Drainage basin morphometry and evaluating its role on flood-inducing capacity of tributary basins of Mayurakshi River, India

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Abstract

The Mayurakshi River Basin (MRB), one of the most flood-prone areas of India, registers flood almost every year. The present work intends to identify the relative capacity of the tributary basins of the Mayurakshi system (three sub-basins of Dwaraka, two of Kuye and eight of Mayurakshi) to induce flood in its lower stretch. Based on basic morphometric parameters (basin length, area, perimeter, relief, stream number, and length) computed from Survey of India topographical maps (1:50,000) and SRTM DEM (30 m) using ArcGIS 10.4 software, we have derived 15 morphometric indices (linear-2, areal-7 and relief-6). The principal component analysis (PCA) depicts that there are three clusters of indices on the varimax-rotated component plot with the centroid of the distribution in positive–positive (++) quadrant which signifies a peak flow. Besides, the bi-variate relations between basin lag time and different morphometric indices signal that all the variables except compactness coefficient, hypsometric integral, dissection index, and bifurcation ratio portray negative relations implying peak flow instead of sustained one. In this paper, we have developed a technique called the flood-inducing capacity index (FCI) to measure the contribution of a tributary river to its master based on the morphometric coefficient and basin area coefficient. The FCI depicts that sub-basin Mayurakshi-6 has topped the list with ~21% contribution to MRB flood while Mayurakshi-8 having less than 2% contribution lies at the bottom. Besides, Dwaraka-3, Dwaraka-1 and Mayurakshi-3 basins each having more than 8% contribution control flood in the lower stretch of the Mayurakshi system. A statistically significant positive correlation ($R^2 = 0.75$) between the maximum discharge measured for the nine sub-basins and the FCI and the area under curve (0.889) on ROC plot ground the validation of the proposed method.

Keywords Morphometry analysis · Basin lag time · Compound ranking method · Flood-inducing capacity index · Maximum discharge

1 Introduction

Flood is a geo-hydrologic process commonly observed in floodplains and deltas. On the one hand, it creates and modifies the fluvial landscape and on the other, it brings sufferings to the people [1, 2]. Frequent flooding is inherent in the Ganga–Brahmaputra Delta [3]. Every year large rivers of this delta like Ganga, Brahmaputra inundates huge area triggering the sufferings of human beings [4].

Similarly, floods of Damodar, Ajay and Mayurakshi systems are widely noted for their severity on the life and livelihood of the people. Hence, this river system is often called as the sorrow of Bengal [5]. Thus, understanding and modeling flood behaviour become vital for resource appraisal and regional planning. Though flood is primarily a hydro-meteorological hazard, basin geomorphology plays an important role in triggering floods [6]. The study of a flood using morphometric properties of drainage basin was pioneered

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through the works of [7, 8]. This long-established tradition of studying flood in terms of linear, areal and relief aspects in geomorphology continues worldwide. However, recently geo-spatial techniques coupled with other field measurements are increasingly used in estimating flood hazards. Annis et al. [9] evaluated flood mapping using the digital terrain model (DTM) and stream order in Italy, Spain, and the UK. Similarly, flood mapping in the ungauged and data-sparse environment was done based on the linear binary geomorphic classifier derived from the digital elevation model [10, 11].

Mayurakshi River Basin (MRB) has been explored widely in terms of morphometric analysis. Pal et al. [12] found channel instability and asymmetry of the channel width of Mayurakshi, Dwaraka, and Kuye to be correlated strongly with anthropogenic activities. Besides, the flood behavior of MRB has drawn special attention for its history of colossal destruction of more than two century [13]. Flood of this basin is mainly due to the drainage congestion at the lower stretch of the river and typical basin morphometry [14]. Mukhopadhyay and Das [15] correlated occurrences of the flood with channel derangement of Mayurakshi River. Jha and Bairagya [16] depicted the spatiotemporal variation of flood and stressed the importance of paleo-flood data in flood management of the data-sparse environment. Mukhopadhyay and Let [17] showed that the intensity and frequency of flood of Dwaraka River, a tributary of the Mayurakshi system were found to be increasing with time due to increasing anthropogenic activities like construction of barrages, embankment and sand mining. Kuye River, another tributary of Mayurakshi has depicted increasing flood frequency with time [18]. Similarly, flood frequency of the Mayurakshi sub-basin is increasing after the construction of Tilpara barrage [19]. The impact of this barrage is not only confined to the main channel, but the tributaries joining the master get affected by channel sedimentation and reduced cubic capacity triggering more flood in the backwaters [20]. After the construction of Masanjore dam, stretch downstream of dams portrayed significant changes in hydro-geomorphology like lowering of pre-monsoon and monsoon water level and attenuation of the duration of the peak period [20, 21]. Based on a 75-year flood and rainfall data, Ghosh and Pal [22] depicted that flood of Lower Mayurakshi River has changed its character from the high magnitude low-frequency event to low magnitude high-frequency event due to controlled river regime by dams and barrages. The above literature portrays the severity of flood hazard in the MRB, especially in its lower stretch. The impact of dams and barrages on the flood is also adequately addressed. However, the role of an individual component (tributary river basins) to affect the whole system (MRB flood) is barely missing. Thus, the present research would address the following objectives:

Main objective: To assess the relative capacity of the tributary river basins in triggering a massive flood of the lower stretch of the Mayurakshi system using drainage basin morphometry.

Sub-objectives:

- (i) To find out the linear, areal and relief parameters (basic and ratio) of the tributary drainage basins and identifying the main control variables,
- (ii) To estimate discharge and basin lag time of the tributary basins using morphometric indices, and
- (iii) To propose flood-inducing capacity index based on morphometric parameters.

