2 Flood Susceptibility Mapping Using Morphometric Parameters and GIS

Md. Hasanuzzaman, Aznarul Islam, Biswajit Bera, and Pravat Kumar Shit

Abstract

The present study investigates sub-watershed prioritization for flood susceptibility mapping of the Silabati River basin (India) based on morphometric parameters. This river basin is a sixth-order drainage system with an adendritic drainage pattern and traverses an area of 4247.99 km^2. Almost every year, the lower stretch of the Silabati river basin experiences floods due to physiographic characteristics and excessive rainfall during a short time. The present work has been conducted with an integrated outlook involving the morphometric parameters, geological, and climate data by geospatial techniques for determining the probability of spatial flood risk. A ranking method has been employed to prioritize the sub-watersheds for susceptibility to flooding. The results of this study depict that 48.18% area of the basin including 11 out of 26 sub-watersheds has a high to very high flood susceptibility area. Drainage density, basin slope, circulatory ratio, relative relief, relief ratio, stream frequency, and ruggedness number are the most important morphometric parameters for flooding in the study area. Since there were no such government or private historical flood records that are required for flood modeling, various morphometric parameters have been accurately used to measure sub-watershed-wise flood susceptibility. The performance and efficiency of this method are validated using ROC and AUC, which ensures a considerable amount of accuracy (89.2%) of the study. Moreover, this research may be used as a guideline for surface runoff harvesting and flood mitigation at the sub-watershed level.

Keywords

Flood · Geospatial technology · Silabati River basin · Morphometric parameters · Sub-basin prioritization

2.1 Introduction

Floods are one of the most vital hydrological and meteorological hazards (Huang et al. 2008; Markantonis et al. 2013; Toduse et al. 2020). It has several negative and sudden impacts on human life and livelihood especially the agrarian

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economy (Leskens et al. 2014; Yang et al. 2015; Bui et al. 2020; Islam and Ghosh 2021). United Nations Office for Disaster Risk Reduction (UNISDR) reported that the human life losses due to flood events were around 15 lakhs and around 11.1% mortality rate in the world during 1996–2015. Developing nations like India, Sri Lanka, and Bangladesh portray a very high impact rate. The flood scientists and organizations have predicted that annual losses up to US $415 billion worldwide due to floods in 2030 (Grabs 2010; Karamouz and Fereshtehpour 2019; WMO 2016; UNISDR 2015). Floods of small watersheds area (less than 1,000 km^2) reveal a complex and sudden response time due to the orographic nature of rainfall in the high land region (Destroet al. 2018; Obeidat et al. 2021). Some direct and indirect factors such as rainfall characteristics, drainage properties, infiltration, environmental conditions, evapotranspiration, and anthropogenic activities are the significant factors that impact the intensity of flood susceptibility (Azmeri and Vadiya 2016; Jodar-Abellan et al. 2019; Samanta et al. 2018). Identification of vulnerable areas for floods is a very important precursor to reduce the negative impact on human life and infrastructure (Ali et al. 2020).

Watershed management focuses on reducing the negative impact of surface runoff or floods, and surplus water use for various beneficial purposes such as irrigation, groundwater storage, and reduces erosion (Ratna et al. 2017; Sebastian et al. 1995). For water resource management, the optimum use of watersheds is important (Worku et al. 2020). Morphometric parameters for prioritization of sub-watersheds within a basin is necessary for the conservation of land and water resource (Aher et al. 2014). Various research studies have employed morphometric investigation for the prioritization of sub-watershed-wise flood or erosion susceptibility (Bhatt and Ahmed 2014; Abuzied et al. 2016; Ameri et al. 2018; Asfaw and Workineh 2019; Charizopoulos et al. 2019; Hussein et al. 2019; Kannan et al. 2018; Rajasekhar et al. 2020; Alam et al. 2020; Das 2020; Islam and Deb Barman 2020). These researches have employed some algorithms from some classic works such as Horton (1945, 1932), Smith (1950), Strahler (1952), Miller (1953), and Schumm (1956). According to Strahler (1964), morphometric parameters depicted a relatively very simple method. To investigate the geomorphic history, geological and hydrological conditions of the basins, it may be employed. Morphometric features of the basin are very important parameters that influence flood intensity. Therefore, this research of the basin morphometry can provide a very significant database in relation to their hydrological responses (Borga et al. 2008). Of late, remote sensing (RS) and geographical information systems (GIS) have been extensively employed with the objective of watershed management (Chatterjee et al. 2013; Okumura and Araujo 2014; Hasanuzzaman et al 2021). Digital elevation model (DEM) is a very high-resolution RS data and it's freely available for access. It is a very effective tool for the accurate investigation of watershed morphometric parameters (Ratnam et al. 2005; Samanta et al. 2018; Majumder et al. 2019; Hasanuzzaman and Mandal 2020).

Silabati Basin of West Bengal is also having ample water resources but very unevenly distributed in its upper, middle, and lower reaches of the basin. The western part is a drought-prone area while the eastern part faces the flood problem in years of surplus rain. In both cases, people suffer from loss of life and damage to properties. Therefore, this region is demanding to utilize the available water resources judiciously to solve the problems of water shortage as well as to prevent the misuse of water. This research work is a small effort to evaluate the flood of Silabati Basin that contributes to its present configuration in an integrated manner for scientific and judicious use and also for development watershed and sub-watershed wise surface runoff harvesting and flood management. Moreover, this type of work is relatively absent at the national level or regional level. Thus, the main objective of this research is the prioritization of sub-watersheds corresponding to flash floods or floods based on morphometric analysis using geo-spatial techniques. The output of this present research can be utilized to help the government to take the necessary steps in those regions that are susceptible to floods and very high possibility for runoff harvesting.

