood Control Commission (GFCC) at Patna Secretariat. This data is utilized to estimate the probable discharge in the years yet to come. It is known as discharges for recurrence years. It is analyzed on the principle of extreme value distribution techniques. The techniques used here are five in numbers. They are given below and the methods adopted for estimation of floods by these methods are discussed simultaneously while discussing those techniques.

Flood Frequency Analysis

Flood frequency analysis is a method of investigation in which the single maximum discharges of different years are used to estimate the probable discharge for a certain interval based on different methods. Sometimes, it happens that the highest discharge in 365/366 days of a particular year may be less in comparison to the several discharges in another year which are not included. By the assumption of the peak discharge analysis method, only one highest discharge is included in the data set and not the others which may be even larger than other year's highest. Reasonably bigger duration random data from the sample representing the universe is the prime concern for this analysis. Hence, by the use of this type of data, estimation of discharge for certain return period is helpful in determining different measures to be adopted in the area to protect from the vagary of floods. Once the likely discharge is known, some engineering structures may be created in the field to tackle that much of discharge. In this regard, there may be several measures like construction of several dams/check dams in the upper catchment, barrage, diverging water from the main river to other adjoining areas, embankments in the plain, dredging of riverbed, creating several storages. All these could be possible when precise and appropriate estimation of discharge is computed.

The estimation of discharge in the future could be estimated based on the available data by different methods. It is always fair to use long-duration data for better analysis and precise prediction. When the long-period data is available with correct figures, it delivers very accurate, suitable, and reliable results. Based on this information, a fair degree of precise and accurate extrapolation could be done. There is no set pattern about the limit of extrapolation period. Many of the hydrologists give their opinion, but K.N Mutreja (1986) says, 'some hydrologists set a limit of extrapolation of about twice the length of record, i.e., a 50-year runoff data can be used to determine the magnitude of events up to 100 year flood but not of a longer return period, while others do extrapolate runoff record of 40 to

100 years in length to estimate a 1000-year or even 10000-year flood.' The flood estimation for varying recurrence interval could be possible to have by using the mathematical equation as well as graphically by plotting the values on probability graph paper. The present analysis is based the recorded peak discharge of Gandak River at Lalganj for a period of 33 years from 1981 to 2013. There are five methods used here—they are —Gumbel's method, log-normal method, Ven Te Chow's method, Pearson type III method, and Foster type III method. They are discussed below:

Frequency Factor

The method of frequency factor is the application of statistical procedures. The techniques based on frequency factors can be formulated. It is a represented through the following formulae equation:

$$X_t = \bar{X} + K\sigma$$

where

X_t = flood magnitude of given return period T,
$\bar{X}$ = mean of recorded peak floods,
σ = standard deviation of recorded floods, and
K = frequency factor which depends upon the return period, T and the assumed frequency distribution.

Chow (1964) has expressed that the most frequency distribution functions applicable in hydrologic studies have been expressed by the above-mentioned equation. This formula is commonly known the general equation of hydrologic frequency analysis.

Gumbel's Method

This method was introduced by Gumbel (1941) and is commonly known as Gumbel's extreme value distribution method. Gumbel was the first to realize that the annual peak flood data (or annual maximum one storm rainfall and similar type of data) is nothing but the extreme values in

different years' observation. It is one of the most widely used probability distribution functions for extreme value in hydrologic studies for prediction of flood peaks, maximum rainfall, maximum wind speed, etc. concerning the extreme events. From the first equatation mentioned above, the frequency factor, K is expressed as:

$$\frac{yT - \bar{y}N}{Sn}$$

where

$\bar{y}N$ = reduced mean, a function of sample size N and it is taken from the given table (Subramanya 1988: p. 215),

Sn = reduced standard deviation, a function of sample size N and it is taken from the given table (Subramanya 1988: p. 215), and

yT = reduced variate, a function of T and it can be calculated by

$$yT = -\left(1n.1n.\frac{T}{T-1}\right).$$

Example, for a return period of 50 years, yT, is:

$$
\begin{aligned}
yT &= -\left(1n.1n.\frac{T}{T-1}\right) \\
&= -\left(1n.1n.\frac{50}{50-1}\right) \\
&= -(1n.1n.50/49) \\
&= -(1n.1n.1.0204) \\
&= -(1n.0.020202707) \\
&= -(-3.901938658) \\
&= 3.901938658 \\
&= 3.9019 \,(\text{rounded off})
\end{aligned}
$$

All these equations have been used under the following steps to estimate the flood magnitude corresponding to a given return based on an annual flood event.