2 Study area

Mayurakshi River has originated from Trikut Hill near Deoghar, Jharkhand and has made a confluence with the Bhagirathi River at Kalyanpur having a flow path of 250 km. It extends from the 23° 37' 43" N to 24° 37' 36" N latitude and 86° 50' 16" E to 88° 15' 52" E longitude (Fig. 1) and covers a basin area of about 9596 km². This basin is configured by the three main rivers—Mayurakshi, Dwaraka, and Kuye. Based on the 'V' rule of Patton and Baker [23], we have demarked 13 sub-basins having a minimum order of 4 (8 sub-basins of Mayurakshi—M1 for Bhurbhuri River, M2 for Dhobai River, M3 for Matihara River, M4 for Tepra River, M5 for Bhamri River, M6 for Siddheswari River, M7 for Kushkarani River, M8 for Pusharo Nala; 3 sub-basins of Dwaraka- D1 for Dwaraka River, D2 for Chila-Gharmora Nala, D3 for Brahmani River and 2 sub-basins of Kuye-K1 for Kopai River and K2 for Bakreshwar River) (Fig. 1). The upper stretch of the river is a part of plateau fringe influenced by typical heavy downpour in the monsoon months especially during September and October [24]. This typical rainfall regime coupled with a low-pressure system developed over the Bay of Bengal induces floods in the basin. Apart from the classic floods at the historic time (1787 and 1806) as noted by O'Malley [25] in District Gazetteers, the study area in Mayurakshi basin is very vulnerable to flood attacks as far as previous scholarships are concerned. Moreover, the records of the District Disaster Management Plan prepared by [26] and Flood Preparedness and Management Plan by [27] coupled with the description of O'Malley [28, 25], and Walsh [29] give testimony to the severity of flood hazard in the study area and hence each flood event year and its related severity are presented in Table 1. Thus, huge monsoon discharge along with its annual sediment load of about 2.52 million tons trigger channel instability of the Mayurakshi system itself and the Lower Bhagirathi River system as well [30, 31]. It is to note that during

Fig. 1 Location of the tributary basins of the Mayurakshi River system and validation points

the colossal flood of 2000, the lower stretch of the basin was almost completely inundated. The total area of the basin under the flood water has been computed to be

~ 1490 km² during this flood (Fig. 2). Therefore, the frequent and violent floods marginalize agriculture and animal husbandry of this tropical region.

Table 1 Historical flood events in the Mayurakshi River Basin

Flood year	Flood severity
1787	A high flood occurred in Birbhum District due to excessive rainfall. Several villages, inhabitants, cattle, crops on the ground were washed out.
1806	The Mayurakshi River suddenly rose to an extraordinary height on 28th September and inundated the surrounding villages. Along the river bank, villages were completely washed out and the people were forced to climb trees for 3 nights. Large agricultural fields were also affected by sandsplay with several feet depth.
1884	Due to the breaching of the embankment along the Mayurakshi River, Kandi Town and surrounding areas were flooded at the end of August. The area was inundated for 24 h with a water depth of 2–3 feet.
1900	Due to 3 days (September 19–21) excessive rainfall, the Mayurakshi River and the Dwaraka River overflowed banks and flooded Kandi Town and Surrounding areas, damaging crops and mud-houses in 22 villages of Kandi Police Station. In Hijal lowland area cultivated Aman crops were mostly destroyed.
1902	The Suri Police Station and Murarai Police Station area were inundated due to overflowing of the Mayurakshi River and Brahmani River respectively as a consequence of heavy rainfall for 24 h in September. Along the north bank of the Mayurakshi River, several villages were damaged. Besides, Suri to Mahammad Bazar road was inundated and masonry bridge was destroyed. The villages near the railway line next to the Brahmani River were washed out
1904	Kandi Subdivision was affected partially by the overflowing of the Mayurakshi River.
1931	Kandi Subdivision suffered heavy losses due to this flood.
1933	Five thousand mud-houses in the Rarh area broke down and eight thousand people were affected by this severe flood.
1956	The 6-day stagnation of flood-water of the Dwaraka River destroyed many houses including 25% of the total crops of this area.
1959	The Dwaraka River overflowed and the floodwater remained for 3 weeks.
1968	The Mayurakshi, Brahmani, Dwaraka and Gambhira Rivers flooded simultaneously affecting Kandi Subdivision. The water level rose to a maximum of 7 feet above the normal level.
1978	On account of post-monsoon flood spill from the Mayurakshi River in October, 732 Mouzas in Birbhum and Murshidabad District especially the Kandi Subdivision were affected.
1989	The release of 19,000 cusecs of water on 2nd September from Tilpara barrage triggered inundation in the Kandi Subdivision destroying crops spreading over 18,000 acres of land.
1999	The irrigation bunds in Kandi Subdivision breached at several points due to the persistent release of water during September 24 to 27 from the Tilpara Barrage which caused the dreaded flood of the year.
2000	Due to the development of a low-pressure system in Bihar Plateau Region, heavy rainfall occurred in West Bengal and upper part of the Mayurakshi Basin. Consequently, 904 mouzas were affected in Birbhum and Murshidabad District.
2006	The C.D. Blocks Kandi, Bharatpur I, Bharatpur II, Khargram, Nabagram, Burwan were affected by flood due to overflowing of the Mayurakshi, Brahmani, Dwaraka, Kuye River
2007	The heavy rainfall (1622.6 mm) and consequent release of water from different barrages triggered floods which swept away 151 villages.
2009	The C.D. Blocks Kandi, Khargram, and Nabagram were severely affected.
2015	The Kandi Municipality and 7 C.D. Blocks suffered due to flood of Mayurakshi, Dwaraka, and Brahmani River.

Based on the report prepared by the Office of the District Magistrate [27, 26], O'Malley [28], O'Malley [25], and Walsh [29]

3 Database and methodology

The present work has been carried out using a systematic methodological design that starts with the identification of the research problems and ends with the validation of the results derived through some sequential steps (Fig. 3).

3.1 Collection of data

The five basic morphometric parameters (basin area, perimeter, length, maximum and minimum relief, stream number and length) for the 13 tributary river basins of MRB computed from the 1:50,000 Survey of India

topographical maps (72 L-14, 15, 16; 72 P- 2,3,4,7,8,11, 12,15,16; 73 M-1,5,6,9,10,13,14; 78 D-3, 4; 79 A-1, 2) and 30 m Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) using ArcGIS 10.4 software constitute the major source of the data for the present inquiry. Basin morphometry parameters (area, perimeter, and length) are derived through the processing of DEM using flow direction and accumulation function of the ArcGIS. Moreover, stream number and length have been measured from the topographical maps.

Fig. 2 Flood inundation area of the Mayurakshi River Basin in 2000 (Computed from Dartmouth Flood Observatory (DFO)-2000-061 East India and Bangladesh and Landsat 5 - path 139, row 43,44 dated 29.09.2000)

3.2 Methods of data processing

3.2.1 Computation of morphometric indices

With the help of the basic parameters, two linear, seven areal and six relief aspects/indices have been computed using the algorithms in Table 2.

