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Technical Note

Spatial Flood Potential Mapping with Flood Probability and Exposure Indicators of Flood Vulnerability: A Case Study from West Bengal, India

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Abstract: Flood is an annual event in the district of Jalpaiguri. Almost all the administrative blocks of the district are more or less flood prone. Numerous rivers and rivulets are originated and pass through this district, which create floods mainly on account of rainfall in the source regions of these rivers, apart from rainfalls in the district itself. The shivering rivers during monsoon periods carry massive discharge and frequently cross danger levels. Danger level is the threshold level of water from which the event is considered as a flood. The probability of the occurrence of flood can be calculated with the past records of flood events in flood prone areas. On the other hand, the vulnerability of flood events is entirely dependent on the exposure of the area. Exposure of the area and the probability of the adjacent rivers can explain how much this area is subject to floods. In this paper, the authors tried to prepare a spatial flood potential map for the entire district based on probability analysis and an exposure indicator.

Keywords: assessment, probability, danger level, exposure indicator, flood potential

1 Introduction

Probability is defined as the chance of occurrence of an event. Flood is a natural event. With probability analysis, the chance of occurrence of a flood can easily be predicated. Like the probability analysis of the river flood, the analysis of the exposure indicators of the adjacent area is equally important for flood predication. An Exposure Indicator explains how the place is physically exposed to potential flood hazards. Exposure Indicators include percentage of flood area in a particular place, flood frequency, flood water depth, flood water stagnant period, elevation of the place and velocity of the adjacent river. Both the probability of flood events and the Exposure Indicators can express the future flood potential of the concerned areas. Moreover, in vast flood prone areas, flood potential analysis helps in proper flood management because flood potential analysis provides a clear picture of high, medium and low potential areas, which can furthermore help to find out which areas should get priority in management and relief distribution.

Various attempts have been made for flood vulnerability assessment, flood risk zoning, flood hazard zoning in various flood prone areas. There are no fixed methods for vulnerability assessment, risk zoning or hazard mapping associated with flood related hazards. Some emphasize on hydro-geomorphic factors (Clement 2013, Gogoiet al 2013, Nyarko 2013), and some others emphasize on cultural land use factors (Bera 2012, Mollah 2013). Very few scholars have incorporated socio-economic and infrastructural parameters in their flood risk zonation methods and models (Saynal and Lu 2006), and also less attempts have been made in vulnerability of exposure indicators (Messner and Mayer 2006) for vulnerability mapping. On the other hand, in flood probability analysis various works have been done on return periods. There is no work on flood probability from where we can get the number of chance or the likelihood of flood occurrence. In any areas which are affected by flood annually and by various flood prone rivers, it is necessary for that area to find out flood potential zones. Only combination of exposure indicators and probability index can give the way out for spatial flood potential of the place.

Jalpaiguri is a district in West Bengal, India. The district is geographically situated from 26º16'35"N to 26º59'30"N and from 88º04'59"E to 89º55'20"E, comprising an area of 6,227 km^2. It is located on the southern flanks of the foothills of the Himalaya. Jalpaiguri district is bounded on the north by Darjeeling district and Bhutan, on the south by Uttar Dinajpur and Coochbehar districts, on the west by Uttar Dinajpur and Darjeeling districts and Purnea district of Bihar, while Goalpara district of Assam occurs on the east (Figure 1). Administratively, as per the 2011 Census records, Jalpaiguri district consists of three sub-divisions, viz. Sadar, Mal and Alipurduar. These sub-divisions consist of 13 Community Development (CD Blocks), 17 police stations, 756 mouzas and 4 Municipalities (Census Report 2011).

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From 2014, the Jalpaiguri district has been divided into Jalpaiguri and Alipurduar district.

Floods in this area occur annually. However, its intensities vary from year to year. Flood intensities vary in term of area affected by flood, population affected, cropped area affected, housing affected and infrastructure affected. Almost all the administrative blocks are more or less affected by floods every year. The main rivers in this district contributing to floods are Teesta, Jaldhaka, Torsa, Kaljani, Raidak, Riti, Titi, Mujnai, Sankosh etc (Table 1). Their influencing areas are shown in Figure 2.