2.2 Study Area

The present study is executed over the Silabati river basin situated in the southwestern part of the Bengal Basin. The Silabati or Silai River as well as Arkusa Nala and their ramifying channels have furrowed up the Dwarkeswar-Kangsabati interfluve at Hura block and flows over three districts of Puruliya, Bankura, and West Medinipur. It is the principal tributary of the Rupnarayan River (Shit et al. 2015). The river Silabati originates at Baragram village (23°15′N and 86°39′E) of Puruliya district on Manbazar-Adra road and flows southeast for about 20 km in Puruliya district. The river leaves the district at Puncha block and enters Bankura district near Salanpur of Indpur block (Fig. 2.1).

Silabati River watershed presents a unique physical setting in the sense that hard rock plateau and fringe area, laterite covered upland, undulating tract, and flat alluvial plain, all are found in a single basin (Shit et al. 2016; Islam et al. 2020). Actually, the entire geomorphic unit is the southeastern continuation of the Chhotanagpur Plateau (Fig. 2.2). Plateau Fringe lies in the extreme northwestern part, which is the remnants of the spurs projecting from the Chhotanagpur plateau. Its elevation varies from 160 to 227 m and is characterized by high relative relief and moderate slope. Archaean rocks composed of granite, gneiss, schist occupy this area (Dolui et al. 2014; Gayen et al. 2013). The plateau slope lies in the eastern part of the plateau fringe. This part is covered by crystalline rocks of the Archaean age and characterized by hillocks, low ridges, and valleys. Passing over the plateau slope, the basin area presents a dissected upland covered by hard rocks and old alluvium with lateritic capping. The terrain is characterized by irregular, non-contiguous, and uneven tracts (Shit and Pati 2012). The central undulating and rolling plain to the east of this dissected upland presents a flattened and rolling topography. This lateritic part is underlain by deposits of older alluvium and shows dissected badland topography at places (Shit and Maity 2012). This rolling plain gradually merges into a flat alluvial plain to the east consisting of assorted materials of sub recent to recent age. Flood plains are confined mainly along the major rivers which allow sudden discharge sometimes causing heavy floods.

Silabati River basin has got its climatic characteristics due to its tropical location. The upland tract in the west is much drier than that of the eastern part. The basin area enjoys a sub-tropical humid climate characterized by “Monsoon” conditions with marked seasonal variations. The mean annual rainfall of the basin varies from 110 cm in the west to 121 cm in the east (Fig. 2.2). The rainfall during monsoon months from June to September receives around 78% of the total annual rainfall with July and August being the rainiest months. The temperature starts rising from March and attains its extremes up to 48 °C during May. Otherwise, the basin is characterized by a mean minimum temperature of 21 °C and a maximum temperature of 33 °C. With the onset of the monsoon, the temperature drops appreciably. December and January are the cold months with mean maximum and minimum temperature as 26 °C and 11 °C, respectively.

2.3 Data and Methods

The conceptual framework of the method applied in this present study is depicted in Fig. 2.3. For the objective of watershed characterization and prioritization of sub-watersheds of the Silabati River basin, twenty-six morphometric parameters were selected (Table 2.1). According to the total weight value of sub-watersheds, the total ranking method was used for the ranking sub-watersheds (Watershed prioritization) (Biswas et al. 1999; Puno and Puno 2019). The main morphometric parameters of the basin are linear, areal, and relief aspects of watersheds (Melton 1957; Strahler 1964). For computing the morphometric indices, basic parameters of a watershed like a basin length, basin area, perimeter, lengths of streams,