Procedures

(a) Assembled the peak discharge data in descending order,

(b) Computed the mean ($\bar{X}$) given variate
Mean ($\bar{X}$) = $\Sigma X/N$,

(c) Found out the standard deviation ($\sigma n - 1$)
= $\sqrt{\sum(xt - \bar{X})^2/N}$ of the sample,

(d) Determined $\bar{y}n$ (reduced mean) and Sn (reduced standard deviation) to the given N:
Found out the yT for a given T yT = − (1 n.1n.T/T − 1) and
Found out the frequency factor, K = yT −$\bar{y}$n/Sn, and

(e) Computed the required magnitude of flood xT
$X_t = \bar{X}\ K\sigma n - 1$.

Discussion

The estimation of peak recurrence at Lalganj on the Gandak River has been computed based on the above-mentioned procedures/steps and the results of the same are presented in Table 1 below. The peak discharge data collected from the field has been used here. It belongs to 33 years from 1981 to 2013 for the said discharge site. The first column of the table is showing different return periods and the same is converted into probability in percentage in the column second. From these two columns, it is clear that the higher period of recurrence of peak discharge has very low probability and vice versa. It is the basic principle of the return period of flood event and its probability.

The average peak discharge for entire period under study at Lalganj is 9343 cumecs. For a return period of 1000 year, the computed peak discharge is 24822.58 cumecs which is quite a large value in comparison to the mean or even the observed discharge. The maximum discharge for 33 years is only 15750 cumecs under records. With higher return periods, it increases very rapidly, but its probability decreases very drastically. It had been estimated that a flow of

Table 1 Flood frequency analysis of Gandak River at Lalganj: Gumbel's method (1981–2013)

Return period T (Years)	Probability P (in %)	$\overline{X}$ (in cumecs)	yT	ȳN	Sn	$K = \dfrac{yT - \bar{y}N}{S_n}$	бn-1	$X = \overline{X} + K\text{б}n\text{-}1$
1000	0.1	9343	6.9073	0.5384	1.1211	5.6809	2724.85	24822.58
200	0.5	9343	5.2958	0.5384	1.1211	4.2435	2724.85	20905.89
100	1	9343	4.6001	0.5384	1.1211	3.6230	2724.85	19215.12
50	2	9343	3.9019	0.5384	1.1211	3.0002	2724.85	17518.09
10	10	9343	2.2504	0.5384	1.1211	1.5271	2724.85	13504.11
5	20	9343	1.4999	0.5384	1.1211	0.8576	2724.85	11879.83
2	50	9343	0.3665	0.5384	1.1211	-0.1533	2724.85	8925.28
1.2500	80	9343	−0.4759	0.5384	1.1211	−0.9047	2724.85	6877.83
1.0526	95	9343	−1.0974	0.5384	1.1211	−1.4591	2724.85	5267.18
1.0101	99	9343	−1.5272	0.5384	1.1211	−1.8425	2724.85	4322.47

4322.47, 8925.28, 11879.83, 17518.09, 19215.12, 20905.89, and 24822.58 cumecs discharges are expected to occur in 1.01, 2, 5, 50, 100, 200, and 1000 years at Lalganj. The return probabilities for those discharges are 99, 50, 20, 2, 1, 0.5, and 0.1%, respectively. However, it is important to note that all such recurrence intervals of hydrologic processes are simply averages and do not indicate when an event of a particular magnitude would occur. It is often very difficult to accurately estimate the recurrence interval of an extreme and rare event due to unpredictability of the nature and natural events.

Log-Normal Method

Log-normal method is based on the principle of log-normal probability law. This method assumes that the flood values are such that their natural logarithms are normally distributed. The computation of this method has carried out in following steps.