All the rivers have observation sites established by Central Water Commission and Irrigation and Waterways Department, Jalpaiguri. Gauge height, which is a measure of water level of the river, has been recorded in monsoon periods (from May to October 15) in these stations.

The objective of this study is to find out the probability of flooding of each river to occur in a given year in the district, how much the administrative blocks are exposed to floods, and moreover the spatial flood potential in block level of the district.

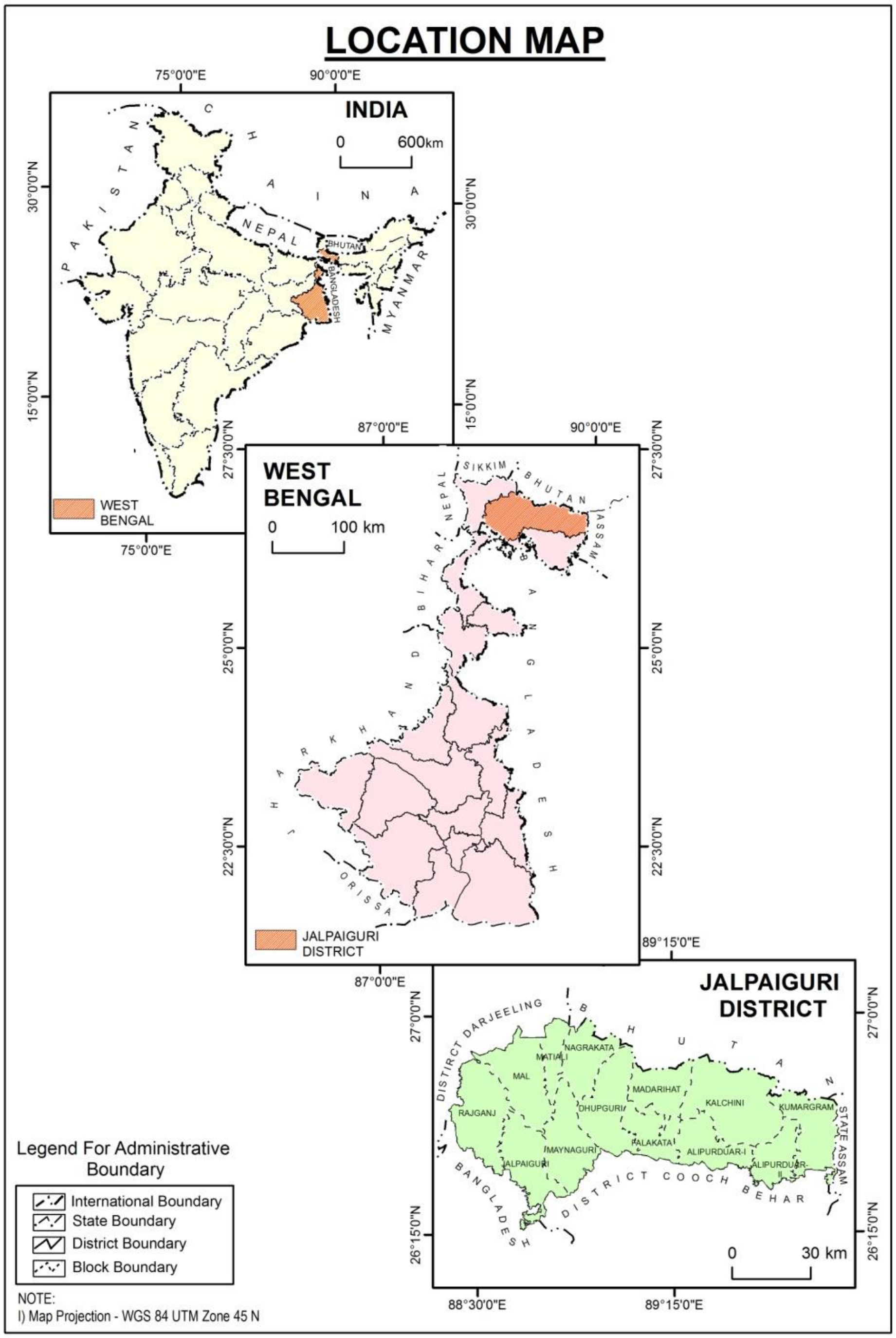

Figure 1. Location map

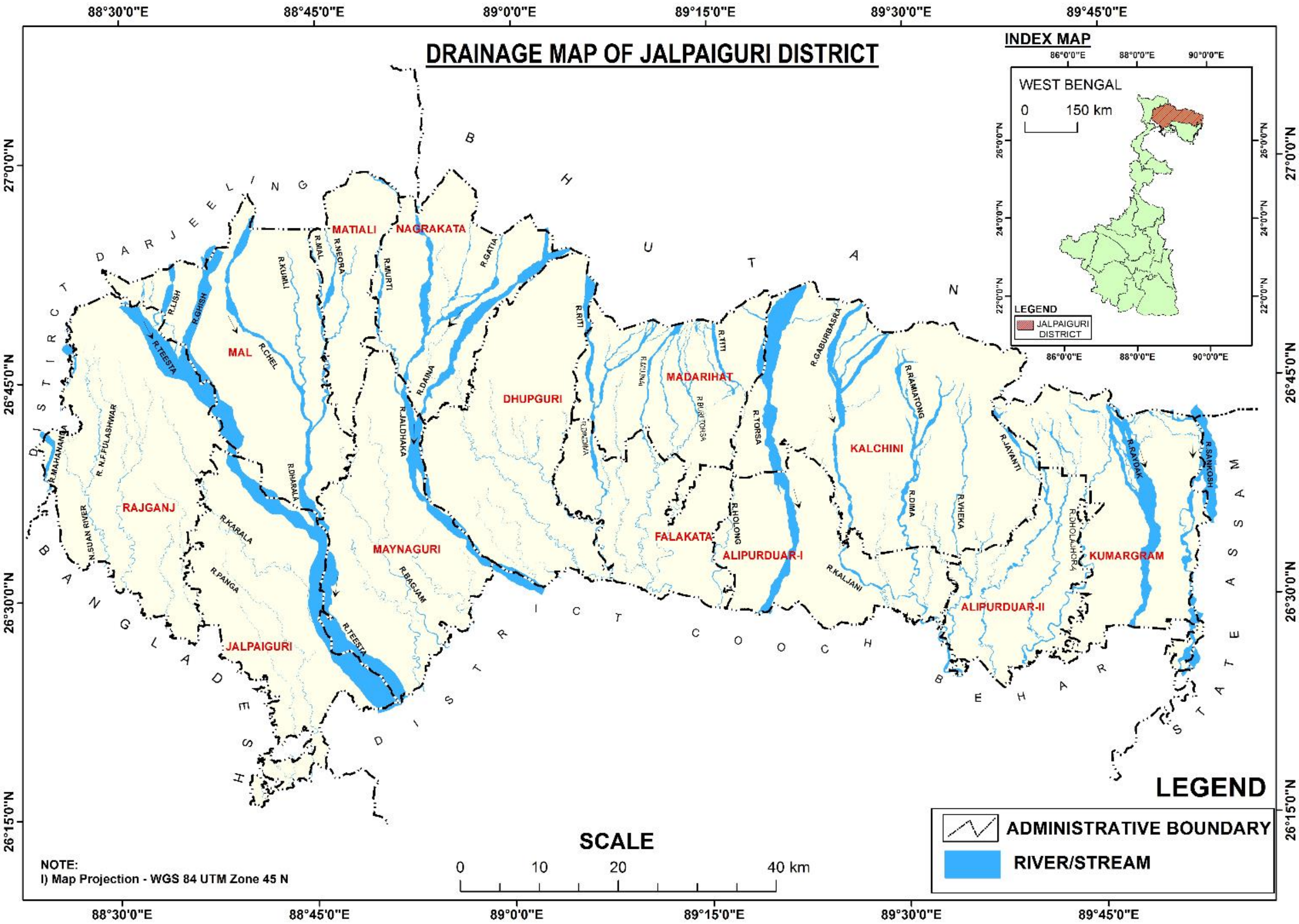

Figure 2. Drainage map.