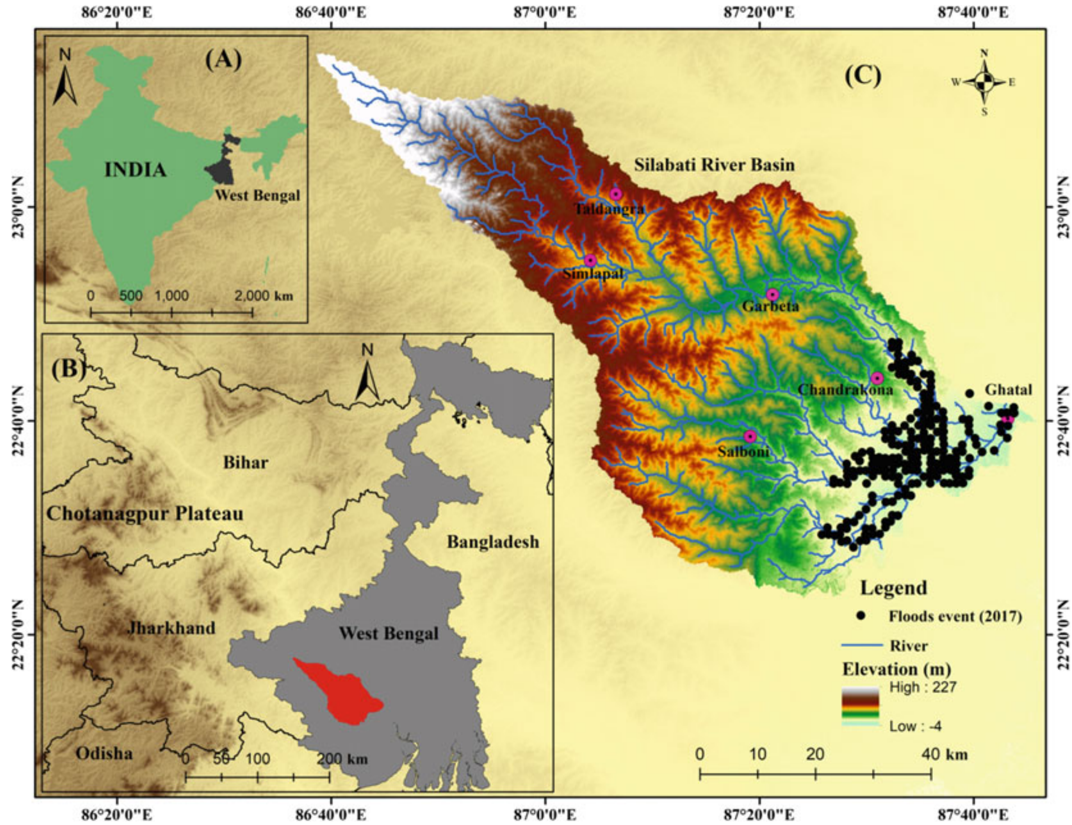

Fig. 2.1 Location of the study area

and the number of streams for each stream order have been calculated directly from the Digital Elevation Model (DEM) using GIS techniques. The DEM was downloaded from www.search.earthdata.nasa.gov and www.earthexplorer.usgs.gov with the resolution is 30 m and 12.5 m (Radar Imagery 2001–2006). First of all, filling the DEM for finding out the missing data was accomplished followed by the generation of stream network and flow accumulation map of the Silabati River Basin (SRB) and then to subdivide the SRB into sub-watersheds. Mathematical equations were used for the measurement of other morphometric parameters of the basin like drainage density, ruggedness number, circularity ratio, basin relief, length of overland flow, relative relief ratio, basin slope, hypsometric integral, elongation ratio, stream frequency, and relief ratio (Obeidat et al. 2021). These mathematical equations are depicted in Table 2.1. For the sub-watersheds prioritization, the morphometric ranking method (Total Rank) was employed (Patel et al. 2012). According to morphometric parameters value, each sub-watershed was divided into various prioritized rank groups, where rank 1 represents the very low probability for floods risk, and so on (Obeidat et al. 2021).

The selected 12 parameters of morphometric have been employed for the sub-watersheds susceptibility map of the flood (Table 2.1). All these parameters of morphometric are related to flood either directly or indirectly. Out of twelve parameters, eight parameters (relief ratio, basin area, circularity ratio, drainage density, basin slope, ruggedness number, relative relief ratio, and stream frequency,) have a direct relationship with the surface flow or flood possibility. The higher values of eight parameters are indicating the higher degree of possibility to flood risk. So, these parameters of sub-watershed having the

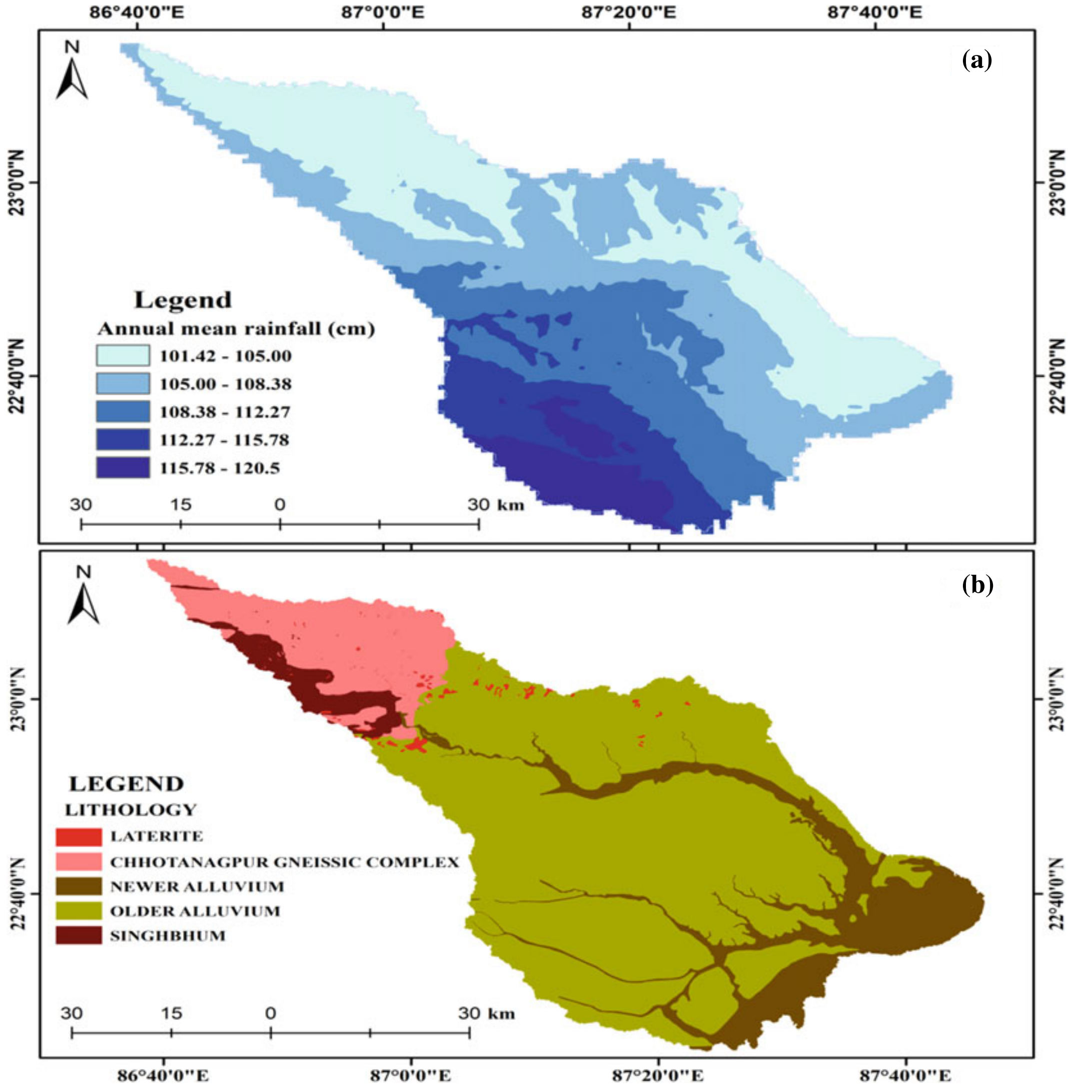

Fig. 2.2 **a** Climate map and **b** Geological map (*Source* Geological Survey of India) of the study area

highest values are given the top rank (5). On the opposite side, the other four parameters (shape factor, hypsometric integral, length of overland flow, and elongation ratio) have an inverse relationship to surface runoff or flood possibility. The lower values of the four parameters are indicating a higher degree of flood possibility and these parameters are given the top rank (5). Firstly, each parameter value was summed, and normalized from 0 to 1 to find out the specific prioritized rank of the sub-watershed. The same value of sub-watershed has defined the similar ranking. After that the sub-watersheds are divided into five floods susceptibility categories (very high, high, moderate, low, very low priority) following a simple equation to demarcate the interval length that is (Maximum–Minimum)/5 (Farhan and Anaba 2016).

