



Flood vulnerability mapping using frequency ratio (FR) model: a case study on Kulik river basin, Indo-Bangladesh Barind region

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Abstract

Flood is a natural but inevitable phenomenon occurring over the period of time. It not only damages the life, property and resources, but also hampers the economy of a nation. In this paper, an attempt has been made to delineate flood vulnerability areas for Kulik river basin through frequency ratio model. Parameters like slope, elevation, rainfall, drainage density, land use–land cover, TWI, population density, road density and household density were endorsed for understanding flood mechanism. In general, 70 (70%) flood locations from flood inventory map were randomly selected for constructing flood vulnerability map parameters and the rest 30 (30%) flood locations were used for justifying the outcomes. Flood vulnerability zone map was classified into five zones such as very low (2.02 km²), low (2.45 km²), moderately low (2.44 km²), high vulnerable (2.26 km²) and very high vulnerable (1.21 km²) area. As the AUC value for success rate is 0.901, the constructed flood vulnerable map with FR model is very much accurate for this river basin. The outcome of this paper will help the planners and decision-makers to take some probable measure to minimize flood vulnerability in this region.

Keywords Kulik river basin · Flood · Vulnerability · Frequency ratio (FR) model · Receiver operating characteristic (ROC)

Introduction

Across the globe in every year, different kinds of natural as well as man-induced hazards and disasters like floods, earthquakes and landslides are causing a large amount of life loss and property damage (Youssef et al. 2011; Du et al. 2013; WHO 2003; Tehrany et al. 2017). Floods occur when there is an overflow of huge volume of water beyond its normal limits, causing inundation of river banks and water stagnation for temporary season. Floods play a role of prime mover for damaging environmental ecosystem, transport system, agriculture and farming, and sociocultural hereditament and altering human life (Billa et al. 2006; Yu et al. 2013; Messner and Meyer 2006; Rahmati et al. 2016a, b, c, d). An immense number of research works have been done on classifying different types of floods and their short- and long-term effects. Magnitude of flood is one of the major

factors that determine its impacts. In estimating all inclusive impacts, the direct or indirect damages due to floods can be stratified into materialistic and non-materialistic things (Li et al. 2012; Merz et al. 2004; Smith and Ward 1998). Throughout the globe, floods are considered the major catastrophic events that occur suddenly, causing huge money, health and wealth loss. In between 1963 and 1992, among the different kinds of hazardous events floods are causing 32% of damage to human and environment. In Orissa and Andhra Pradesh, high-catastrophic sudden flood causes huge amount of property and life loss (Dhar et al. 1981a; WMO 1994; Dhar and Nandargi 2003). Failure of dam due to sudden heavy precipitation has stimulated flood downstream. In 1979, Morvi town of Saurashtra discern uncountable loss of property, crops, livestock and about 10,000 human lives due to Machhu dam failure (Dhar et al. 1981b; Dhar and Nandargi 2003). Uncertainty in climatic condition in Iran persuades a vast number of flooding events throughout the year. The financial vandalization amount escalates to 1705 thousand dollars ascribed to flooding situation in the past decade (Norouzi and Taslimi 2012; Khosravi et al. 2016). India is situated under highly inconsistent monsoon climate, a large number of rivers flow through all over the country, and a heavy downpour of rains for a prolonged time can

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persuade flooding condition. According to Central Water Commission 2010, India is the second largest flood-prone country after Bangladesh with about 40 million hectares of land under flood prone. In every year in India on an average 7.6 million hectares of land is affected by floods. Statistical data provided by CWC divulge that in India flood causing around 200 billion dollars worth of capital loss and 92,000 people died in between 1953 and 2009 (CWC 2010). Every year, people died due to this calamity all over the Earth, an approximately 20% of world's people died in India. Around 1500 peoples lost their lives, and in average 3 cores of peoples are affected by flood in every rainy season in India (Gupta et al. 2003; Singh and Kumar 2013; Sing and Kumar 2017). As flooding is a terrific natural disaster and it is almost impossible to prevent it completely (Cloke and Pappenberger 2009), it is very necessary to create flood susceptibility mapping and flood vulnerability assessment through which we will be able to design some management schemes for diminishing vandalization of flood in time to come in the future and it is a utilitarian tool to direct the governments and planners to formulate proper flood management plans (Esteves 2013; Haghizadeh et al. 2017; Kia et al. 2012; Khosravi et al. 2016; Feng and Wang 2011; Tehrany et al. 2015; Samanta et al. 2018a, b). Different kinds of parameters like climate and geomorphological structure regulate the occurrence of flood and its intensity. The multi-criteria-based flood susceptibility and vulnerability estimation will much more reliable and validate instead of single criterion-based flood susceptibility analysis (Booij 2005; Minea 2013; Tehrany et al. 2014a, b; Xu et al. 2013; Poussin et al. 2014). In majority of the cases, flood management plan means strategies taken for distributing reliefs and resettling flood-affected people. Flooding prediction, preparation according to flood predictability, implementing strategies during flood, and overall damage assessment are the major four steps for flood management (Konadu and Fosu 2009). Now, in recent decades, remote sensing (RS) and GIS software techniques are intensely used as they provide a brand new dimension for vulnerability assessment with proper justification. Analysing satellite imageries on RS and GIS platform assigned satisfactory results for flood susceptibility and vulnerability mappings as it is providing flawless information about a region (Ali et al. 2019). It creates an amazingly pleasant environment where a wide variety of models can run and manipulate information to evaluate flood vulnerability, and the results become more logical and acceptable. At the present time, RS and GIS techniques are being used very successfully for flood vulnerability all over the world (Khosravi et al. 2016; Dewan et al. 2007; Haq et al. 2012). There are so many models and techniques alternatively used for flood vulnerability mapping. Frequency ratio (FR) model (Lee et al. 2012) is one of the highly acceptable techniques for hazards assessment with high accuracy rate. Frequency ratio (FR) is

a one kind of bivariate statistical analysis (BSA), and this method gives value to every single class of each parameter and evaluates its impact on flood occurrence (Jebur et al. 2014; Tehrany et al. 2017). FR model is a simple process to run on GIS environment and can construct scientifically valid flood vulnerability map (Tehrany et al. 2014a, b; Liao and Carin 2009; Samanta et al. 2018a, b). RS- and GIS-like sophisticated software provides an easy way for preparing flood susceptibility mapping by FR model. The main objective of the present research is to prepare flood vulnerability map of Kulik river basin by using FR model. The objective of this work is to critically analyse flood risk potential zone of Kulik river basin.