Table 1. List of administrative blocks and the influencing rivers which contribute flooding. Source: NBFCC, Jalpaiguri.

Symbol	River Observation Site)	Influencing Blocks
B1	**Teesta** (at Domohani bridge Sadar-Maynaguri Block	Sadar-Maynaguri Block
B2	**Jaldhaka** (at NH31 bridge crossing Maynaguri-Dhupguri)	Maynaguri-Dhupguri
B3	**Diana** (at Changmari, Nagrakata)	Nagrakata
B4	**Torsa** (at Hasimara,)	Kalchini
B5	**Raidak I** (at Chepan)	Falakata
B6	**Raidak II** (at Telepara, Kumargram)	Kumargram
B7	**Kaljani** (at P.W.D road crossing, Alipurduar I)	Alipurduar I
B8	**Sankosh** (at NH 31 C crossing, Kumargram)	Kumargram
B9	**Mujnai** (Bhutnirghat, Madarihat)	Madarihat
B10	**Jainti** (Alipurduar II)	Alipurduar II
B11	Chel, Neora and Mal Join course **Dharala** (at Basusuba, Mal)	Mal
B12	**Neora**(Bidhannagar gram Panchayet, Matiali)	Matiali

2 Database and Methodology

North Bengal Flood Control Commission (NBFCC) in Jalpaiguri has provided the gauge height data of different rivers. From these data, flood and non-flood years are obtained for different rivers. The data are given in Table 2.

In addition, for the analysis of Exposure Indicator of vulnerability, different variables have been used (Messner and Meyer 2005) these variables data are collected from various sources. These are given in Table 3.

“Bayes” Theorem is applied for probability analysis in different rivers [named after Thomas Bayes (1702-1761), an English theologian and mathematician] (Croxton et al 1967). It helps us determine posterior probabilities by expressing them in term of prior probabilities (Ebdon 1977).

In Table 2, B1, B2, B3, …, B12 are different rivers in different blocks which influence the blocks in flood situation. Their flood data is given in the column based on the danger level crossed by that river. "A" is the flood event and "P" is the probability.

An event "A" (flood event) can occur only if one of the mutually exclusive and exhaustive set of events B1, B2, …, Bn occurs. Supposed that the unconditional probabilities P(B1), P(B2), …, P(Bn) and the conditional probabilities P(A/B1), P(A/B2), …, P(A/Bn) is known. Then the conditional probability P(Bi/A) of a specified event Bi is:

$$\frac{P(Bi) \times P(A/Bi)}{\sum_{i=i}^{n} P(Bi) \times P(A/Bi)}$$

Table 2. Flood and Non- flood event in different rivers in Jalpaiguri district. Source: North Bengal Flood Control Commission.

Symbol	River	No. of floods	No. of non-Floods	No. of total observations years
B1	Teesta	14	9	23
B2	Jaldhaka	18	8	26
B3	Diana	7	8	15
B4	Torsa	14	1	15
B5	RaidakI	11	4	15
B6	Raidak II	6	9	15
B7	Kaljani	9	6	15
B8	Sankosh	5	10	15
B9	Mujnai	8	7	15
B10	Jainti	12	3	15
B11	Dharala	11	4	15
B12	Neora	7	9	16

Other than the probability analysis for exposure indicator, Principal Component Analysis (PCA) is also used. PCA is a statistical method – a branch of Factor Analysis based on large number of variables statistically reduced to smaller number of general components. It also identifies how components that account for the overall variability within the variables (Spiegel 1961). Principal components are linear combinations of these variables accounting for the common and unique variability explained by them. In this research PCA was done with SPSS (IBM Corporation). To examine correlation matrix, SPSS provides Bartlett's test and KMO (Kaiser- Meyer- Olkin test). Bartlett's test is used to test the hypothesis that a correlation matrix is an identity matrix and KMO measure of sampling adequacy is an index for comparing the magnitudes of the observed correlation coefficients to the magnitude of the partial correlation coefficient.