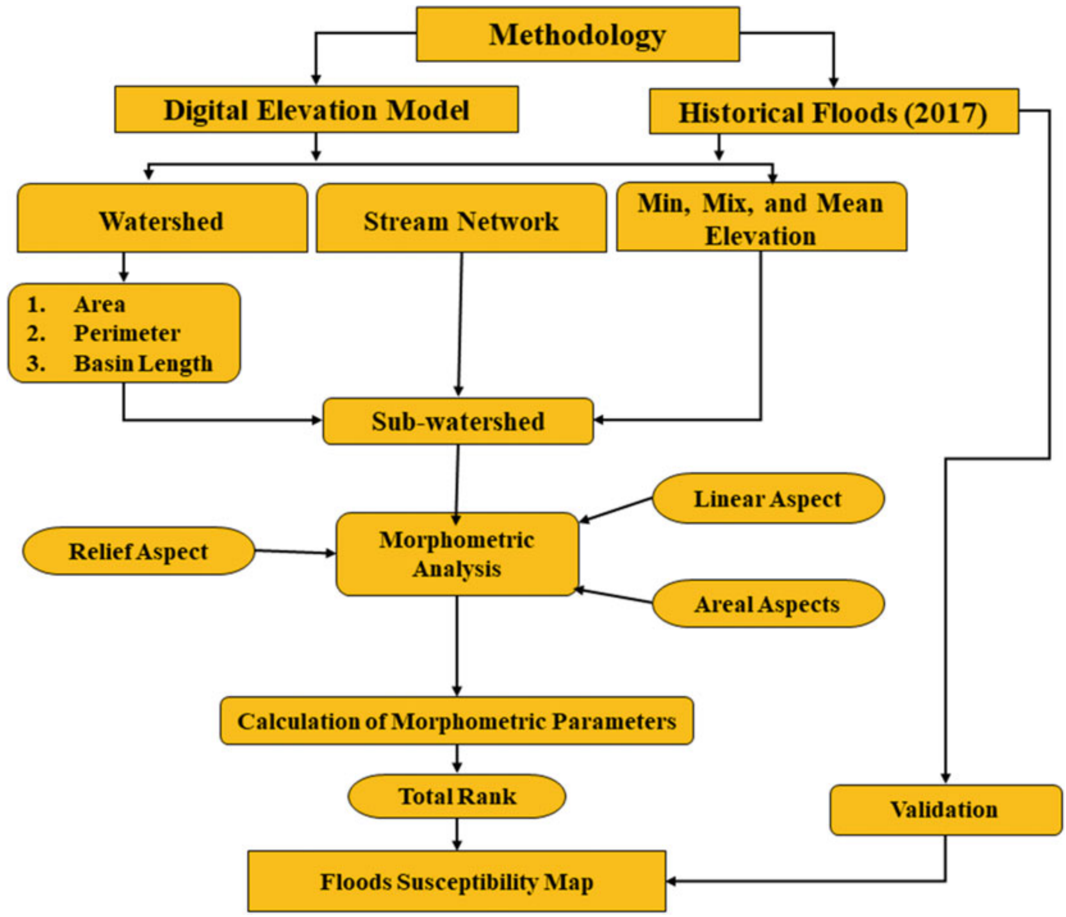

Fig. 2.3 Conceptual framework of the methodology of the study

2.4 Results and Discussion

2.4.1 Morphometric Parameters

According to the flow accumulation of the SRB, 26 sub-watersheds were demarcated using the ArcGIS 10.8 software (Fig. 2.4). The final outputs of the morphometric investigation of all sub-watersheds were depicted in Fig. 2.5 and Table 2.2. To determine the flood susceptibility map, the geomorphologic and hydrological relation in the study area was used (Fig. 2.5).

2.4.1.1 Linear Parameters

Basin perimeter is a very significant basic parameter of morphometric parameters as an indicator of basin shape and size. The minimum perimeter value was found as 32 km (SW 5) and the maximum value was found as 176.44 km (SW 25). A strong correlation is depicted between basin perimeter and area (Obeidat et al. 2021). A significant indicator of surface runoff feature is basin length (Christopher et al. 2010; Taha et al. 2017). In the present study, basin length rangesfrom 5.89 km (SW 13) to 49.36 km (SW 25). Also, a strong correlation is depicted between stream length and basin length (Obeidat et al. 2021). The stream order of the SRB extends up to six orders but all sub-watersheds vary from first order to fourth order. The high stream numbers represent the high surface flow or rapid peak flow (Bhat et al. 2019). In the study river basin, the total stream number is 2559, and 1285