Study area

The latitudinal and longitudinal extensions of Kulik river basin are 25°32'00" N to 26°10'06" N and 87°60'00" E to 88°24'56" E, respectively. Kulik river basin is situated in the mature alluvium of Indo-Bangladesh Barind tract. The maximum height of the Kulik river basin is 71 m which has been observed in the source segment of the Kulik River, and the minimum height is only 17 m which is found in the confluence point. The Kulik River originated in the Thakurgaon District of Bangladesh which flows 133.27 km and joins the Nagar River in Itahar CD Block of Uttar Dinajpur, India. Since the difference between the highest and lowest altitude is only 54 m, it is very easy to assume that the Kulik River flows over a flat region. Total area of the Kulik river basin is 1038.51 km². A decrease in water carrying capacity of river due to aggradations and rainfall during monsoon is the main reason for flooding in this region. Although some of the measures are taken to prevent flood in some places, like plantation along the river side, they are less than necessary, so every year flood causes huge damage to property and life. Evidences collected from USGS toposheet (1951) show that, before 1951, Kulik River drains its water to Mahananda River directly, but due to some tectonic movement triggers now Kulik River merged with Nagar River, and after flowing to some distance Nagar River merged with Mahananda River (Sarkar and Pal 2018). About 281 numbers of oxbow lakes and paleo-channels along the both sides of Kulik River defined its migratory behaviour in nature (Sarkar 2018). Due to the fact that the river basin is in the plain region, a large number of lowlands in the form of oxbow lakes, ponds and paleo-channels scatteredly located all over the basin create an ideal condition for flooding. This region has an annual rainfall of 2280 mm and located under sub-humid monsoonal climate. This region receives about 80% of all rainfall from the month of June to October. This region is often flooded by floods due to excessive rainfall in this short

period (Sarkar and Pal 2018). Figure 1 shows the flood-inundated area on 24 June 2017.

Data source and methodology

For flood vulnerability mapping of Kulik river basin, nine individual parameters were taken into consideration. Table 1 shows the detail specification of different data sets and their characteristics. All the layers have been constructed and combined in ArcGIS (v.10.3.1) environment and Fig. 2 showing the flowchart and methodology for preparing flood vulnerability mapping of Kulik river

basin. Slope map, elevation map and TWI map have been constructed from SRTM DEM data (Table 1). The land use–land cover (LULC) map has been prepared using maximum likelihood classifier method. All stream segments have been digitized from Google Earth image for construction of drainage density map in ArcGIS (v.10.3.1) platform. Road density map also is extracted from the same source using hand-held GPS tracking system which can be used wherever it is needed. Population and household data have been collected from official census website (Census 2011) of both countries. A field inspection during flood and post-flood study has been conducted (June–August 2017) for assessing probable causes, damages due to