From the result of Probability score (P_x) obtained from Probability Analysis and the Exposure Indicator Score (*EIS*) obtained from PCA, final Spatial Flood Potential Index (*SFPI*) can be calculate by Equation $SFPI = P_x \times EIS$. With the *SFPI* score, the SFP mapping can be obtained.

Table 3. The variables for the block level study of exposure as an indicator of flood vulnerability.

Variables	Source of data
Percentage of flood prone area in a given block	Calculated from Natural Calamity C(A) II Report, Block Development Office, Govt. of West Bengal,1998-2012
Percentage of Mouza affected in the block	Calculated from Natural Calamity C(A) II Report, Block Development Office, Govt. of West Bengal,1998-2012
Maximum number of day's flood water stayed	Based on Questionnaire Survey
Depth of the flood water in metre	Based on Questionnaire Survey
Velocity of the adjacent river in metre/second	Field Survey
Average elevation of the block in metre	Based on SRTM data

3 Discussion and Analysis

Probability of flood in individual flood prone rivers was analysed using Bayes Theorem of Probability analysis. Results show that the maximum probability of flood in the river Torsa (B4), followed by the river Jainti (B10) and the Kaljani (B5). Other rivers with remarkable high probability are Jaldhaka (B2) and Dharala (B11). The smallest probability is observed in the river Sankosh (Table 4 and Figure 3).

Like the rivers block wise probability was calculated, the main influencing rivers in the individual block have been identified. Sadar is mainly influenced by the river Teesta (B1), whose probability [P_X] is 0.08; Maynaguri block is mainly influenced by two rivers, Jaldhaka (B2) and Teesta (B1), its probability [P_X] is 0.086. The block wise probabilities of flood are given in Table 5.

High probability of flood has been found in the Kalchini block followed by Alipurduar II and Alipurduar I. Besides these blocks, high flood probability has also been observed in Mal and Dhupguri blocks. Rajganj block in this situation has not been taken into consideration because some ungauged forest rivers (originate from Baikunthapur forest, which is situated in the north of the block) including the Karala, Fulashwar, and Suan are mainly responsible for flooding.

Exposure Indicator explains how the block under consideration is physically exposed to flood hazards. In Exposure Indicator PCA analysis, the Kaiser- Mayer- Olkin (KMO) sampling adequacy test values are > 0.5 and Bartlett's sphericity tests returned P < 0.05. This suggests that the variables are suitable for PCA Analysis. KMO value > 0.5 or higher is acceptable for PCA. The structural matrix loading for exposure indicators of each component (i.e. PC1, PC2, ...) which Eigen value > 1 and together the three components of Exposure Indicator account for 76.09%. Eigen values are used to determine the number of factors to be extracted in PCA (Tables 6 & 7).