Table 2.1 Detailed information of morphometric parameters

Parameter no		Morphometric parameter	Formula/definition	References
Linear	1	Basin perimeter (P)	Perimeter of the watershed (km)	Horton (1945)
	2	Basin length (L_b)	Length of the basin (km)	Horton (1945)
	3	Stream order (U)	Hierarchical rank	Strahler (1952)
	4	Total number of streams (N_u)	Total no. of streams of all orders	Strahler (1952)
	5	Stream length (L_u)	Length of the stream (km)	Horton (1945)
	6	Total number of streams (N_u)	Total no. of streams of all orders	Strahler (1952)
	7	Stream length (L_u)	Length of the stream (km)	Horton (1945)
Areal	8	Basin area (A)	Plan area of the watershed (km^2)	Horton (1945)
	9	Drainage density (D_d)	(D_d = L_u/ A, where L_u = total stream length of all orders (km) A = area of the watershed (km^2)	Horton (1945)
	10	Length of overland flow (L_o)	L_o= 1/(2*D_d), where D_d = drainage density	Horton (1945)
	11	Stream frequency (F_s)	F_s= N_u / A, where N_u = Total number of streams of all orders A = area of the basin (km^2)	Horton (1945)
	12	Elongation ratio (R_e)	R_e= 1.128*(A^0.5)/L_b, where A = area of the basin (km^2) L_b = basin length (km)	Strahler (1957)
	13	Circularity ratio (R_c)	R_c= 4 × π x A/ P^2, where π = 3.14 A = area of the basin (km^2) P = perimeter (km)	Schumm (1956)
	14	Shape factor (S_f)	S_f= L_b^2 / A, where L_b = basin length (km) A = area of the basin (km^2)	Miller (1953)
Relief	15	Basin relief (H)	H = $h - h_1$, where h = maximum height (m) h_1= minimum height (m)	Horton (1945)
	16	Relief ratio (R_r)	R_r= H/L_b, where H = total relief (km) L_b = basin length (km)	Malik et al. (2011)
	17	Relative relief ratio (R_v)	R_v= H/P, where H = total relief (km) P = perimeter of the basin (km)	Schumm (1956)
	18	Basin slope (B_s)	B_s= H/L_b $*$ 60, where H = total relief (km) L_b = basin length (km)	Melton (1957)
	19	Ruggedness number (R_n)	R_n= $D_d * H$, where H = basin relief (km) D_d = drainage density	Farhan and Anaba (2016)
	20	Hypsometric integral (HI)	HI = (E_{mean}–E_{min})/(E_{max}–E_{min}), where E_{mean} = the weighted mean elevation E_{max} = maximum elevation E_{min} = minimum elevation	Schumm (1956)

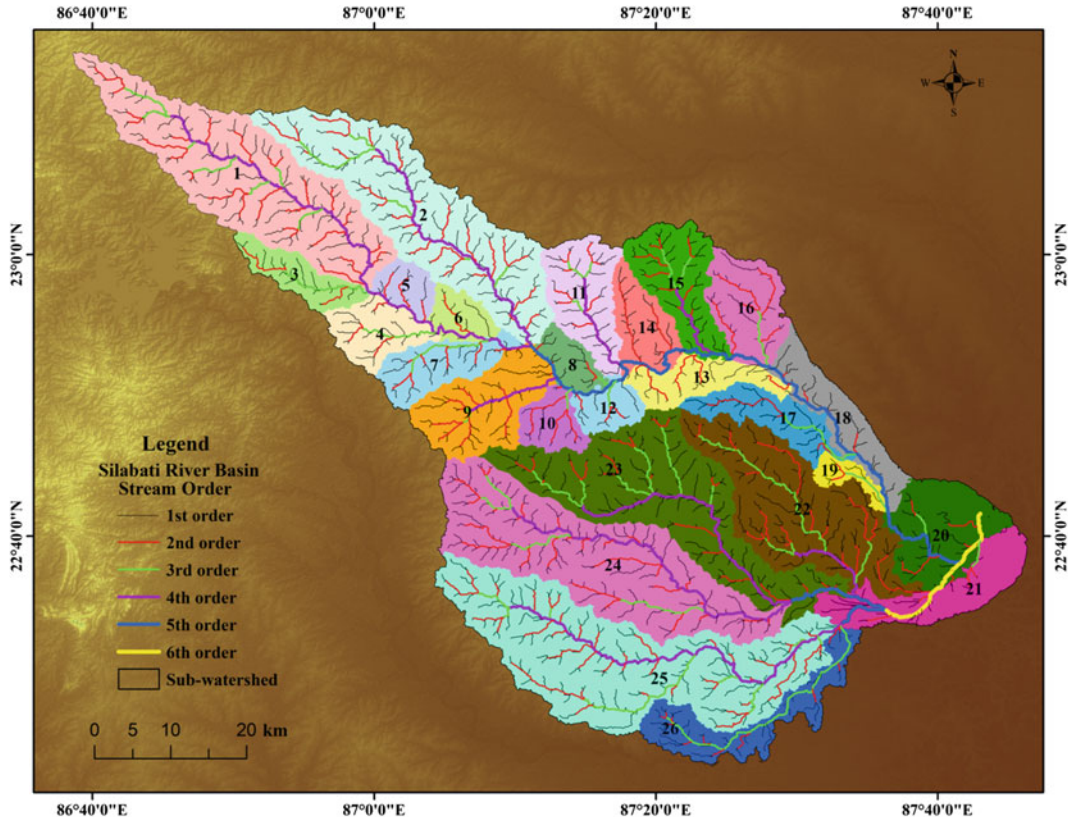

Fig. 2.4 Sub-watershed of the Silabati River basin with drainage pattern and stream order