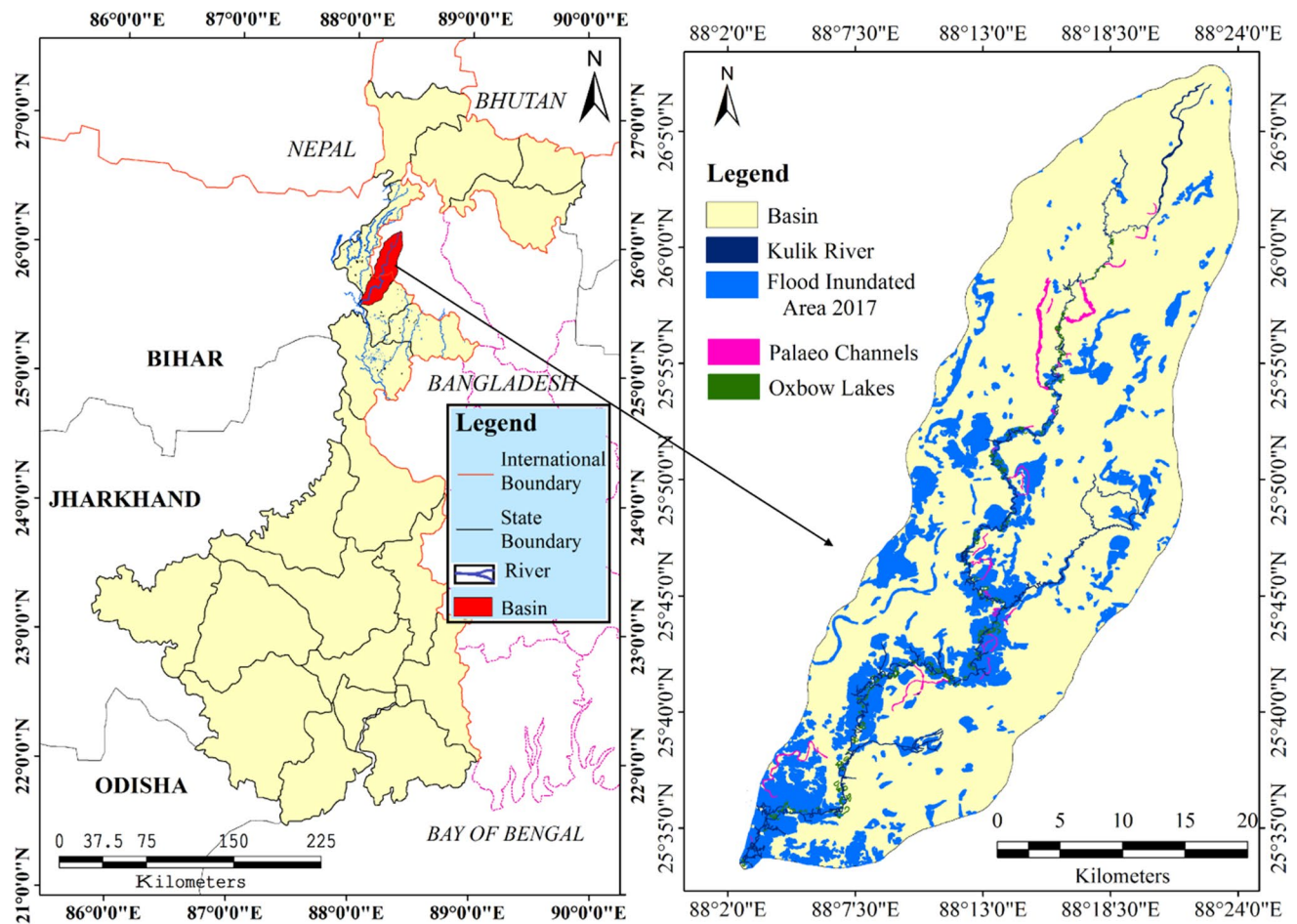
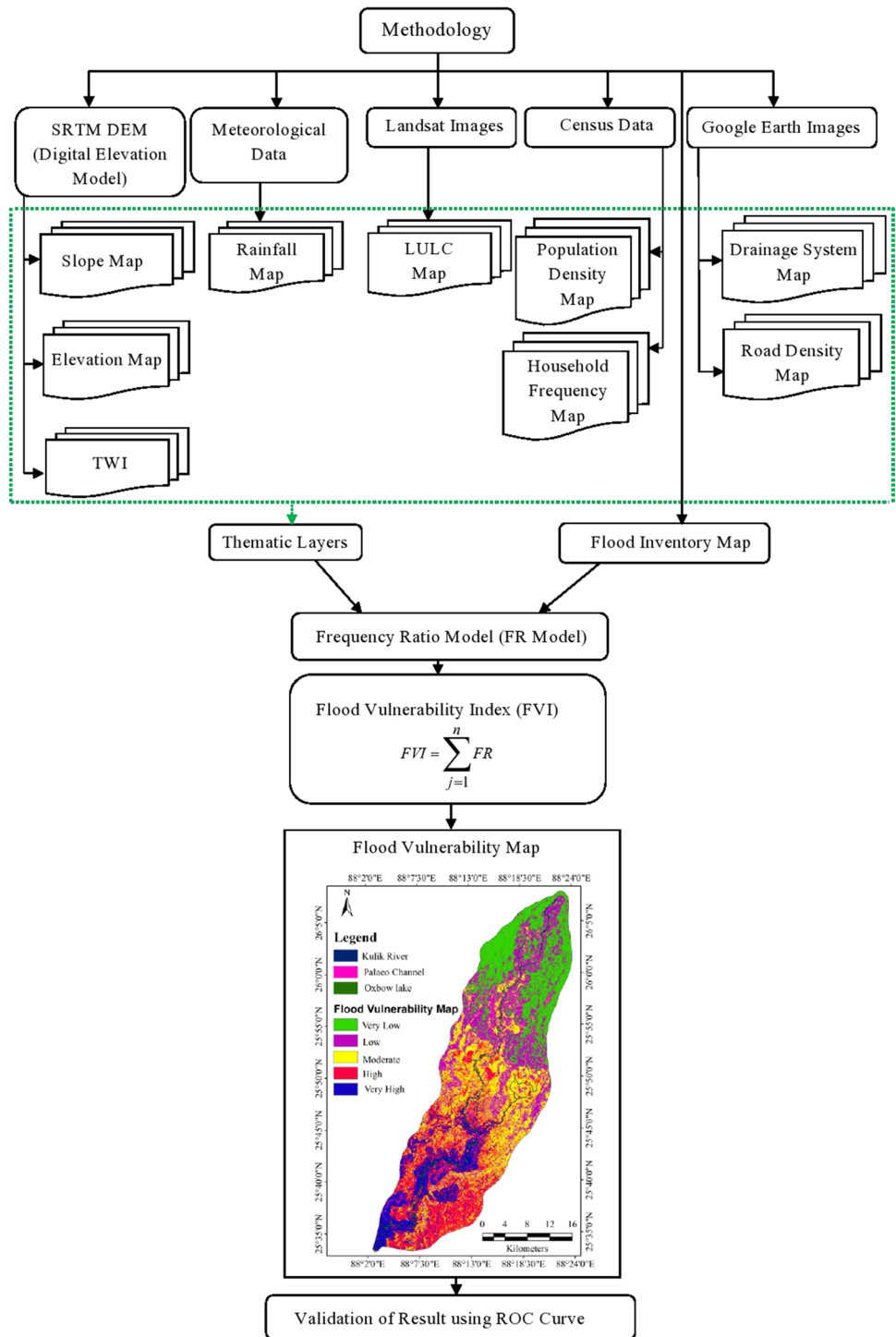


Fig. 1 Location of the study area

Table 1 Data source and data type used in the research work

Sl. no.	Data description	Data type/resolution	Year	Source
1	LANDSAT-8 OLI	Satellite image	2018	USGS
2	ASTER DEM	30 m	2018	USGS
3	Rainfall	Point data	2018	Data collected from weather station, secondary source
4	Population	–	2018	Census, India and Bangladesh, 2011

Fig. 2 Flow chart and methodology for preparing flood vulnerability map



flooding and people’s perception about this threatening calamity.