3.2.2 Estimation of discharge-related parameters

Estimation of discharge (Q) from morphometric variables is a long-held tradition in fluvial geomorphology. Most of the previous works have estimated the discharge from the area of the drainage basin. However, depending on the climatic and hydro-geomorphic differences the coefficient and the exponent varies significantly. For example, Kirpich [43] derived α as 0.00032 and β as 0.77, Chow [44] derived α as 0.0012 and β as 0.64, Kennedy and Watt [45] derived α as 0.00018 and β as 0.75, Natural Environment Research Council [46] derived α as 0.0215 and β as 0.47. For the present case, the algorithm of Dickens as mentioned

by Alexander [47] has been embraced as it was developed to compute the peak discharge (Q) of the then Bengal province of India.

$$Q = 825A^{0.75} \quad (1)$$

Besides, components related to discharge is the competence of flow which can be measured in terms of computation of lag time (t_L) after Watt and Chow [48] and time of concentration (t_c) after National Resource Conservation Service [49] as follows:

$$t_L = 0.000326 \left(\frac{L}{\sqrt{S}} \right)^{0.79} \quad (2)$$

For basins with Area (A) 0.5 ha to 5840 km², Length (L) 100 m to 200 km, and Slope (S) 0.001–0.09 m/m.

$$t_c = 1.67t_L \quad (3)$$

Fig. 3 Flowchart of the methodology

3.2.3 Varimax rotation method

Varimax rotation method, a popular rotation method in PCA and factor analysis, was propounded by Kaiser [50] to simplify the interpretation of variable—factor relationship. This method converts the original factor loadings into two distinct groups—a few numbers of large loading (one) and a large number of small loading (zero). Following the methodology of Kaiser [50] it has been computed as below:

$$v = \sum_a \left\{ \left[n \sum_j (a_{js}^2 | h_j^2) 2 - \left[\sum_j (a_{js}^2 | h_j^2) \right] 2 \right] / n^2 \right\} \quad (4)$$

where $j=1,2,\dots,n$ are tests, $s=1,2,\dots,r$ are factors, a_{js} is the factor loading of the j th test on the s th factor, h_j^2 is the communality of the j th test

3.2.4 Compound ranking method and flood-inducing capacity index

To gauge the relative contribution of each tributary basin for inducing the flood of the Mayurakshi system, we have proposed an index i.e. flood-inducing capacity index (FCI) which is computed following a few steps. First, to get the compound rank (Cr) of each river basin, the compound ranking method, a popular technique to portray the ordering of the data [51], has been embraced for the present case. Thus, the compound rank of each

Table 2 Methods for computing morphometric indices

Sl. No.	Dimensions	Parameters	Algorithms	References
1	Linear	Basin magnitude (BM)	$BM = \sum N_{\mu} i$ N_{μ} = Number of stream; i for First order	[32]
2		Bifurcation ratio (BR)	$BR = \frac{N_{\mu}}{N_{\mu+1}}$ N_{μ} = Number of stream of a certain order; $N_{\mu+1}$ = Number of stream in next higher order	[33]
3	Areal	Drainage density (DD)	$DD = \frac{\sum L}{A}$ L = Length of the rivers; A = Basin area	[34]
4		Stream frequency (SF)	$SF = \frac{\sum N}{A}$ N = Number of stream segments; A = Basin area	[34]
5		Drainage texture (DT)	$DT = \frac{N_{\mu}}{P}$ N_{μ} = Total number of stream segments; P = Basin perimeter	[35]
6		Elongation ratio (ER)	$ER = \frac{\pi R^2}{A}$ R = Diameter of an equivalent circular area	[33]
7		Circularity ratio (CR)	$CR = \frac{4 \pi A}{P^2}$ P = Basin perimeter, A = Basin area	[36]
8	Relief	Form factor (FF)	$FF = \frac{A}{L^2}$ A = Basin area; L = Basin length	[34]
9		Compactness coefficient (CC)	$CC = 0.2821 \left(\frac{P}{A} \right)^{0.5}$ P Perimeter of the basin A = Basin area;	[37]
10		Relative relief (RR)	$RR = H_x - L_x$ H _x = Maximum relief; L _x = Minimum relief	[38]
11		Dissection index (DI)	$DI = \frac{RR}{H_x} \times 100$ H _x = Maximum relief; RR = Relative relief	[39]
12		Ruggedness number (RN)	$RN = \frac{RR \times DD}{K}$ K = a conversion constant (1000); RR = Relative relief; DD = Drainage density	[40]
13		Average slope (AS)	$AS = \tan^{-1} \frac{N x i}{K}$ N for Number of contour crossing per km; i for contour interval; K for constant (636.6)	[41]
14		Relief ratio (RT)	$RT = \frac{RR}{L}$ RR Relative relief of a basin; L Basin length.	[33]
15		Hypsometric integral (HI)	$HI = \frac{L_s}{L_{us}}$ L _s = Percentage of area uneroded; L _{us} = Percentage of area eroded	[42]

sub-basin is derived through the summation of the rank score (assigned according to flood-inducing capacity) of each morphometric variable following a ranking principle (Table 8). Second, the basin area coefficient has been computed as a ratio of the individual basin area to the total basin area. Third, the morphometric coefficient has been computed as a ratio of the compound rank of an individual basin to the compound rank of the total basin. Finally, the computation of FCI takes the consideration of basin area coefficient and basin morphometry coefficient. Theoretically, the higher the basin area coefficient the higher the potential discharge. However, the nature of flow (sustained or peak) depends on the morphometry coefficient which also directly controls the pace of flow. Therefore FCI is conceived as a multiplied form of the coefficients and may be equated as follows.

$$crj = \sum_{i=1}^n ri \quad (5)$$

$$FCIj = \left(\frac{a_j}{A} \right) \times \left(\frac{crj}{CR} \right) \quad (6)$$

where crj stands for the compound rank score for j sub-basin; i for morphometric parameters, and ri for the rank of the i th parameters; $FCIj$ for the flood-inducing capacity of the j th basin, a_j area of the j th sub-basin, A for total basin area accounted for by all tributary basins, CR for total compound rank score accounted for by the all tributary basins.