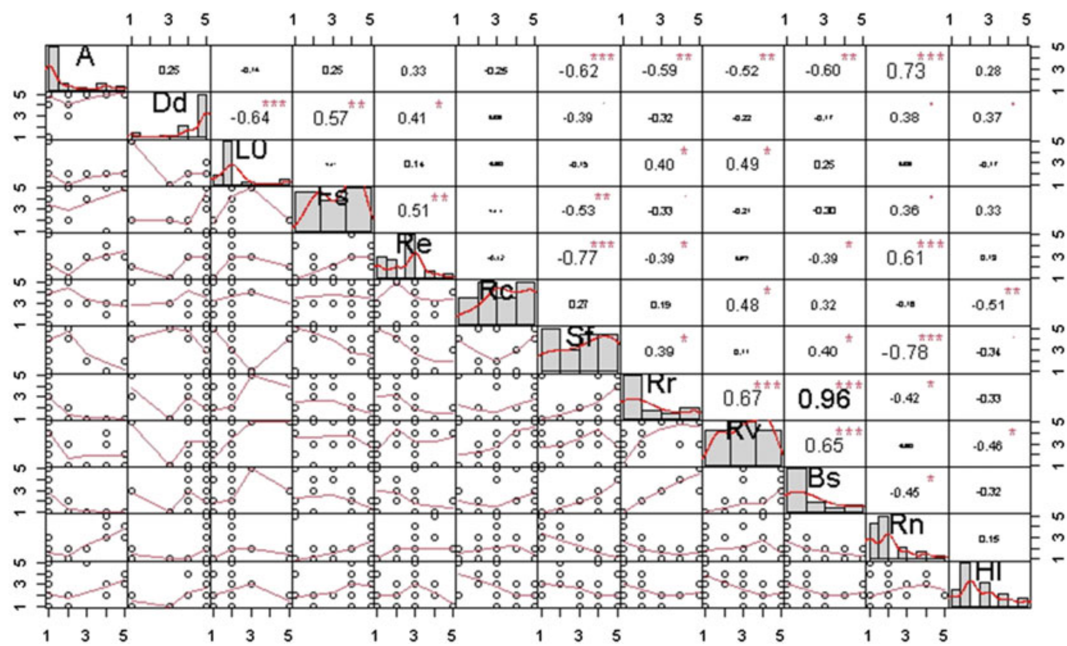

Fig. 2.5 The matrix of the Pearson correlation coefficient for all twelve morphometric parameters weight value

streams are first-order streams (50.2%) in all sub-watershed. Among the 26 sub-watersheds, SW 25 has the highest total number of the stream (320) and SW 8 has the minimum total number of the stream (18 streams). Stream length indicates the contributing area of a basin of a certain order (Magesh et al. 2011). According to Strahler (1952), the higher the stream length the lower the infiltration, and the greatest runoff-producing power of the basin. The SRB's total stream length of all orders is 3274.96 km.

2.4.1.2 Areal Parameters

The sub-basin area of the SRB ranges from 26.26 km^2 (SW 19) to 543.42 km^2 (SW 25). These sub-watersheds are located at the maximum rainfall area of the basin. Drainage density is controlled mainly by two factors, such as relative relief and slope of the basin (Magesh et al. 2011). So, it is directly correlated with flood or flash flood. The drainage density is high which means minimum infiltration rate and maximum surface runoff of the watershed (Kelson and Wells 1989). In the current study, maximum drainage density was found as SW 3, and the minimum was found as SW 5. According to Horton (1945), length of overland flow denotes the length of water flow over the land surface before it becomes concentrated into defined stream channels. Climate conditions, rocks, soil material, relief, and vegetative are the main influential factors of the length of overland flow (Youssef et al. 2009). The length of the overland flow value of the SRB is 0.77 and it varies from 0.06 (high probability to flood) for SW 5 to 0.88 for SW 18. Therefore, sub-watersheds 5 and 6 were given the top rank (5) that these sub-basins have high susceptibility for the flood. According to Horton (1932), stream frequency denotes the ratio between the total number of streams and area. If the stream frequency value is high, maximum surface flow and minimum infiltration are recorded (Melton 1957). The highest stream frequency of the SRB is found for SW 3 and the lowest for SW 1. SW 3 with the high vulnerability of sub-watershed for flooding with low infiltration capacity. According to Schumm (1956), the bifurcation ratio is the ratio between the number of stream segments of a given order to the number of segments of the next higher order. Its low value means that it is structurally less disturbed watersheds (Strahler 1964) and the maximum value represents the high runoff producing capability of a basin in a short lag time (Howard 1990). The SRB has found a mean bifurcation ratio value of 2.52, and it varies from 1.64 to 4.75 across the sub-watersheds.

According to Horton (1932), the elongation ratio signals about the basin shape. The elongation ratio ranges between 0.6 and 0.8, which means basin characteristics have steep slopes and high relief. Another side, its value is close to 1 which means that the basin characteristic has very low relief (Dar et al. 2013). In this work, SW 12, 13, 18, 19, 20, and 21 have the lowest sensitivity to flooding, whereas SW 7 has the highest indicating more susceptibility to flooding. According to Miller (1953), the circulatory ratio is the proportion of the watershed area to the area of the circle having the same perimeter of the watershed. Geological structures, roughness, slope, climate, frequency of stream, and length of stream are controlled by the circulatory ratio (Bisht et al. 2018). Its value is directly correlated with flash floods. Its higher value indicates the minimum time taken to surface runoff and maximum time taken to infiltration. In this research, SW 6 has the lowest circulatory ratio value, and SW 12 to have the highest value (high potential for flooding). Sub-watersheds 4, 5, 8, 9, 10, 12, and 16 are given the highest rank (5) due to the high circulatory ratio value, whereas sub-watersheds 6 and 26 are referred to the least rank (1). The shape factor determines the rate of sediment and water yield (Farhan et al. 2017). The low value of the shape factor represents maximum relief and steep slopes that indicate a high probability of flood. The shape factor values of the SRB vary from 0.93 (SW 12) to 5.83 (SW 23). Sub-watersheds 1, 2, 3, and 23 with high shape factor values are denoted by the lowest rank (1), and sub-watersheds 10, 12, 13, 18, 19, 20, and 21 with the low values are denoted by the highest rank (5).

2.4.1.3 Relief Parameters

The difference between the highest elevation and lowest elevation is called basin relief. It plays an important role in various aspects such as drainage development, erosional properties of the terrain, landforms development, surface and subsurface water (Magesh et al. 2011). In this study, sub-watershed 21 is determined as the minimum and sub-watershed 3 as the maximum. It depicts that the basin has the maximum potentiality to produce floods. In the present study, SW 12 is the most sensitive sub-watershed for floods, whereas SW 20 is the least sensitive one. Sub-watersheds 6, 12, and 13 are found to have a high value of relief ratio values. According to Macka (2001), the relative relief ratio has a direct relationship with the probability of floods. In the present study, sub-watersheds 20, 21, 22, 23, 25, and 26 with low relative relief ratio value has been given the lowest rank (1) and sub-watersheds 3, 4, 5, 6, 8, 12, and 14 with high values are denoted by the highest rank (5). Basin slope has an impact on the hydrological processes such as the amount of surface runoff and speed, and the time (Meraj et al. 2013). Steep slope and high relief of the basin increase the probability of flash floods. In the present study, sub-watersheds 1, 2, 20, 21, 22, 23, 24, 25, and 26 with the lowest basin slope values are denoted by the lowest rank (1). Sub-watersheds 3, 12, and 13 with the highest values are denoted by the highest rank (5). Ruggedness is the nature of the surface undulations of the basin (Selvan et al. 2011). If the ruggedness number is maximum, there is a high possibility for erosion and flash floods (Patton and Baker 1976). It is directly related to flooding (Obeidat et al. 2021). Sub-watersheds of the study areas 8, 12, 13, 18, 19, 20, 21, and 26 with the lowest ruggedness number are denoted by the lowest rank (1). Sub-watershed 1 with the highest ruggedness number are denoted by the highest rank (5). Hypsometric Integral is a very important parameter to determine the interrelations existing among the lithology, climate, erosion, and tectonic uplift (Pavano et al. 2018). Hypsometric integral value is lowest for SW 22 and SW 26 and hence these watersheds are given top rank (5) while SW 5, SW 7, SW11, and SW 21 with the highest hypsometric integral are given the lowest rank (1).