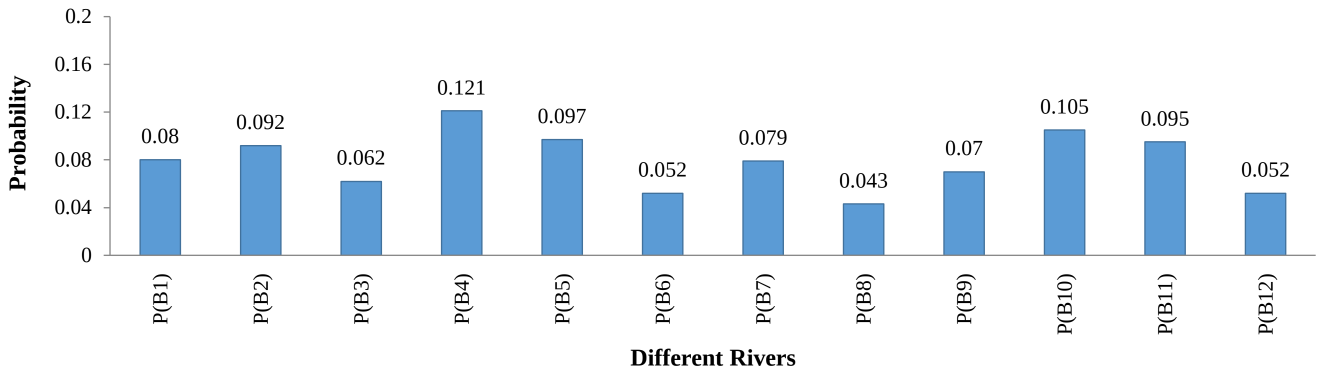

Figure 3. Flood probability in different rivers in the Jalpaiguri district.

Table 4. Probability of different rivers with their percentage.

Probability (Px) of flood event in the rivers. "A" (flood)	$P(Bi)\times P(A/Bi)=a$	$\sum_{i=i}^{n} P(Bi)\times P(A/Bi)=b$	$P(x)=(a/b)\times 100$
P(B1)	0.048	0.61	0.080 × 100 = 8.0%
P(B2)	0.056	0.61	0.092 × 100 = 9.2%
P(B3)	0.038	0.61	0.062 × 100 = 6.2%
P(B4)	0.074	0.61	0.121 × 100 = 12.1%
P(B5)	0.059	0.61	0.097 × 100 = 9.7%
P(B6)	0.032	0.61	0.052 × 100 = 5.2%
P(B7)	0.048	0.61	0.079 × 100 = 7.9%
P(B8)	0.026	0.61	0.043 × 100 = 4.3%
P(B9)	0.042	0.61	0.070 × 100 = 7.0%
P(B10)	0.064	0.61	0.105 × 100 = 10.5%
P(B11)	0.058	0.61	0.095 × 100 = 9.5%
P(B12)	0.032	0.61	0.052 × 100 = 5.2%

Table 5. Probability of different Blocks.

Name of the Block	**Influencing River's Symbol**	P_X
Sadar	B1	0.080
Maynaguri	B1 + B2	(0.080+0.092)/2 = 0.086
Dhupguri	B2	0.092
Nagrakata	B3	0.062
Kalchini	B4	0.121
Falakata	B9	0.070
Kumargram	B5 + B6 + B8	(0.097+0.052+0.043)/3 = 0.064
Alipurduar I	B7 + B4	(0.079+0.121)/2=0.10
Madarihat	B9	0.070
Alipurduar II	B10	0.105
Mal	B11	0.095
Matiali	B12	0.052
Rajganj	---------	-----------

Table 6. Factor analysis for Exposure Indicator and computed value loading structure matrix.

Input Variables	Principal Components		
	PC1	PC2	PC3
Percentage of flood prone area	-0.086	0.001	**0.811**
Percentage of high flood frequent mouzas	-0.172	0.044	**0.720**
No. of days water stagnant	0.178	**0.860**	0.135
Depth of water	0.374	**-0.839**	0.129
Velocity of adjacent river	**0.892**	0.175	-0.154
Average elevation in metre	**0.830**	-0.423	-0.238
Percent Variance Explained	32.35	24.81	18.93

Table 7. KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.684
Bartlett's Test of Sphericity	Approx. Chi-Square	28.259
	df	15
	Sig.	0.020

With PCA application, scores to calculate the Exposure Indicator, i.e. PC1, PC2 and PC3, have been obtained (Table 8). PC1 explains velocity of the adjacent river and elevation of the area, PC2 explains the number of days when water remains stagnant as well as depth of the flood water, and PC3 explains the percentage of flood prone area in the block and percentage of high flood prone mouzas in the block. The total score of PC1, PC2 and PC3 indicates the score of Exposure Indicator of a given block. Table 8 refers to the exposure indicator scores and their corresponding ranks.