Theoretically, the index value will range from '0' to '1', but these extreme values are never reached in the real situation. Regarding basin area coefficient $\left(\frac{a_j}{A} \right)$, '0' signi-

fies no basin area for the sub-basin j and therefore no potential discharge and '1' signifies $a_j = A$ and total potential discharge through the sub-basin j . Concerning the morphometry coefficient $\left(\frac{c_j}{CR}\right)$, '0' indicates no flow and '1' extremely peaked flow. And regarding FCI, '0' implies no flood-inducing capacity while '1' for maximum flood-inducing capacity.

3.2.5 Validation techniques

For validating the results of the FCI, maximum discharge (Q_M) following a rainstorm was measured as an indicator of flood-inducing capacity at the outlet of the selected 9 drainage basins (Fig. 1) during the monsoon period (September 2019). To gauge maximum flow, the discharge was measured a day after the rain started taking the consideration of flow concentration. Doing with that, first, the cross-sections were undertaken using an Auto level and surface velocity was taken by float method. Then, the cross-sectional area (A) concerning wetted perimeter was computed using trapezoid method while the mean velocity (V) was obtained through the multiplication of the surface velocity with a commonly used constant 0.85 [52]. Thus, the maximum discharge (Q_M) is calculated as follows.

$$Q_M = A \times V$$

Finally, the observed discharge was compared with the computed FCI using a bivariate correlation. And the validity of 'r' was tested using Student's t test as follows.

$$t = \sqrt{\frac{r^2(N-2)}{1-r^2}}$$

where r = correlation of coefficient, N = number of observations.

Besides, the validation check is necessary to estimate the level of accuracy of the proposed FCI method. Thus, we have applied the receiver operating characteristics (ROC) curve which plots true positive rates (TPR) against the false positive rate (FPR) against different threshold points. The area under the curve is categorized as—excellent (0.90–1.00), good (0.80–0.90), fair (0.70–0.80), poor (0.60–0.70) and fail (0.50–0.60) for showing the level of accuracy [53]. For this present work, ROC has been prepared using IBM SPSS Statistics 20 software.

4 Results and discussion

4.1 Basin morphometry

The study of basin morphometry has a legacy in quantitative geomorphology for understanding the hydro-dynamics of a drainage basin. The classical approach to comprehend the fluvial response within a basin involves the careful consideration of the linear, areal and relief aspects. In the present context, we have attempted to study two linear, seven areal and six relief parameters/indices to trace out their role on flood-inducing capacity of the tributary basins. The 15 morphometric variables are presented uniformly concerning their spatial variation and descriptive statistics. The first parameter involves stream order, number, and length. Strahler basin order (highest stream order of a basin after Strahler) is positively correlated with peak discharge [54, 55]. In the MRB, D3, M2, M3, M5, and M6 have basin order above 6. However, Baker and Patton [23] found that Strahler order is not a good measure of flood peak because it does not have any control over basin topology. Thus, Shreve magnitude (number of the first-order streams of a basin after Shreve) was found to be strongly correlated with the flood discharge. In the MRB, D1, M3, M4, and M7 basins have higher Shreve magnitude per unit basin area with their correspondingly effect on the flood. Furthermore, the stream order is indirectly correlated with the stream number and length (Fig. 4a, b). The order-number relationship is strongly negative ($r^2 > 0.95$) while the order-length relationship is also negative with a variable degree of correlation (Table 3). For example, the basin K1 portrays a poor relation ($r^2 = 0.16$) while basin K2, D1 and M3 also have a moderate degree of relation ($0.5 < r^2 < 0.80$). However, the rest of the sub-basins portray $r^2 > 0.90$. Moreover, if we look into the ratio of first-order stream number and length to that of the total, it appears that more than 70% streams are first order having the highest for M6 ($n = 1506$) river and lowest for M8 ($n = 106$). However, the ratio regarding length portrayed that about 50% of the total is the first-order length having the highest for M6 (969.13 km) and lowest for M8 (65.50 km). Regarding length ratio, the Dwaraka and Kuye are located well below 50% (Fig. 4c). Similarly, concerning the average bifurcation ratio a moderate degree of the range and standard deviation (SD) is observed (Table 4) and is spatially segregated into low (2.5–3.99), medium (4–5.49) and high (5.5–6.99) classes (Fig. 5a). The higher the bifurcation ratio, the lesser the flood magnitude in the lower reaches of the river. We have also computed order wise bifurcation ratio which shows that the median bifurcation ratio is decreasing with higher order. The range, quartile 1 and quartile 3 and median have been plotted on boxplot

Fig. 4 Spatial dynamics in stream order. **a** Stream order in relation to stream number, **b** Stream order in relation to stream length, **c** Basin-wise first order stream number and stream length to total

(Fig. 5b) which portrays that the range of the data is high for the 4/5th order ratio. The drainage density strongly controls flood magnitude in two opposite ways. On the one hand, higher density coupled with high slope transfers water quickly towards downstream thereby inducing peak

discharge in the lower stretch. On the other, higher density with minimum slope retains water in the concerned basin itself. However, theoretical debates indicate that the higher density increases drainage response thereby producing flood peaks. In the Mayurakshi Basin, the spatiality

Table 3 Relationship between stream order, stream number, and stream length

Sub-basin	The relation between stream order and stream number		The relation between stream order and stream length	
	Equation	R ²	Equation	R ²
D1	$4133.5e^{-1.693x}$	0.9931	$584.99e^{-0.555x}$	0.7147
D2	$843.93e^{-1.411x}$	0.9852	$259.3e^{-0.568x}$	0.8478
D3	$3803.3e^{-1.246x}$	0.9875	$1027.6e^{-0.48x}$	0.9047
K1	$620.1e^{-1.35x}$	0.9854	$100.51e^{-0.252x}$	0.1618
K2	$1632e^{-1.512x}$	0.996	$346.29e^{-0.487x}$	0.5925
M1	$1312.4e^{-1.465x}$	0.9963	$268.25e^{-0.587x}$	0.8944
M2	$1393.3e^{-1.234x}$	0.9956	$475.46e^{-0.644x}$	0.9695
M3	$1898.5e^{-1.326x}$	0.988	$470.08e^{-0.628x}$	0.7959
M4	$4150.7e^{-1.636x}$	0.9978	$629.53e^{-0.636x}$	0.912
M5	$302.07e^{-1.009x}$	0.9681	$180.99e^{-0.663x}$	0.9628
M6	$6447.5e^{-1.49x}$	0.9979	$1432.5e^{-0.642x}$	0.9702
M7	$1718.1e^{-1.796x}$	0.9858	$252.64e^{-0.597x}$	0.9496
M8	$292.85e^{-1.189x}$	0.9872	$99.261e^{-0.59x}$	0.9706