The eight direct morphometric parameters (basin slope, basin area, circularity ratio, ruggedness number stream frequency, relief ratio, drainage density, and relative relief ratio) and four indirect parameters (length of overland flow, shape factor, hypsometric integral, and elongation ratio) weights are employed for the Pearson correlation coefficient matrix in Fig. 2.5. This matrix revealed that the correlation of the all-morphometric parameters are correlated to each other. According to the result of the correlation analysis, the strongest correlation has been found between the basin relief and basin slope (r = 0.96). Moreover, the circularity ratio to other morphometric parameters has been found as the weakest correlation.

2.4.2 Prioritization of the Sub-basin for Flood Susceptibility

The morphometric total ranking method was used for assessing the flood hazard. Table 2.2 and Fig. 2.6 illustrate the results of this study. The total ranking method was used for the total score of twelve factors for each sub-watershed. The flood prioritization map of the SRB represents two sub-watersheds (18, and 21) with very high flood probability. About 5.61% of the total area is under this category and this area is also the same as that of the historical flood. Around 42.57% of the total area encompassing nine sub-watersheds (12, 13, 17, 19, 20, 22, 24, 25, and 26) are under the high flood susceptibility zone. The results of the study represent that this is a high flood-prone area. Around 27.65% of the total basin area distributed over ten sub-watersheds (5, 6, 7, 8, 9, 10, 11, 15, 16, and 23) are included in the moderate class flood risk category. Sub-watersheds 1 and 14 are fall under the low flood risk class with around 11.60% of the total basin area. Sub-watersheds 2, 3, and 4 with around 12.68% of the total area of the basin are included under very low flood risk areas. The

Table 2.2 Details description of the results of the study with weight values

SW	A	D_d	L_o	F_s	R_e	R_c	S_f	R_r	R_v	B_s	R_n	HI	Total rank	Normalization	Prioritized rank	Priority
1	1	5	2	5	3	1	4	1	1	1	1	5	30	0.40	3	Low
2	2	4	1	2	1	5	5	1	1	1	1	2	26	0.20	2	Very low
3	2	3	1	2	1	3	5	1	1	1	1	1	22	0	1	Very low
4	1	4	1	1	1	2	5	2	2	2	1	4	26	0.20	2	Very low
5	1	1	5	2	2	5	4	3	5	3	1	1	33	0.55	7	Moderate
6	1	1	5	2	2	1	4	5	5	3	2	2	33	0.55	7	Moderate
7	4	5	2	1	4	3	1	1	4	1	5	2	33	0.55	7	Moderate
8	1	3	2	2	3	5	3	3	5	3	1	2	33	0.55	7	Moderate
9	2	5	2	5	2	5	2	2	2	2	2	2	33	0.55	7	Moderate
10	1	5	2	2	2	3	5	2	5	2	2	2	33	0.55	7	Moderate
11	1	5	2	5	3	4	3	2	3	2	2	1	33	0.55	7	Moderate
12	1	4	2	1	1	5	5	5	5	5	1	2	37	0.75	9	High
13	1	5	2	3	1	3	5	5	3	5	1	2	36	0.75	9	High
14	1	4	1	2	1	3	5	4	3	4	1	2	31	0.45	4	Low
15	1	5	2	4	3	2	2	2	3	2	2	4	32	0.50	5	Moderate
16	3	5	2	4	3	3	2	1	1	1	2	5	32	0.50	6	Moderate
17	1	5	2	5	3	4	3	2	4	2	3	2	36	0.75	9	High
18	1	5	2	4	3	5	4	3	5	3	2	2	39	0.85	10	Very high
19	1	5	2	4	3	4	3	2	5	2	2	3	36	0.75	9	High
20	4	5	2	5	3	3	1	1	3	1	4	3	35	0.65	8	High
21	1	5	3	5	3	4	1	5	5	5	2	3	42	1.00	11	Very high
22	1	5	2	5	2	5	4	2	4	2	2	3	37	0.75	9	High
23	4	5	2	5	4	2	1	1	1	1	3	3	32	0.50	6	Moderate
24	5	5	2	5	3	3	2	1	2	1	3	3	35	0.65	8	High
25	5	5	2	5	3	3	2	1	1	1	4	4	36	0.65	8	High
26	1	5	2	4	5	4	3	2	4	2	2	1	35	0.65	8	High

upper part of the basin is a very low flood risk area. The lower-middle segment of the river basin is observed to be in a vulnerable condition since it belongs to the very high to high flood susceptible category. Also, these results are the same as that of the rainfall active area and geology. Current research represents that rainfall has a strong relationship with flood susceptibility. This work will be helpful for the authorities to take appropriate measures for reducing flood risk or surfaces runoff harvesting. Moreover, this work may be employed in other areas, when the historical flood data and validation are not available.