Flood inventory map

For analysing flood vulnerability, it is extremely important of having a scientifically justified past flood occurrence data for estimating future flood (Manandhar 2010). The correctness and reliability of the future flood vulnerability hinge on the precision of the previously recorded flooding events (Merz et al. 2007). For Kulik river basin, flood

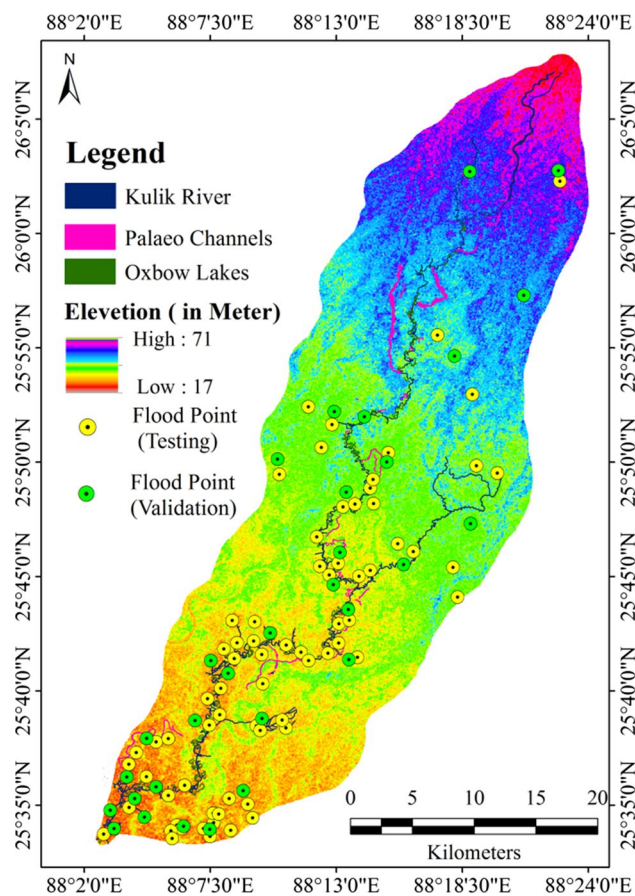


Fig. 3 Flood inventory map of Kulik river basin

inventory map has been prepared based on 2017 extreme flood event (geoapps.icimod.org/BD2017) on ArcGIS 10.3.1 environment (Fig. 3). A total of 100 flood points are randomly divided into two groups of training and validation data sets for preparing and justifying the result of flood vulnerability.

Though there are no specific rules for defining how flood point will be allocated into training and validation data sets (Pradhan and Lee 2010), usually research work has been done by using 70% of floods events as training data set for preparing flood vulnerability model and the rest 30% have been used for validation of the output model (Ohlmacher and Davis 2003; Tunusluoglu et al. 2008; Pourghasemi et al. 2012; Pourghasemi and Beheshtirad 2014). In this research work, 70 (70%) training points were randomly nominated for flood modelling and 30 (30%) validation points have been used for authentication of the model (Rahmati et al. 2016a, c).

Flood conditioning factors

There are so many geo-environmental and man-made independent factors controlling flood occurrences in a region (Tehrany et al. 2015). So for investigating flood risk assessment it is strategically important to select appropriate factors to get reliable outcomes because an individual flood controlling factor may be very much functional in a specific catchment, but in other areas it may not be necessary (Kia et al. 2012). For the present research work, totally nine conditioning factors such as (1) slope, (2) elevation, (3) drainage density, (4) rainfall, (5) LULC, (6) topographical wetness index (TWI), (7) road density, (8) population density and (9) household frequency are taken into consideration.

Slope and elevation maps (Fig. 4a, b) of the study area have been prepared from DEM by using ArcGIS software (Khosravi et al. 2016; Tehrany et al. 2017). Slope and elevation are most important factors for flood vulnerability assessment. Land elevation always plays an important and effective role for contriving flood vulnerability mapping (Rahmati et al. 2016a, c; Fernandez and Lutz 2010). The climate of the region is regulated by the variability of the height of the land in that region (Samanta et al. 2012). Different altitudinal zones receive different amounts of rainfall and temperature; as a result, it creates different types of vegetation cover and soil forms (Aniya 1985). Slope is one of the principle components of flooding (Mishra 2013; Haghizadeh et al. 2017). Land slope controls the surface water flow, vertical infiltration process (Youssef et al. 2011) and rate of soil erosion (Adiat et al. 2012) of a region.

Drainage density has a great significant impact on flood occurrence. It has a positive correlation with flooding as a large number of streams raise the flood potentiality multiplied by it. For preparing rainfall map (Fig. 4d), rainfall values put against seven weather stations, i.e. Slilguri, Islampur, Dalkhola, Raiganj, Raghunathpur (India) and Thakurgaon and Dinajpur (Bangladesh), and by using IDW (inverse distance weighting) in ArcGIS environment rainfall map of the study area has been constructed.

Different types of LULC of a region control flood vulnerability differently. Vegetation cover has a negative relation with flood as it slows down surface water flow and recharging groundwater by promoting infiltration process (Rahmati et al. 2016a, b, c, d; Tehrany et al. 2013a, b). On the other hand, built-up area with high surface run-off creates flooding condition. LULC map was constructed from Landsat 8 OLI imageries. Supervised image classification is done by using maximum likelihood classifier algorithm of ERDAS Imagine (v.9.1) (Samanta 2013).