Computed by the authors, 2018

of the drainage density is recorded through low (0.5–0.99), medium (1–1.49) and high (1.5–1.99) classes (Fig. 6a) and thus portraying their corresponding roles on the flood. The fourth is the stream frequency indicating a relative presence of stream segments in a particular basin and has similar control over flood frequency and magnitude like drainage density. In the MRB, the spatial heterogeneity is measured through low (0–0.99), medium (1–1.99) and high

(2–2.99) classes (Fig. 6b) to relate it with the flood. Similarly, the drainage texture denotes the relative spacing of the drainage lines in an area. It may be fine or coarse depending on the evolutionary history of the basin, climate and rock type [56]. The wide range and the SD are notable (Table 4) and its spatial segregation into low (0–1.99), medium (2–3.99), and high (4–5.99) is also remarkable (Fig. 6c). The elongation ratio (ER) signals about the basin shape. Schumm [33] indicated that the higher the value of ER the higher the circularity of the basins. The MRB is constituted by diversified tributary basin shape and hence ER ranges from 0.44 (K1) to 0.93 (M2) (Table 4). The spatiality of the ER is noted through low (0.4–0.59), medium (0.6–0.79), and high (0.8–0.99) categories (Fig. 6d). The previous scholastic works are in wide agreement that the higher the circularity, the higher is the flood peak and vice versa. The circularity ratio (CR) signifies structural control and stages of basin evolution. The higher the CR, the higher is the structurally controlled drainage system besides its advanced stage of evolution. It also greatly determines the flood potency in a way similar to the elongation ratio. For example, the higher CR is often marked as inducing peakedness in the discharge. In the MRB, the circularity ratio ranges from 0.42 (M1) to 0.14 (K1) and segregated into three categories—low (0.1–0.24), medium (0.25–0.39), and high (0.4–0.54) with their corresponding effects on flood (Fig. 6e). The form factor is another dimensionless ratio indicative of basin shape. For the Mayurakshi Basin, the form factor ranges from 0.68 (M2) to 0.15 (K1) basin. The sub-basins are clubbed into low (0.1–0.29), medium (0.3–0.49), and high (0.5–0.69)

Table 4 Descriptive statistics of the morphometric variables

Morphometric variables	Average	SD	Minimum	Maximum	Kurtosis	Skewness
Basin magnitude/basin area (BM)	1.33	0.53	0.32	2.03	−0.27	−0.69
Average bifurcation ratio (BR)	4.32	1.08	2.95	6.76	0.82	1.10
Drainage density (DD)	1.52	0.41	0.60	1.93	1.00	−1.34
Stream frequency (SF)	1.72	0.66	0.43	2.58	−0.03	−0.83
Drainage texture (DT)	2.85	1.47	0.25	4.92	−0.48	−0.50
Elongation ratio (ER)	0.64	0.12	0.44	0.93	2.67	1.05
Circularity ratio (CR)	0.31	0.08	0.14	0.42	−0.17	−0.69
Form factor (FF)	0.33	0.13	0.15	0.68	4.28	1.71
Compactness coefficient (CC)	1.86	0.33	1.56	2.73	3.25	1.71
Relative relief (RR)	322.77	158.30	98.00	604.00	−0.47	0.34
Dissection index (DI)	0.80	0.11	0.62	0.97	−1.33	0.05
Ruggedness number (RN)	0.26	0.15	0.06	0.54	−0.50	0.57
Average slope (AS)	1.85	0.68	0.75	3.13	−0.18	0.02
Relief ratio (RT)	10.39	5.54	2.24	18.19	−1.22	−0.21
Hypsometric integral (HI)	0.23	0.09	0.13	0.42	0.14	0.94

Fig. 5 Bifurcation ratio. **a** Basin-wise average, **b** Order-wise distribution

categories (Fig. 6f). The higher the value the greater the circularity and hence higher flood potency. Moreover, the compactness coefficient (CC) is a good measure of basin efficacy to the hydrologic response. If the value of this measure becomes 1 the basin would be perfectly circular and the basins having a value greater than this limit tend to be elongated [37]. In the MRB, the compactness coefficient ranges from 2.7 (K1) to 1.6 (M1) basin implying none of the sub-basins having circular shape. The wide variation is segregated into low (1.5–1.99), medium (2–2.49), and high (2.5–2.99) categories (Fig. 7a) with an implication that the lower the value the greater the flood potency. Furthermore, basin relief and slope have long been recognized as important hydrologic parameters. The previous works of Sherman [57], Horton [56] and Strahler [58] indicate that higher basin relief leads to lower time of concentrations of surface run-off and thus producing higher flood peaks. In the MRB, the relative relief ranges from 604 m (M6) to 98 m (M7) basin. Due to the wide variations in the relief we have segregated the sub-basins into three classes—low (50–249), medium (250–449), and high (450–649) (Fig. 7b). Similarly, the dissection index ranges from 0.97 (D3) to 0.62 (M7) basin (Table 4). For the present study, there are three graduated classes of dissection index—low (0.55–0.69), medium (0.7–0.84), and high (0.85–0.99) (Fig. 7c). The higher DI induces more flood potency. Ruggedness number is the product of basin relief and drainage density [59]. It is one of the important relief parameters controlling the floods of record. In general, the higher value of this ratio

induces flood peak. Patton [60] stated that a highly dissected basin of low relief is as rugged as that of a basin with a moderately dissected area of high basin relief. In the MRB the ruggedness number ranges from 0.54 (M6) to 0.06 (M7) with a high SD (Table 4). Based on the observation of the ruggedness number of the individual drainage basin, they have been segregated into three classes—low (0–0.24), medium (0.25–0.49), and high (0.5–0.74) (Fig. 7d). The basins having higher ruggedness number produce more flood peak. The average slope is an important determinant of flood magnitude as it increases the flow competence of the river by decreasing the time of concentration of surface run-off [57]. For the present basin, the average slope ranges from $\sim 3^\circ$ (M1) to $\sim 1^\circ$ (K1). The division of sub-basins into low (0.5° – 1.49°), medium (1.5° – 2.49°), and high (2.5° – 3.49°) categories portrays the spatiality of the average slope (Fig. 7e). The higher the basin slope the higher the flood peak. Relief ratio is another important tool in assessing the floods especially in the diverse hydrologic and physiographic control [23] in the way similar to the average slope. In the MRB, relief ratio ranges from 18.19 (M5) to 2.24 (K2) with a high SD (Table 4) and segregated into three classes—low (0–7.49), medium (7.5–14.99), and high (15–22.49) (Fig. 7f). The last parameter is hypsometric integral (HI) which defines the stages of geomorphic evolution of the landscape. After [42], the value of HI less than 0.35 denotes old, 0.35–0.60 indicates mature and greater than 0.60 implies youth. In the MRB, the hypsometric integral ranges from 0.42 (M7) to 0.13 (M3). The spatiality