Procedures

(a) Computed the ($\overline{X}$) of the given variate Mean ($\overline{X}$) = ΣX/N and found out the standard deviation (бn − 1) by

$$= \sqrt{\sum (xt - \overline{X})^2 / N}$$ of the sample N,

(b) Computed the coefficient of variation Cv, Cv = бn − 1/$\overline{X}$,

(c) Found out the coefficient of skewness C_s, $C_s = 3(Cv + Cv^3)$,

(d) Determined theoretical log-probability (K) frequency factor corresponding to the computed value of C_s and selected probability (P) from the Table (Mutreja 1986: p. 708),

(e) Computed the value Kбn − 1, and

(f) Added $\overline{X}$ to get the required magnitude of flood.

Discussion

The results of the flood frequency of the Gandak River at Lalganj site by log-normal method have been presented in Table 2. It is clear that the flood magnitude is changing with their probability. Higher discharge is associated with higher return period of occurrence and lower probability, whereas the lower discharge is related to higher probability and lower return period of occurrence. According to this method, the discharges of 13335.25, 17436.25, 11414.00, 8961.50, and 4601.50 cumecs are estimated for the return periods of 1000, 100, 5, 2, and 1.01 years, respectively. It is based on the data for 33 years at Lalganj discharge site as mentioned above.

Table 2 Flood frequency analysis of Gandak River at Lalganj: log-normal method (1981–2013)

Return Period (years)	Probability P (%)	$\overline{X}$	C_s	K (for C_s = 0.9)	K_s	$X=\overline{X}+K_s$ (in cumec)
1000	0.1	9343	2725	4.55	12401.25	13335.25
100	1	9343	2725	2.97	8093.25	17436.25
5	20	9343	2725	0.76	2071.00	11414.00
2	50	9343	2725	−0.14	−381.50	8961.50
1.2500	80	9343	2725	−0.84	−2289.00	7054.00
1.0526	95	9343	2725	−1.37	−3733.25	5609.75
1.0101	99	9343	2725	−1.74	−4741.50	4601.50

V.T. Chow's Method

V.T. Chow's method is the graphical fitting process. The observed peak discharges are plotted on the probability graph paper. After the plotting of values, a line is drawn which suits the best. It could be drawn by simply observing the plotted values. But to avoid the visual/subjective error of inspection, it is generally drawn mathematically. This method is known as V.T. Chow's method. In fact, this method is a modification of Gumbel's method. The procedures of computation by this method are as follows:

Procedures

(a) Arranged the peak discharge figures in descending order,
(b) Assigned the rank values for those figures as first for the highest flood and the last for the lowest one,
(c) Found out the return period, T = N + 1 divided by the weight given in step 'b',
(d) Got the Z which is equal to log.log [T/(T − 1)],
(e) Found out XZ by multiplying respective peak discharge with the Z in step 'd',
(f) Got Z^2, i.e., step d×d, and
(g) Got the summation of steps (d), (e), and (f) and annual peak discharge.

The formula for least-square line is as follows:

$$X = A + B\log.\log T/T − 1$$

where

$$A = \Sigma x/N − B\ \{\Sigma z/N\}$$

$$B = \frac{\sum XZ − \sum Z\{\sum X/N\}}{\sum Z^2 − (\sum Z)^2 \big/ N}$$

Discussion

According to the steps mentioned above, the magnitude of floods has been computed for the discharge site Lalganj which lays along the Gandak River. The computed values are presented in the Table 3:

The estimated magnitude of flood discharge of 24529.40, 20687.26, 19028.60, 17363.86, 11636.80, 8934.39, and 4414.13 cumecs are expected to occur in 1000, 200, 100, 50, 5, 2, and 1.01 years, respectively. The same may be translated into their probabilities which are equivalent to 0.1, 0.5, 1, 2, 20, 50, and 99% for Lalganj site. This estimation is based on the 33 years (from 1981 to 2013) sampled data of annual peak discharge in the Gandak basin at Lalganj site. For 95% probability (chances of return period −1.05 years) is 5405.98 cumecs according to this method.