Topographical wetness index (TWI) is also known as compound topographical index (CTI). TWI technique is

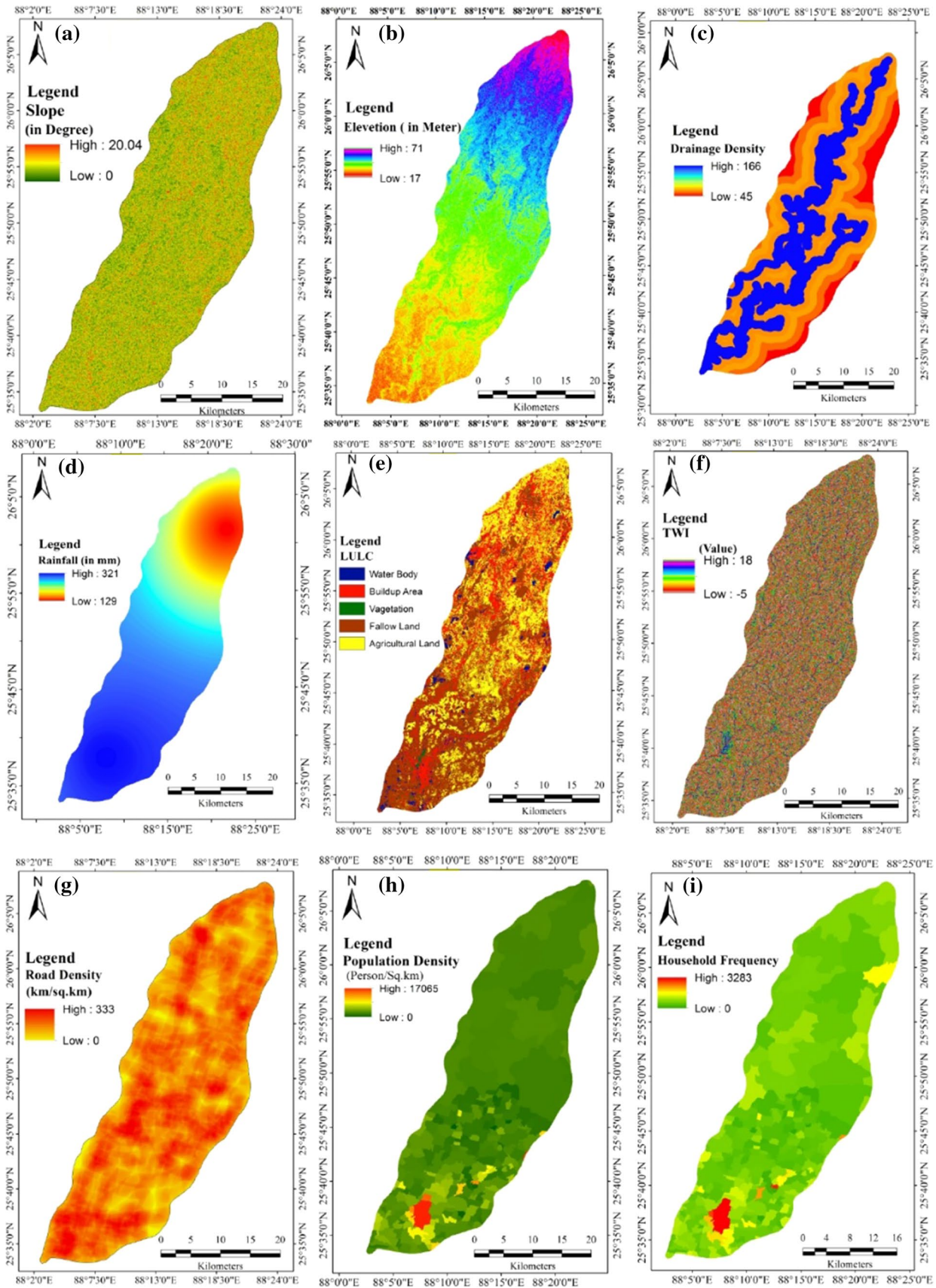


Fig. 4 a–i Spatial data layers used for preparing flood vulnerability mapping: **a** slope, **b** elevation, **c** drainage density, **d** rainfall, **e** LULC, **f** TWI, **g** road density, **h** population density, **i** household frequency

used to understand the topographical influence on the rate of wetness of a catchment area and to show the rate of over land flow (Samanta et al. 2018a, b). Amount of flow accumulation at any point in the catchment area can be calculated by TWI technique, and it shows the flow of water under the influence of gravity (Moore et al. 1991). TWI is a very effective technique for analysing flood potentiality (Rahmati et al. 2016a, b, c, d; Haghizadeh et al. 2017; Samanta et al. 2018a, b; Khosravi et al. 2016; Ali et al. 2019; Tehrany et al. 2015, 2017). TWI map has been constructed from DEM by running flowing equation on Raster Calculator in ArcGIS environment (Regmi et al. 2010; Moore et al. 1991; Jaafari et al. 2014; Nampak et al. 2014; Ali et al. 2019):

$$TWI = [\text{Ln}(\text{FLOWACC} * 900 / \tan(\beta))], \tag{1}$$

where FLOWACC is the flow accumulation derived from DEM in ArcGIS environment and β is the slope (in $^\circ$).

For preparing road density map, all major roads of Kulik river basin have been extracted by manual digitization process from Google Earth image and imported to ArcGIS (v10.3.1). Road has a significant effect on flooding as it works as an artificial barrier in the way of flood. To some extent, high road density reduces the destruction process of flood. The horrors of floods were measured by judging environmental and societal aspects. Extreme flood events leave the evidence of huge loss of property, houses and death every year around the world. In densely populated areas, the number of deaths increases in multiples by flooding.