Fig. 6 Drainage characteristics and basin shape. **a** Drainage density, **b** Stream frequency, **c** Drainage texture, **d** Elongation ratio, **e** Circularity ratio, **f** Form factor

Fig. 7 Basin relief. **a** Compactness coefficient, **b** Relative relief, **c** Dissection index, **d** Ruggedness number, **e** Average slope, **f** Relief ratio

Fig. 8 Hypsometric curve of the tributary basins

Table 5 Correlations matrix

	BM	BR	DD	SF	DT	ER	CR	FF	CC	RR	DI	RN	AS	RT	HI
BM	1														
BR	0.189	1													
DD	0.955**	0.112	1												
SF	0.992**	0.108	0.975**	1											
DT	0.983**	0.108	0.961**	0.993**	1										
ER	0.423	−0.264	0.505	0.467	0.431	1									
CR	0.429	−0.198	0.558*	0.498	0.485	0.653*	1								
FF	0.357	−0.292	0.434	0.402	0.368	0.992**	0.584*	1							
CC	−0.51	0.101	−.646*	−.572*	−0.549	−.662*	−.966**	−.583*	1						
RR	0.618*	−0.284	0.619*	0.629*	0.644*	0.311	0.361	0.261	−0.359	1					
DI	−0.269	−0.079	−0.352	−0.332	−0.331	−0.287	−0.373	−0.295	0.392	0.371	1				
RN	0.49	−0.231	0.488	0.486	0.498	0.184	0.214	0.136	−0.221	0.972**	0.557*	1			
AS	0.538	−0.419	0.660*	0.603*	0.567*	0.481	0.593*	0.424	−.583*	0.551	−0.212	0.437	1		
RT	0.612*	−0.524	0.680*	0.677*	0.661*	0.698**	0.773**	0.652*	−.722**	0.564*	−0.317	0.393	0.772**	1	
HI	−0.432	0.55	−0.433	−0.454	−0.432	−.606*	−0.551	−.568*	0.483	−.751**	−0.276	−.687**	−.585*	−.800**	1

Computed by the authors, 2018

**Correlation is significant at the 0.01 level at 2-tailed, *Correlation is significant at the 0.05 level at 2-tailed

Table 6 Factor loading in PC-I and PC-II

Variables	PC-I loadings		PC-II loadings		PC-I explained variation		PC-II explained variation	
	Initial	Rotated (vari-max)	Initial	Rotated (vari-max)	Initial	Rotated (vari-max)	Initial	Rotated (vari-max)
BM	0.828	0.785	−0.076	0.275	53.956	47.462	16.517	23.011
BR	−0.24	−0.069	−0.36	−0.427	($\Sigma^2 = 8.093$)	($\Sigma^2 = 7.119$)	($\Sigma^2 = 2.478$)	($\Sigma^2 = 3.452$)
DD	0.887	0.865	−0.14	0.243				
SF	0.872	0.837	−0.106	0.266				
DT	0.855	0.815	−0.091	0.273				
ER	0.73	0.761	−0.234	0.092				
CR	0.764	0.808	−0.273	0.07				
FF	0.666	0.705	−0.24	0.059				
CC	− 0.782	− 0.844	0.319	−0.036				
RR	0.727	0.395	0.637	0.882				
DI	−0.245	− 0.594	0.892	0.709				
RN	0.576	0.205	0.766	0.936				
AS	0.779	0.683	0.06	0.379				
RT	0.903	0.833	−0.03	0.349				
HI	− 0.749	−0.484	−0.472	− 0.741				

Computed by the authors, 2018 (Note the bold numerical figures indicate strong loadings)

portrays that most of the sub-basins belong to the old stage ($HI < 0.35$) (Fig. 8). Thus, all the basins have attained steady-state equilibrium conditions in the evolutionary

process. One of the important features is the presence of residual hills akin to monadnock [61].

4.2 Association between morphometric parameters and their orientation to flood

To glean out the perspective of association between the 15 morphometric variables we have performed bi-variate correlation (Table 5) that depicts a strong and significant

Fig. 9 Association of morphometric indices on 2-dimensional component plot

correlation between some bi-variate couplings while others have had insignificant relations. The strong positive relations ($r > 0.65$) have been observed between RR-RN, RT-AS, BM-DD, BM-SF, BM-DT, RT-ER, RT-DT, RT-SF, RT-DD, RT-CR, RT-FF, DD-SF, DD-DT, SF-DT, ER-FF. The correlations are significant at the 0.01 level (2-tailed). Besides, moderately strong positive relations ($r = 0.55$ to 0.65) have been shown by the couplings of RR-BM, RR-RT, RR-DD, RR-SF, RR-DT, DI-RN, AS-SF, AS-CR, BM-RT, DD-CR, CR-FF. These are also significant at the 0.05 level (2-tailed). Similarly, there are few couplings HI-RT, HI-RR, HI-RN, RT-CC, CR-CC, ER-CC having strong negative correlations ($r \geq -0.65$) and also portraying high significance level (0.01) at 2-tailed. Besides, we have found that some sets HI-AS, HI-FF, HI-ER, HI-CR, AS-CC, DD-CC, SF-CC, FF-CC have moderately strong negative relation ($r = -0.55$ to -0.65). These relations are also significant at 0.05 level at 2-tailed. Thus, we have found that RT is having the widest association with the other variables followed by AS and RR. However, the RN is distancing from the other neighbouring variables significantly.