Pearson Type III Distribution Method

In Pearson type III method, to fit the recurrence intervals and skew coefficients distribution, firstly, annual peak floods are transform to

Table 3 Flood frequency analysis of Gandak River at Lalganj: V.T. Chow's method (1981–2013)

Return period T (year)	Probability P (in %)	Log log (T/T−1)	Estimated flood flow (x) = 6071.942165-5490.025864 log log (T/T-1) (cumec)
1000	0.1	−3.3620	24529.40
200	0.5	−2.6622	20687.26
100	1	−2.3600	19028.60
50	2	−2.0568	17363.86
10	10	−1.3395	13426.04
5	20	−1.0136	11636.80
2	50	−0.5214	8934.39
1.2500	80	−0.1555	6925.87
1.0526	95	0.1213	5405.98
1.0101	99	0.3020	4414.13

logarithmic values and then the mean, standard deviation, and skewness coefficient are computed. The steps of computations by this method are as follows:

Procedures

(a) Calculated the mean as $\overline{X}$,
(b) Got Deviation form mean as $X-\overline{X}$,
(c) Calculated $(X - \overline{X})^2$ and $(X - \overline{X})^3$
(d) Calculated standard deviation as:

$$S = \left(\frac{N}{N}\mu^{\wedge 2}\right)1/2,$$

(e) Computed the coefficient of skewness by the following equation:

$$y^{\wedge 1} = \left(\frac{N^2}{(N - 1)(N - 2)}\mu^{\wedge 3}/\mu^{\wedge 2}\right)3/2,$$

(f) Determined frequency factor 'K' corresponding to the computed value of $y^{\wedge 1}$ and selected probability (P),
(g) Computed the value Ks,
(h) Added $\overline{X}$ to get the required magnitude of flood.

Discussion

Flood frequency results of the Gandak River at Lalganj discharge site by Pearson type III

distribution method have been presented in Table 4. For 200 and 100 years, the maximum probable annual peak flood discharges are as high as 20215.14 cumecs and 18574.78 cumecs, respectively. The conversion of their chances in percentage is equal to 0.5 and 1, respectively. With 99 and 95% of probability, it comes down to 6081.36 cumecs and 6364.74 cumecs, respectively.

Foster Type III Method

Foster adopted the use of Pearson's skew functions for fitting observed flood data. The steps of computation of flood frequency analysis by the Foster type III method are hereunder:

Procedures

(a) Found out the mean as $\overline{X}$,
(b) Got Deviation form mean as $X - \overline{X}$,
(c) Calculated $(X - \overline{X})^2$ and $(X - \overline{X})^3$,
(d) Calculated standard deviation as
   $s = \sqrt{\Sigma\Delta x^2/N}$,
(e) Computed the coefficient of skewness
   $Cs = \Sigma x^3/(N)s^3$,
(f) For Foster type III curve, found:
   $\overline{Cs} = Cs (1 + 8.5/N)$,
(g) Determined frequency factor 'K' corresponding to the computed value of $\overline{Cs}$ and selected probability (P),

Table 4 Flood frequency analysis of Gandak River at Lalganj: Pearson type III method (1981–2013)

Return period (Years)	Percent chance	Skewness coefficient	K from Appendix C for	Ks (2724.846768)	X = 9343 + Ks (in cumec)
200	0.5	1.6	3.990	10872.14	20215.14
100	1	1.6	3.388	9231.78	18574.78
50	2	1.6	2.780	7575.07	16918.07
10	10	1.6	1.329	3621.32	12964.32
5	20	1.6	0.675	1839.27	11182.27
2	50	1.6	−0.254	−692.11	8650.89
1.2500	80	1.6	−0.817	−2226.20	7116.80
1.0526	95	1.6	−1.093	−2978.26	6364.74
1.0101	99	1.6	−1.197	−3261.64	6081.36

(h) Computed the value Ks,

(i) Added $\overline{X}$ to get the required magnitude of flood.

Discussion

The Table 5 displays the flood frequency analysis of the Gandak River at Lalganj site. The probable discharge of 12144.34, 11049.40, 9632.14, 9196.06, and 8873.74 cumecs are expected to happen with the recurrence interval of 1000, 100, 5, 2, and 1.01 years. The translations of the same into chances of occurrence in percentage are 0.1, 1, 20, 50, and 99, respectively. With 95% chances of probability, the expected peak discharge comes down to 8892.70 cumecs at this site.