PC1 score explains the magnitude of flood event in the district as a product of high river velocity as well as high elevation coupled with high slope. According to the PC1 score, Madarihat Block stood in the first place (Table 8). Here, river Mujnai is responsible for floods in this block. The reason is that the average velocities of these two rivers are quite high to the tune of 3.5 m/sec. Moreover, the average elevation of the block is as high as 150 m, where slopes are steep from 80-150 m/km to 10-20 m/km. The second highest PC1 score is observed at Kalchini Block followed by Matiali, Nagrakata, Mal, and Jalpaiguri Sadar with positive PC1 scores. Negative PC1 scores are found for the administrative blocks in the order of Rajganj, Alipurduar II Falakata, Dhupguri, Maynaguri, Kumargram and Alipurduar I (Table 8). It may be noted therefore that the negative PC1 values do not suggest occurrence of flood in the above noted administrative blocks for reasons other than high velocity river and high altitude.

PC2 scores explain the occurrence of flood event as a function of duration of water stagnation in days and depth of stagnated water. According to the PC2 score, Kumargram stood first. Here, flood water stays for an average of 3 days and the depth of the stagnated water remains at 0.3 m. Other than the Kumargram block, the occurrence of flood event (positive PC2 score) gradually decreases over Alipurduar II, Kalchini, Matiali, Madarihat and Maynaguri block. Negative results of PC2 score occur at Alipurduar I, Jalpaiguri Sadar, Rajganj, Dhupguri, Falakata, Nagrakata and Mal, the last one has the smallest negative PC2 score.

PC3 scores explain the occurrence of floods as the function of the extent of percentage area experiencing flood and frequency of flood event over a period of 15 years from 1998 - 2012 in the district of Jalpaiguri. The highest positive PC3 score has been found in Mal block. Here, total number of floods affected mouzas as well as frequency of floods is found high. In terms of PC3 score in the district, positive scores are found other than the Mal block in Jalpaiguri Sadar, Maynaguri, Dhupguri, Matiali, Falakata, Madarihat, Alipurduar II and Kumargram. It clearly speaks for the large areal extent and high flood frequency in this district. This is why in almost all the blocks PC3 scores are positive in nature. Negative PC3 scores are found in Kalchini, Alipurduar I, Rajganj and Nagrakata block. In all these four blocks, the main portion of the land is covered with forest.

Exposure Indicator can be derived from the combination of these three PCI scores (PC1+PC2+PC3). According to the sum values of PCIs, the first rank goes to Matiali block (Figure 5), followed by Madarihat and Kalchini. In Matiali block all three scores PC1, PC2 and PC3 are positive in nature. In Madarihat, PC1, PC2 and PC3 scores are also positive. For Kalchini block in spite of the negative PC3 score, due to high PC1 and PC2 scores Kalchini block takes the third place in Exposure Indicator score. Exposure Indicator scores are classified into six major ranges (1 – 6). 1 indicates the highest exposure to floods or most unfavourable conditions in a flood event. Degree or Intensity of exposure decreases with increasing rank (Table 8).

Spatial Flood Potential Index (*SFPI*) is calculated with Probability of individual block (P_X) and Exposure Indicator score of individual blocks (*EIS*). *SFPI* of individual blocks is identified which is given in Table 9 and Figure 4. According to this calculation, the highest *SFPI* is observed in Kalchini block followed by Madarihat and Matiali block. Remarkable high *SFPI* is also observed in Alipurduar II and Sadar blocks. In spite of remarkable high probability in Dhupguri and Nagrakata block, due to low score of *EIS*, the *SFPI* of these blocks become very low. Again, due to high

EIS in Matiali and Madarihat block, *SFPI* is high in spite of a low P_x. With the value of *SFPI*, Spatial Flood Potential Mapping (SFPM) can be obtained for the entire district (Figure 5).

Table 8. Exposure Indicator scores of the Jalpaiguri District.