Bivariate statistical analysis (frequency ratio model)

Assessment of flood vulnerability mapping is very much essential to identify the factors affecting flood. The relationship between flood and associated conditioning factors that can trigger flood could be derived from the past flooding events and their causing parameters. In the present study, frequency ratio (FR) model has been used to construct flood vulnerability mapping of Kulik river basin. FR is a BSA method that critically analyses the contribution of every class of each conditioning factor on future flooding (Lee et al. 2012). FR is calculated by analysing the relationship between flood occurrences and the attributed factors. So FR of every class of each conditioning factor has been calculated with respect to previous flood event as shown in Table 2. FR values were calculated by using the following formula:

$$FR = \left[\frac{N_{\text{pix}}(SX_i) / \sum_{i=1}^m SX_i}{N_{\text{pix}}(X_j) / \sum_{j=1}^n N_{\text{pix}}(X_j)} \right]. \tag{2}$$

After calculating FR values of every class, each controlling factor summed up all the values for generating final flood vulnerability map. The formula of flood vulnerability map given below:

$$FVI = \sum_{j=1}^n FR, \tag{3}$$

where $N_{\text{pix}}(SX_i)$ is the number of flood points in class i of variable X , $N_{\text{pix}}(X_j)$ is the number of pixels in variable X_j , m is the total classes in the variable X_i , and n is the total factors of the study area (Regmi et al. 2013; Jaafari et al. 2014).

FR is one of the simplest and authentic methods frequently applied for flood vulnerability mapping all over the world (Yilmaz 2007; Khosravi et al. 2016; Rahmati et al. 2016a, b, c, d; Samanta et al. 2018a, b). If the FR value is greater than 1, it means parameters are strongly influencing flooding, and if it is below 1 it shows the negative relationship between flood occurrence and controlling variables (Lee and Talib 2005; Pradhan 2010; Sujatha et al. 2013; Akgun et al. 2008; Mondal and Maiti 2013).

Results and discussion

Tables 2 and 3 show the weights of different sub-classes of each of the nine conditioning factors in reference to flood vulnerability mapping. Flood occurrence parameters like slope, elevation, drainage density, rainfall, LULC and TWI have been calculated based on the FR model (Table 2), and road density, population density and household frequency layers are constructed in reference to five-point rating scale (Table 3). High frequency ratio (FR) value is stipulating high flood probability. So a high positive correlation exists in between frequency ratio (FR) and flooding phenomena (Tehrany et al. 2013a, b).

The slope of a region regulates the flood occurrence as low flat plain area has a strongly association with flooding condition in the rainy season. A high number of floods occur in lower slope area as the water cannot discharge swiftly. Slope between 0° and 10.59° supports the fact of flooding as the FR value is considerably more than one (Tehrany et al. 2017). High slope indirectly enhances the flood probability as it fosters speedy water and the area with high slope has the less time to regulate and percolate water under the ground (Jaiswal et al. 2003). In Kulik river basin, the outcome exhibits that the FR value is more than 1 in the first two slope sub-classes 0° – 1.18° and 1.18° – 2.12° and the FR

Table 2 Rating of parameters used for vulnerability mapping through FR model

Factors	Class	Total pixel	% of area	Flood pixel	% of area	FR
Slope (in °)	0–1.18	310,406	26.122	60,568	29.71	1.14
	1.18–2.12	402,832	33.900	72,458	35.54	1.05
	2.12–3.38	324,718	27.326	51,339	25.18	0.92
	3.38–4.88	125,458	10.558	16,485	8.09	0.77
	4.88–20.04	24,887	2.094	3002	1.47	0.70
Elevation	17–27.8	930	0.08	795	0.39	4.98
	27.8–38.6	364,271	30.65	127,260	62.43	2.04
	38.6–49.4	526,380	44.30	69,698	34.19	0.77
	49.4–60.2	273,940	23.05	6052	2.97	0.13
	60.20–71	22,780	1.92	47	0.02	0.01
Drainage density	< 45	435,463	36.65	124,457	61.05	10.67
	45–58	295,848	24.90	33,434	16.40	0.66
	58–65	205,596	17.30	24,088	11.82	0.68
	65–68	151,487	12.75	14,136	6.93	0.54
	68–166	99,907	8.41	7735	3.79	0.45
Rainfall (in mm)	129.24–172.93	139,520	11.74	4972	2.44	0.21
	172.93–218.88	155,625	13.10	5736	2.81	0.22
	218.88–260.31	161,790	13.62	11,742	5.76	0.42
	260.31–294.96	269,291	22.66	55,339	27.15	1.2
	294.96–321.33	462,075	38.89	126,062	61.84	1.59
LULC	Water body	50,876	4.28	17,170	8.42	1.97
	Built-up area	270,809	22.79	15,925	7.81	0.34
	Vegetation	13,450	1.13	256	0.13	0.11
	Fallow land	466,828	39.29	118,809	58.28	1.49
	Agricultural land	386,338	32.51	51,691	25.36	0.78
TWI	– 5.7 to 0.53	241,891	20.36	32,132	15.76	0.77
	0.53–1.79	466,174	39.23	68,386	33.55	0.86
	1.79–3.33	321,054	27.02	62,615	30.72	1.14
	3.33–5.40	130,915	11.02	31,932	15.66	1.42
	5.40–17.32	28,267	2.38	8786	4.31	1.81

Table 3 Assignment of weight to sub-class of individual parameters used for vulnerability mapping through five-point rating scale

Factor	Class	Total pixel	% of area	Flood pixel	% of area	Rating
Road density	0–66.46	171,611	14.44	25,991	12.75	5
	66.45–132.92	314,493	26.47	66,080	32.42	4
	132.92–199.39	349,458	29.41	61,918	30.37	3
	199.39–265.86	244,640	20.59	33,400	16.38	2
	265.86–332.32	108,099	9.10	16,462	8.08	1
Population density	0–602	140,472	11.82	58,415	28.66	1
	602–1070	862,549	72.59	120,968	59.34	2
	1070–2275	146,024	12.29	20,984	10.29	3
	2275–5086	26,930	2.27	3081	1.51	4
	5086–17,065	12,327	1.04	404	0.20	5
Household frequency	0–162	421,146	35.44	57,389	28.15	1
	162–254	496,546	41.79	95,519	46.86	2
	254–446	219,597	18.48	47,000	23.06	3
	446–1122	38,745	3.26	3565	1.75	4
	1122–3283	12,267	1.03	379	0.19	5

value is less than 1 where slope is greater than 2.12°, respectively. About 60% of flooding occurred in the area having less than 2.12° of slope (Table 2).