Bi-variate correlation gives an impression of the two variables only. Thus, to depict the association between different variables on multi-dimensional space and to find out the main morphometric variables responsible for inducing flood we run a PCA. The initial factor loading in PC-I shows that the RT with the highest score (0.903) is controlling the system in a positive direction thereby inducing a

Table 7 Estimation of discharge, lag time and time of concentration

Sub-basin	Basin area (km ²)	Basin length (km)	Slope (°)	Q max (825A ^{0.75})	Basin lag time (h)	Time of concentration (h)
D1	557.07	42.48	1.51	94,599.32	6.47	10.80
D2	272.66	27.86	1.54	55,357.04	4.59	7.66
D3	1262.94	72.77	2.32	174,779.79	8.06	13.46
K1	554.11	60.27	0.75	94,221.36	10.78	18.00
K2	726.16	54.49	0.84	115,406.10	9.52	15.90
M1	202.68	24.31	3.13	44,316.62	2.98	4.97
M2	321.61	21.82	1.99	62,654.94	3.30	5.51
M3	316.32	31.98	1.93	61,879.98	4.52	7.56
M4	381.70	34.33	1.94	71,242.95	4.78	7.99
M5	121.87	16.33	2.66	30,260.94	2.35	3.93
M6	874.45	49.42	2.09	132,664.17	6.12	10.22
M7	177.92	26.70	1.18	40,190.12	4.64	7.76
M8	72.68	16.56	2.18	20,535.06	2.50	4.18

Computed by the authors, 2018

flood peak. Similarly, other variables like RR, RN, AS, BM, DD, SF, DT, ER, CR, and FF having scored above 0.5 (Table 6) also controls strongly to induce peak flood. However, some variables like HI, DI, BR, and CC are controlling the system in a negative direction thereby producing sustained flow pattern in the basin. In PC-II, RR, DI, and RN having loading above 0.5 control the system in a positive direction. However, the factors loadings derived through rotation in Varimax with Kaiser Normalization portray that reduced number of variables (DI, AS, BM, RT, DD, SF, DT, ER, CR, FF, and CC) appeared in PC-I with higher factor loadings (> 0.5) while an increasing number of variables (HI, RR, DI and RN) appeared in PC-II with factor loadings above 0.5 (Table 6) after rotation. Thus, the variations explained are distributed between the PCs. We have also observed that explained variation has decreased from about 54% at initial to about 47% after rotation in PC-I. Contrarily, Eigenvalue (λ) has increased from about 17% at initial to about 23% after rotation in PC-II. Thus, the varimax rotation has eased the problem of finding the major control factors for the flood of the MRB. Based on the factors loadings (after varimax rotation) of the first two components of the PCA, we have delineated three clusters of variables (Fig. 9). It is interesting to note that all three clusters are located in the positive–positive quadrant (+ +). The first cluster is consisting of RN and

RR while the second and largest cluster is formed by six variables like AS, RT, BM, DT, SF, and DD. Similarly, the third cluster is constituted by the three variables like ER, CP, and FF. Furthermore, four variables have formed outliers in the system of which one (DI) is located in the positive–negative (+ –) quadrant another three (CC, HI, and BR) are located in the negative–negative (– –) quadrant (Fig. 9). However, the plot of spikes on the centroid method depicts that gravity of the system components is located in the positive–positive quadrant thereby inducing a peak flow.

4.3 Discharge, lag time and flood

Estimation of discharge using morphometric parameters especially the drainage basin area is a long-held tradition in flood geomorphology. However, computing the constant (c) and the exponent (k) is a major task before the hydrologists which depends on regional setting, range of area and climatic regime [62, 63]. The 'k' trends to decrease with increasing area and aridity and increase with the increasing number of variables. Thus, 'k' varies according to the regional factors. For example, Myers [64] in the USA has devised $k = 0.5$ while Dickens' value for India (then Bengal province) was 0.75 which continues its use in flood hydrology [47]. Similarly 'c' also varies in different regions.

Fig. 10 Relation between basin lag and drainage basin area

Table 8 Relationship between basin lag time (tL) and other morphometric properties

Morpho-metric variables	Basin lag time			Nature of flow	Ranking principle
	a	b	r		
BM	9.487	− 3.041	−.605*	Peak discharge	2
BR	3.912	0.352	0.143	Sustained flow	1
DD	12.531	− 4.675	−.726**	Peak discharge	2
SF	10.073	− 2.704	−.668*	Peak discharge	2
DT	8.643	− 1.127	−.621*	Peak discharge	2
ER	14.936	− 14.912	−.655*	Peak discharge	2
CR	13.163	− 24.743	−.790**	Peak discharge	2
FF	9.538	− 12.482	−.599*	Peak discharge	2
CC	− 6.688	6.502	0.804**	Sustained flow	1
RR	6.467	− 0.003	− 0.191	Peak discharge	2
DI	− 6.389	14.803	0.633*	Sustained flow	1
RN	5.530	− 0.370	− 0.020	Peak discharge	2
AS	10.449	− 2.709	−.697**	Peak discharge	2
RT	9.491	− 0.390	−.814**	Peak discharge	2
HI	2.385	13.047	0.430	Sustained flow	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). a y intercept with x; b slope of the line; r correlation coefficient; 1 higher rank for lower value of the variables; 2 higher rank for higher value of the variables

For example, in the Bengal area, it was computed to be 825. Thus, using this algorithm the maximum discharge has been computed for the sub-basins of the Mayurakshi River (Table 7). Similarly, we also have computed the other two significant variables of flood discharge—basin lag time and time of concentrations. We have observed that basin length is directly correlated with the basin lag and time of concentration and basin slope is inversely correlated with it. In the present study, we have found the sub-basin K1 has secured the highest ‘tL’ of about 11 h and ‘tc’ of about 18 h. On the other hand, sub-basin M5 is

located at the bottom with ‘tL’ of about 2.4 h and ‘tc’ about 4 h (Table 7). It can thus be argued that the higher the ‘tL’ and ‘tc’, the lesser is the flow competence of the basin. This results in higher basin inundation and lesser capacity to induce flood in the lower stretch of the basin. Basin lag which thus determines the flood greatly is inversely correlated with rainfall intensity. However, the non-linearity in the relationship increases with the decreasing drainage density [65]. Boyd [66] established a geometric relation between stream orders and lag time like the equations of stream length [56] or stream area [33]. The higher the stream order, the higher is the basin lag. It is obvious that the higher the stream order, the higher is the basin area. Thus, lag time increases with the increasing basin area. For the Mayurakshi Basin, we have established a strong direct relation ($R^2 = 0.72$) with an exponent of 0.51 (Fig. 10).