Summing-up Different Methods

Five methods of flood frequency analysis have been discussed above to estimate the annual peak floods. All these five methods have been used for the same annual peak discharge data of the Gandak River at Lalganj discharge measuring site. The results by different methods of flood frequency analysis for annual peak discharge have been complied in Table 6. The same is presented on a semilogarithmic probability graphical paper in Fig. 3. All these are studied based on the empirical data analysis. It is presumed that the data is the representation of the peak discharges for a very long duration, and

Table 5 Flood frequency analysis of Gandak River at Lalganj: Foster type III method (1981–2013)

Recurrence interval (year)	Percent frequency	Factor K	Ks (s = 474)	Mean $\overline{X}$ (cumec)	Magnitude of flood x = $\overline{X}$ +Ks (cumec)
1000	0.1	5.91	2801.34	9343	12144.34
100	1	3.60	1706.40	9343	11049.40
5	20	0.61	289.14	9343	9632.14
2	50	−0.31	−146.94	9343	9196.06
1.25	80	−0.78	−369.72	9343	8973.28
1.05	95	−0.95	−450.30	9343	8892.70
1.01	99	−0.99	−469.26	9343	8873.74

Table 6 Comparison of flood frequency analysis obtained by different methods: Lalganj (1981–2013)

Return period (in years)	Probability (P) in %	Gumbel's method	Log-normal method	V.T. Chow's method	Pearson type III method	Foster type III method
1000	0.1	24822.58	13335.25	24529.40	'K' N.A.	12144.34
200	0.5	20905.89	'K' N.A.	20687.26	20215.14	'K' N.A.
100	1	19215.12	17436.25	19028.60	18574.78	11049.40
50	2	17518.09	'K' N.A.	17363.86	16918.07	'K' N.A.
10	10	13504.11	'K' N.A.	13426.04	12964.32	'K' N.A.
5	20	11879.83	11414.00	11636.80	11182.27	9632.14
2	50	8925.28	8961.50	8934.39	8650.89	9196.06
1.2500	80	6877.83	7054.00	6925.87	7116.80	8973.28
1.0526	95	5267.18	5609.75	5405.98	6364.74	8892.70
1.0101	99	4322.47	4601.50	4414.13	6081.36	8873.74

'K' N.A. = Frequency factor 'K' is not available

hence, it is normal. The observed behavior of the recorded peak discharges will keep on occurring in the nature even in the years yet to come. All these are probabilistic and not of any kind of certainty. The probabilistic approach is quantified based on certain assumptions of naturally occurring flood trend and behavior.

Flood Frequency Analysis and Flood Management

Flood frequency analysis by different methods gives an insight about the hydrologic characteristics of the river basin. In fact, flood is an outcome of numerous factors related to the shape, size, slope, nature of soil, amount of water, distance to be traveled by water, vegetation, human activities, and interferences of mankind with area pertaining to hindrances in the flow like road, bridges, embankments, barrages, dams in the basin. The amount of sediment load in a river system is also a function of many factors. When the highly charged sediment loaded water is channelized in the plain from the mountainous catchment, it leads to many vicious problems. Therefore, all the aspects concerning the flood must be tackled seriously in a systematic manner. It needs to bridge and block the loopholes which lead to flooding. It is not only applicable to the

Gandak River basin, but it must be followed for all the rivers on our earth. These are the basic principles of managing the flood. Area and basin-specific flood creating genesis must be identified first, and systematically, they should be taken care one by one but simultaneously as well.

The above-mentioned five methods of flood frequency analysis help us in knowing as to how much maximum discharge is expected to come. By knowing the discharges for different return periods, one can go for planning different flood controlling engineering structures. If the peak discharges for a particular site in the mountainous catchment are taken to analyze, it may help in designing the dam construction in the area concerned. It needs to take care of the discharge which may happen in certain return period. In the same manner, it also helps in determining the spacing between two embankments in the lower reach of the river. Delaying the water to flow from the source region is one of the best suitable methods of flood control. It helps in recharging the underground water and reducing the runoff. Underground water is again helpful to extract for various uses. For this good forest cover, check dams, improved agricultural practices, judicious land use management are the key factors. Building construction activities are completely banned in the flood line area in the riverbed. National Green Tribunal always looks after the