Elevation is one of the major controlling factors of flooding. Generally, the FR value will decrease as the height of the area increases. It is exhibited in Table 2 that the two lower elevated areas (17–27.8 m and 27.08–38.06 m) in Kulik river basin have been recorded high FR values of 4.98 and 2.04, respectively, which illustrate the high probability of flooding in low elevated area (Khosravi et al. 2016). Area with low FR value with high altitude has the less probability of flooding. About 63% of flood (2017) occurred in these two low elevation zones of Kulik River.

Area with low drainage density has the greater chances for flooding; due to low number of drainage systems, water cannot be drained very quickly in a short period of time. In Kulik river basin, the lower drainage density (< 45) area recorded almost 61% of past flooding as the FR value is 0.67 (Table 2).

The amount of rainfall is the most important reason for flooding in any area. No region expects that the rain can be flooded. It is to be observed that the FR value (1.59) is high in places where rainfall is high (294.96–321.33 mm) (Samanta et al. 2018a, b).

The land use–land cover (LULC) in the region can be used as a very important tool to identify flood-prone areas in a river basin. For example if there is no natural. Forest area acts as a natural resistance to flood prevention in any area. On the other hand, the open field enhances flood trends many times. So there is a positive relationship with the flood in the open wilderness and negative relations with forest cover area (Samanta et al. 2018a, b; Shabani et al. 2014). Again, in built-up area due to concretization the amount of underground water percolation is very negligible but surface run-off of very high. In Kulik river basin, the high FR value recorded in fallow land and agricultural land is 1.49 and 0.78, respectively (Table 2). The outcome supports the fact that unprotected area is highly susceptible for flooding.

The TWI factor is one of the extremely necessary factors for future flood prediction. In the case of Kulik river basin, the topographical wetness index (TWI) is divided into five sub-classes. Normally, it is safe to say that the flood probability is high in the places where the TWI is more (Khosravi et al. 2016). The highest FR value of 1.81 is observed

in the class of 5.40–17.31, and the lowest FR value in the class of – 5.7–0.53.

For preparing flood vulnerability mapping, here road density, population density and household frequency layers are divided into five main categories and given rating from 1 to 5 (Table 3) towards vulnerability. The area where the concentration of roads is the highest is given 1 and given 5 where the lowest road concentration found. The road works in an area as an artificial barrier to prevent flooding. Therefore, the more the density of roads is in those areas, the lesser the tendency to flood in those areas. If there is more population density in any area, then the chances of damage to floods in those areas are greatly increased. Here is existing a positive relationship in between population density and flood vulnerability. For preparing flood vulnerability map of Kulik River, maximum class (> 5086) is given a maximum of 5 points and the lowest class (< 602) is given 1 point. Following the same way of population density, household frequency layer has been prepared and given point to five different sub-classes, respectively. As the number of home-steads in flood-prone area is high, the probability of damage due to floods increases.

Flood vulnerability mapping of Kulik river basin

After preparing individual layers of nine conditioning parameters and given weights to those parameters, all the parameters are combined to construct the final flood vulnerability map of Kulik river basin on ArcGIS 10.3.1 environment by overlapping process (Fig. 5). The final flood map has been divided into very low (244–433), low (433–562), moderate (562–693), high (693–819) and very high (819–1327) vulnerable zone (Table 4). The result has shown that 2.02 (19.48%) km² of land is categorized under low flood vulnerability. The low flood vulnerable zone was situated mostly in the high altitude above 50 m from the mean sea level. Around 2.45 (23.64%) km² of land is categorized under low vulnerability zone, 2.44 (23.45%) km² of land under moderately vulnerable, 2.26 (21.74%) km² of land under high flood zone and 1.21 (11.69%) km² of land under very high flood vulnerability zone in future. Very high and high flood vulnerable areas are located in the lower segment

Table 4 Flood vulnerability zone of Kulik river basin and area under different sub-zones

Zone	Class	Total pixel	% of pixel	Total area (km ²)	% of area
Very low	244–433	231,645	19.49	2.02	19.48
Low	433–562	279,627	23.53	2.45	23.64
Moderate	562–693	277,521	23.35	2.44	23.45
High	693–819	257,688	21.69	2.26	21.74
Very high	819–1327	141,821	11.93	1.21	11.69