4.4 Compound raking method and flood-inducing capacity index

The compound ranking method is a common technique used widely by the geoscientists in the areas of rating statistics or order. However, rating the morphometric variables in the context of flood magnitude poses difficulty while assigning scaled values. For example, drainage density may increase the flood magnitude or decrease the flood magnitude depending upon the slope and other parameters of the basins. Thus, in the present context rating of 15 morphometric variables has been based on the empirical observation of the relation between basin lag and other morphometric variables (Table 8). This relation is assessed using the linear ($yc = a + bx$) equation. The ‘a’ (y intercept with x), b (slope of the line) and ‘r’ (correlation coefficient) indicate the nature of relation (Table 8). If ‘r’ is positive between a chosen variable and lag time the flow will be of sustained nature. However, if it is negative flow will be portraying flood peak. Therefore we have followed the principle that the lower the rank scores the lower the lag time and higher efficiency for peak discharge and vice versa. Thus, following this principle we have ranked each of the 15 morphometric variables and summed up to get a compound rank. The un-weighted average (Cra) of this compound rank indicates the dynamics of the sub-basin from the perspective of the morphometric indices (Table 9). Thus, we have observed that regarding Cra, M3 tops the list having a score of ~ 10.5 followed by the M1 and M6 both having a score of 9.13 (Table 9). Similarly, the rest of Mayurakshi sub-basins like the D1 (6.13), and D2 (6.53) induce flood moderately in the downstream portion

Table 9 Morphometric coefficient, basin area coefficient and flood-inducing capacity index

Sub-basin	Compound rank score (Cr)	Average compound rank (Cra)	Drainage basin area (km ²)	Morphometric coefficient (C)	The ratio of Basin area (a/A)	Flood-inducing capacity index (FCI)	The proportion of FCI (%)	FCI rank
D1	92	6.13	557.07	0.0674	0.0954	0.0064	8.92	3
D2	98	6.53	272.66	0.0718	0.0467	0.0034	4.65	9
D3	91	6.07	1262.94	0.0667	0.2162	0.0144	19.99	2
K1	45	3	554.11	0.033	0.0948	0.0031	4.34	10
K2	49	3.27	726.16	0.0359	0.1243	0.0045	6.19	7
M1	137	9.13	202.68	0.1004	0.0347	0.0035	4.83	8
M2	133	8.87	321.61	0.0974	0.0551	0.0054	7.45	6
M3	157	10.47	316.32	0.115	0.0541	0.0062	8.63	4
M4	119	7.93	381.7	0.0872	0.0653	0.0057	7.9	5
M5	128	8.53	121.87	0.0938	0.0209	0.002	2.72	11
M6	137	9.13	874.45	0.1004	0.1497	0.015	20.84	1
M7	70	4.67	177.92	0.0513	0.0305	0.0016	2.17	12
M8	109	7.27	72.68	0.0799	0.0124	0.001	1.37	13
Total			5842.17	1	1	0.0721	100	

Note: Computed by the authors, 2018

Fig. 11 Flood-inducing capacity of the tributary basins

Table 10 Maximum discharge measured for the different sub-basins during the monsoon

Sub-basin	Cross sectional area with reference to wetted perimeter (m ²)	Velocity (m/s)	Maximum Discharge (Cumecs)
D1	100.89	0.57	57.17
D2	48.71	0.56	27.33
D3	139.53	0.63	87.96
K2	143.98	0.41	58.65
M2	45.51	0.57	26.00
M3	55.75	0.62	34.63
M4	70.05	0.68	47.59
M6	114.21	0.93	105.66
M7	59.01	0.74	43.91

Fig. 12 Relation between the FCI and maximum discharge

of the basin. The sub-basins D3 (6.07), and K2 (3.27) and K1 (3) determine the flood of the lower stretch of the basin with the minimum contribution in this scale. However, flood-inducing capacity greatly depends on the basin area. Thus, the ratio of basin area has been computed for every tributary basin which has been multiplied by the morphometric coefficients. Finally, we have derived the flood-inducing capacity index (FCI) that portrays that M6

controls the flood of MRB with maximum efficiency while M8 with the least efficacy (Fig. 11).

4.5 Validation

The FCI has been validated with the maximum discharge (Q_M) data measured from nine sub-basins. The highest Q_M (105.66 cumecs) has been recorded for the M6 sub-basin while the lowest Q_M (26 cumecs) has been portrayed by the M2 sub-basin (Table 10). It has been observed that there is a strong correlation ($R^2 = 0.75$) between the FCI and the maximum discharge (Fig. 12). The student's t test

Fig. 13 Model validation using ROC curve

also portrays that the computed value of 't' is 4.57 at 95% confidence level with 7 degrees of freedom ($v = n - 2$) while the tabulated 't' value is 2.365. This implies a statistically significant relation. Besides, the plot of the ROC curve (1-specificity versus sensitivity) shows that area under the curve (AUC) records 0.889 (Fig. 13). In other words, 88.9% area falls under the ROC implying that the model is validated at a good category against 95% confidence level. This also proves that the proposed FCI is validated.

5 Conclusion

The annual nature of the flood of MRB is principally a response to the flashy nature of the rainfall regime of Chhotonagpur Plateau region. The PCA reveals that out of 15 morphometric indices five (RT, DD, SF, DT, and CR) having factor loading (after varimax rotation) > 0.8 have emerged as the main factors controlling the flood magnitude. The bi-variate relations between the lag time and morphometric variables have segregated the four variables (HI, DI, CC, and BR) promoting the sustained flow thereby reducing the peakedness in the discharge hydrograph. The compound ranking method involving the morphometric indices shows the morphometric coefficient (C) of each of the 13 tributary river basins of MRB. Thus, the M3 has appeared as the principal basin having C of 0.115 while sub-basin K1 (0.033) as the lowest contributing basin. Similarly, we also have derived basin area coefficient (a/A) being highest for D3 (0.216)

and lowest for M8 (0.012). Finally, FCI, a product of the C and a/A, has marked the M6, D3, D1, M3, M4, and M2 tributary basins (each having more than 7% contribution) as highly flood-inducing components of the MRB system. The correlation ($R^2 = 0.75$) between the FCI and maximum discharge collected from the field measurements and the ROC (AUC = 0.889) proves the suitability of the index to portray the role of the tributary basins to induce a flood of the master basin. However, as the index is purely based on the morphometric parameters this may be extended and tested in other climatic regions taking the consideration of factors like climate, vegetation, soil, and land use and land cover characteristics.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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