Fig. 3 Flood probability
analysis at Lalganj site

(a) Lalganj
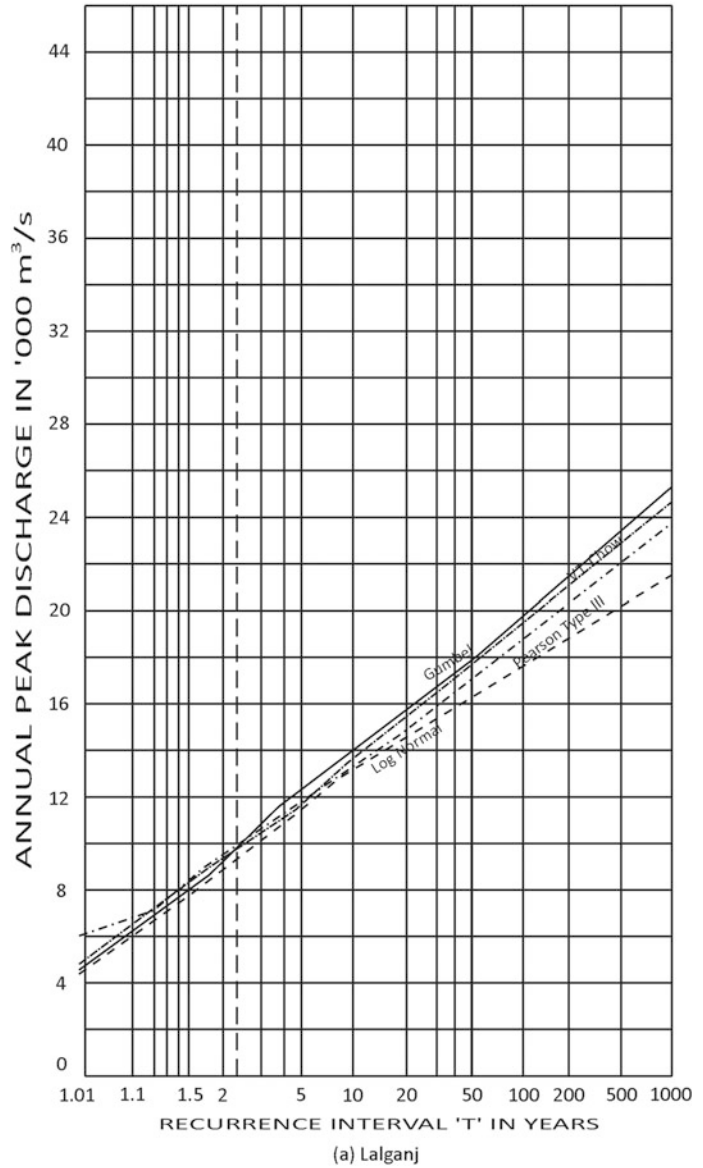
environmental issues. Its approval is needed before any developmental activities are initiated. If it is agreed upon wholeheartedly, many of the human generic problems may be minimized and it is also for the benefit of the overall societal development. Therefore, everything must be taken care in appropriate manner for the overall well-being.

Conclusions

Flood in the Gandak River basin is the result of heavy rainfall and snow melt in the mountainous catchment. Huge sediment is one of the important causes of mega fan building at the foothills. Heavily loaded sediment with water discharge

chocks the channels on the flat slope in the plain. Chocked channels have lesser carrying capacity of water and solutes. This leads to channel avulsion finally leading to shift in the course of river in a bigger span of time. This is also a cause of hardship to the people in its lower basin. Five methods of peak discharge analysis to estimate the recurring flood have been used in this paper. They are (i) Gumbel's extreme value distribution method, (ii) log-normal method, (iii) V.T. Chow's method, (iv) Pearson type III method, and (v) Foster type III method. These methods are helpful in knowing about the probable discharge for a given return period. The knowledge about this helps our civil engineers to plan different measures in river monitoring actions. The crux of flood reduction and mitigation measures is to manage the human activities in an integrated manner and hence achieve everything in the best suitable way. This ideal management must be translated into action in real life and followed by every human being—all inhabitant, all policy makers, and the concerned in implementing the same.

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