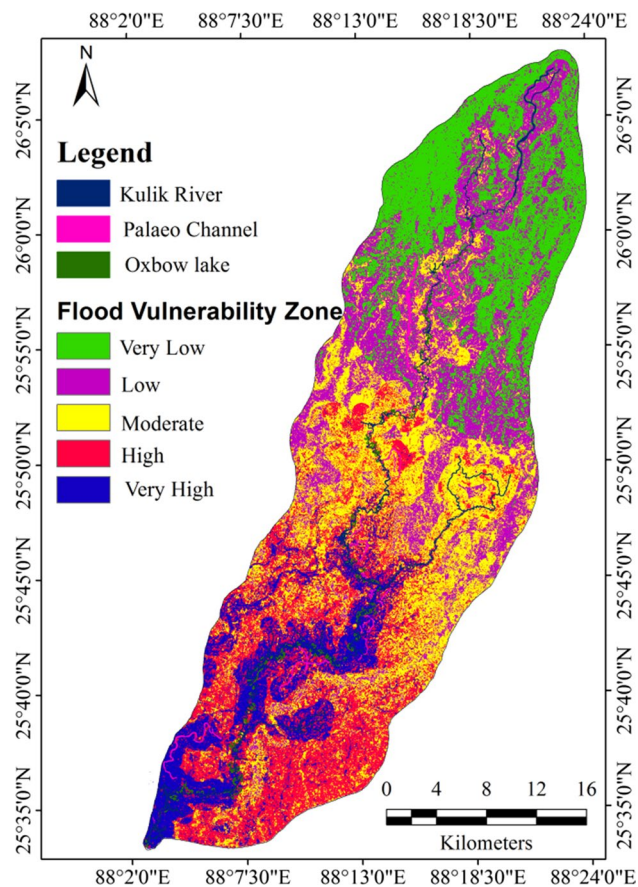


Fig. 5 Flood vulnerability mapping using the FR model

of Kulik river basin. From the final flood vulnerability map, it is clearly identified that peoples living on the banks of Kulik River are most likely to be affected by future floods as this area is situated under very high flood vulnerability zone.

Validation of flood vulnerability map

After creating a model, it is not the scientific way to use it for governmental or non-government purpose without checking the accuracy and reliability of that model (Chung and Fabbri 2003). In the study area, the receiver operating characteristic (ROC) curve was used to verify flood vulnerability map. This ROC curve system is a simple and universal technique based on scientific basis through which we can accurately assess a test. In ROC curve, false positive rate is shown along the X-axis and true positive rate along Y-axis. To substantiate the prediction of any model, area under curve (AUC) is taken into consideration as if the AUC value is 0.5 or less than that the model is inappropriate for flood vulnerability mapping and if the value is perfectly 1 then this model is the most suitable for estimating flood trends and if the AOC value is >0.75 then flood predictability is

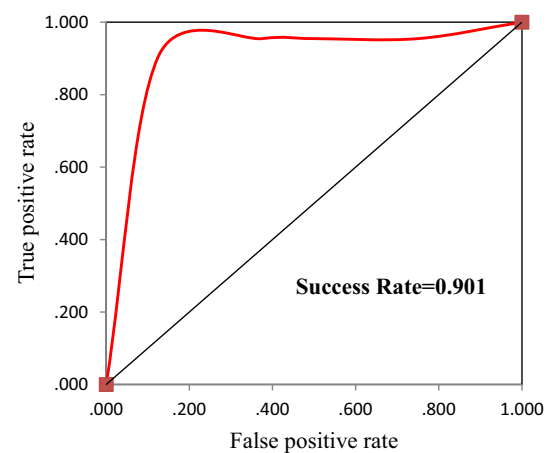


Fig. 6 ROC curve of success rate of the FR model

also well accepted (Saha 2017; Ozdemir and Altural 2013; Akgun et al. 2008; Egan 1975; Pradhan et al. 2010). Based on AOC curve, prediction of model has been classified into five categories as 0.5–0.6 (poor), 0.6–0.7 (average), 0.7–0.8 (good), 0.8–0.9 (very good) and 0.9–1.0 (excellent) (Al-Abadi 2015; Saha 2017). In the present research work, 70 (70%) flood locations are used for flood vulnerability mapping and 30 (30%) of total data set, which is not incorporated with FVM, are used for justifying the flood vulnerability. The AUC value is 0.901 (Fig. 6). It is very easy to establish that the model used for preparing flood vulnerability mapping of Kulik river basin is quite accurate and suitable for determining flood trends. Consequently, it can be concluded that the FR model is very useful technique for determining flood vulnerability mapping.

Conclusion

In recent times, among many geo-environmental hazard and disasters, floods are considered the most catastrophic disaster all over the globe. Analysing flood vulnerability mapping is very much significant for diminishing ruinous flood by implementation of fide approaches. Flood vulnerability-related information is a principle asset for planners for implementation of right land use in flood-prone areas. In the present study, a BSA-based FR model espouses to comprehend the interconnection of flood occurrence and factor variables of Kulik river basin. Nine conditioning factors, i.e. slope, elevation, drainage density, rainfall, LULC, topographical wetness index (TWI), road density, population density and household frequency, were taken, and based on the flood inventory map individual layers have been generated with $30 \times 30 \text{ m}^2$ resolution. A random sampling technique has been used for selecting 70% total flood point for layers construction and 30% for validation purposes. The

authentication of flood vulnerability mapping relies on how precisely factor layers were prepared. The final flood vulnerability map was classified into five zones, very low, low, moderate, high and very high zone, respectively. Figure 5 shows that very high vulnerable areas were delineated in lower segment adjacent to the river with 1.21 km² of lands. The ROC curve was used to evaluate the effectiveness of the present FR model for vulnerability mapping and appraise the outcome. The product divulges that the method applied in the present work produces reliable and accurate result with 90.10% success rate. So it can be concluded that the perfection of the conditioning factors have a noteworthy impact on flood vulnerability mapping as if the standard level of parameters strengthens the performance of the model also increases. The most important parameters and the class for flood vulnerability mapping of Kulik river basin are low slope (0°–1.18°), low elevation (17–27.8 m) and high TWI (5.40–17.32). This model can assist the government, planners and decision-makers to implement proper management schemes in this study area and confined the developmental processes by demarcating flood vulnerable places.

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Compliance with ethical standards

Conflict of interest The authors hereby declared that there is no conflict of interest.

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