2.4.3 Validation

In the present context, accurately measuring and preparing the flood susceptibility map with validation is a very crucial and difficult task. The present study used success and prediction rate methods to validate the model by comparing predicted hazard areas to existing hazard locations (Zare et al. 2013). To do this, a total number of 200 known flood sites are demarcated from the flood map of 2017 (Figs. 2.1 and 2.6) published by the National Remote Sensing Centre (bhuvan.nrsc.gov.in). Therefore, an area under curve (AUC) method evaluated the

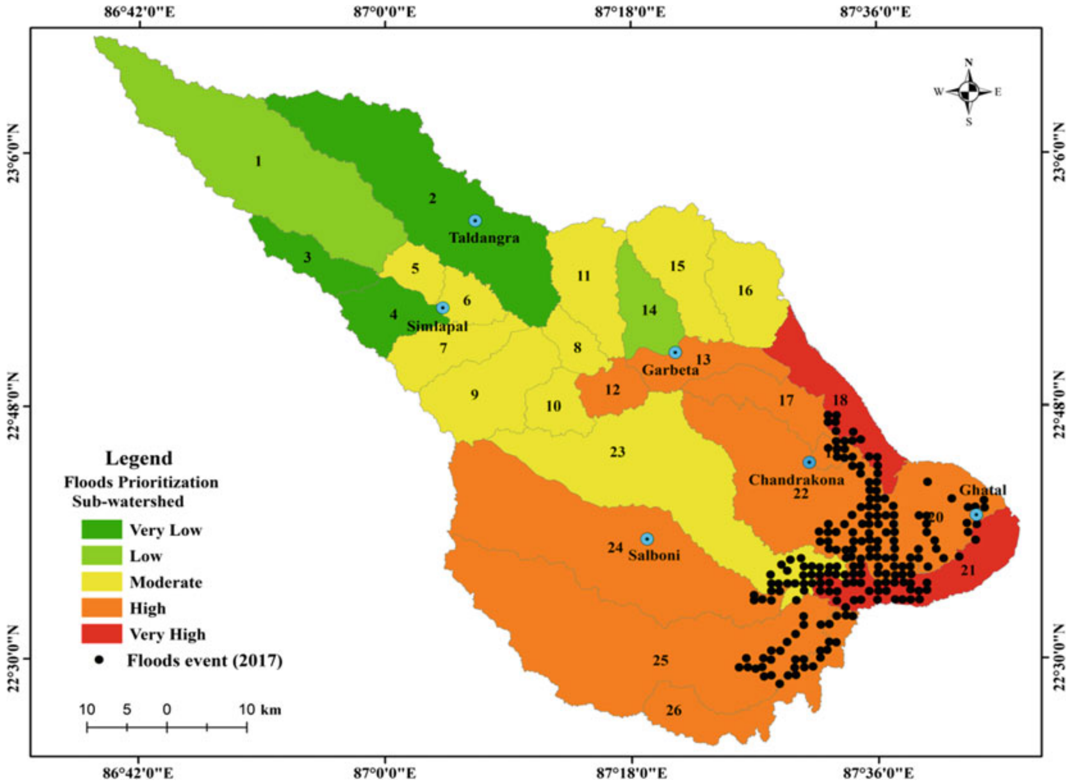

Fig. 2.6 Sub-watersheds-wise final flood susceptibility map

prediction capabilities of validation of the model (Swets 1988; Hong et al. 2015). In this work, the AUC is considered to evaluate the performance and efficiency of this morphometric method. In order to assess the validity of the flood susceptibility map, the AUC is computed, and the output value, i.e., 89.2% depicts that the accuracy level of the flood map prepared to adopt the morphometric analysis technique is well acceptable (Fig. 2.7). Also, different field photos during the flood also validate this work (Fig. 2.8).

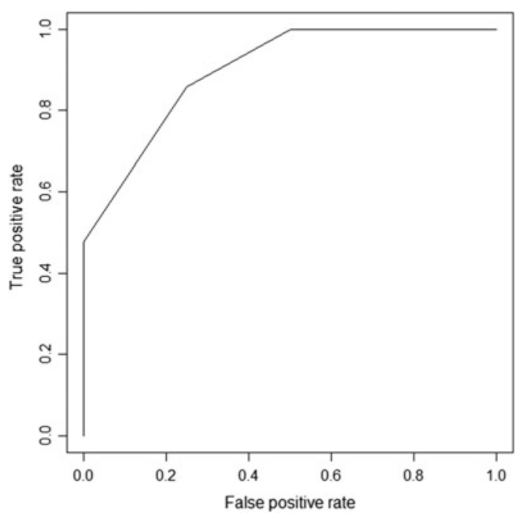

Fig. 2.7 Area under curve for validation of flood susceptibility map

2.5 Conclusion

Hydro-morphometric analysis and GIS techniques are employed to predict flood vulnerable areas of the SRB. Since there were no such

Fig. 2.8 **a** Flood water spill over the area near Ghatal, **b** flood water spill over the road near Ghatal, **c** flood water spill over the bridge near Chandrakona, **d** flood water spill over the area near Chandrakona, **e** flood water spill over the area near Salboni, **f** flood water spill over the road near Salbani (*Source* Field Photographs 2020)

government or private historical flood records that are required for flood modeling, sub-watershed-wise flood susceptibility analysis has been done using the morphometric investigation. The current study result depicts that around 48.18% of the total basin area is included under the high to very-high-flood susceptibility category. Basin slope, relative relief ratio, drainage density, circulatory ratio, relief ratio, stream frequency, and ruggedness number are the most important morphometric parameters for flooding in the study area. The performance and efficiency of this method are validated using the AUC model that ensures a considerable amount of accuracy (89.2%) of the study. The flood prioritization map of the SRB represents two sub-watersheds (18 and 21) with very high flood probability. About 5.61% of the total area is under this category and this area is also the same area as the area of the historical flood. Around 42.57% of the total area over nine sub-watersheds (12, 13, 17, 19, 20, 22, 24, 25, and 26) are under the high flood susceptibility zone. The result of the study represent that this is a high flood-prone area. Therefore, the current study depicts that managing the flood of the area is much needed. It should be the main focus of the government to protect human lives and agricultural land. Moreover, this study carried out using the combination of morphometric analysis with GIS may act as an important tool to understand sub-watersheds parameters related to flooding management.

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