Block Name	PC1 Score	PC2 Score	PC3 Score	Total Score	Range Wise Ranks	Ranks
Sadar (Jalpaiguri)	0.575	-0.087	0.363	0.851	3	5
Rajganj	-0.195	-0.297	-1.325	-1.817	5	12
Maynaguri	-0.721	0.387	0.410	0.076	3	8
Dhupguri	-0.767	-0.491	0.588	-0.67	4	9
Mal	0.062	-1.657	2.216	0.621	3	6
Matiali	0.974	0.931	0.734	2.639	1	1
Nagrakata	0.893	-1.176	-1.244	-1.527	5	11
Falakata	-0.623	-0.514	0.065	-1.072	5	10
Madarihat	1.520	0.631	0.041	2.192	1	2
Kalchini	0.980	1.070	-0.397	1.653	2	3
Alipurduar I	-1.709	-0.053	-0.569	-2.331	6	13
Alipurduar II	-0.539	1.070	0.579	1.11	2	4
Kumargram	-1.102	1.510	0.001	0.409	3	7

Table 9. Spatial Flood Potential Index of Jalpaiguri district.

SL no.	Name of the Blocks	Influencing Rivers	*P(x)*	*EIS*	*P(x)*EIS = SFPI*
1	Sadar	B1	0.080	0.851	0.068
2	Maynaguri	B1+B2	(0.080+0.092)/2=0.086	0.076	0.0065
3	Dhupguri	B2	0.092	-0.670	-.062
4	Nagrakata	B3	0.062	-1.527	-.095
5	Kalchini	B4	0.121	1.653	0.200
6	Falakata	B9	0.07	-1.072	-.0750
7	Kumargram	B5+B6+B8	(0.097+0.052+0.043)/3=0.064	0.4086	0.026
8	Alipurduar I	B7+B4	(0.079+0.121)/2=0.10	-2.331	-.233
9	Madarihat	B9	0.070	2.192	0.153
10	Alipurduar II	B10	0.105	1.11	0.117
11	Mal	B11	0.095	0.621	0.059
12	Matiali	B12	0.052	2.639	0.137
13	Rajganj	---------	-----------	-1.817	----------

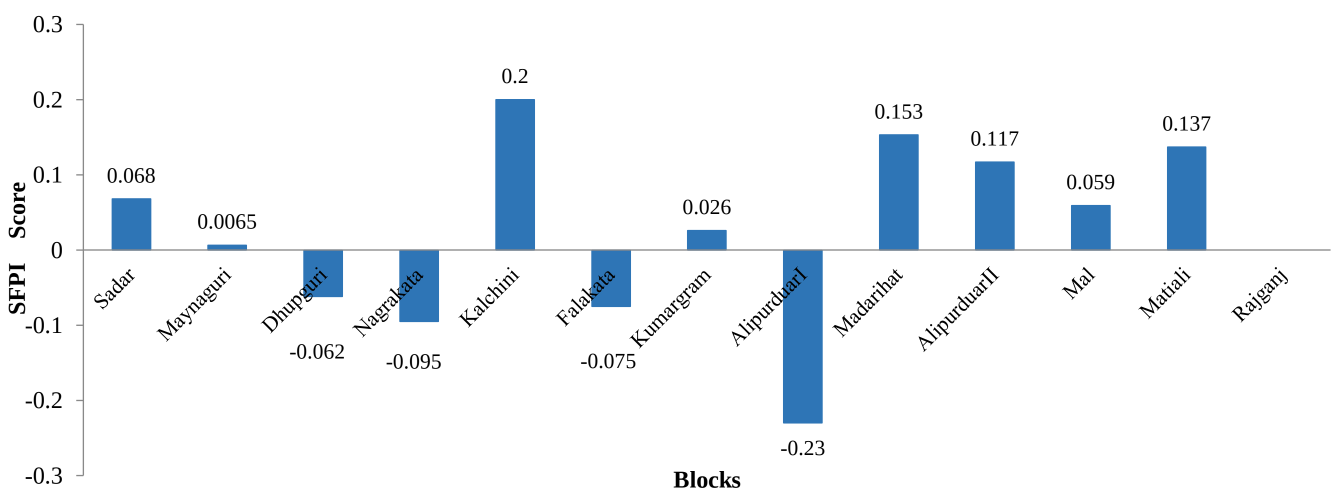

Figure 4. Spatial Flood Potential Index of the Jalpaiguri District.

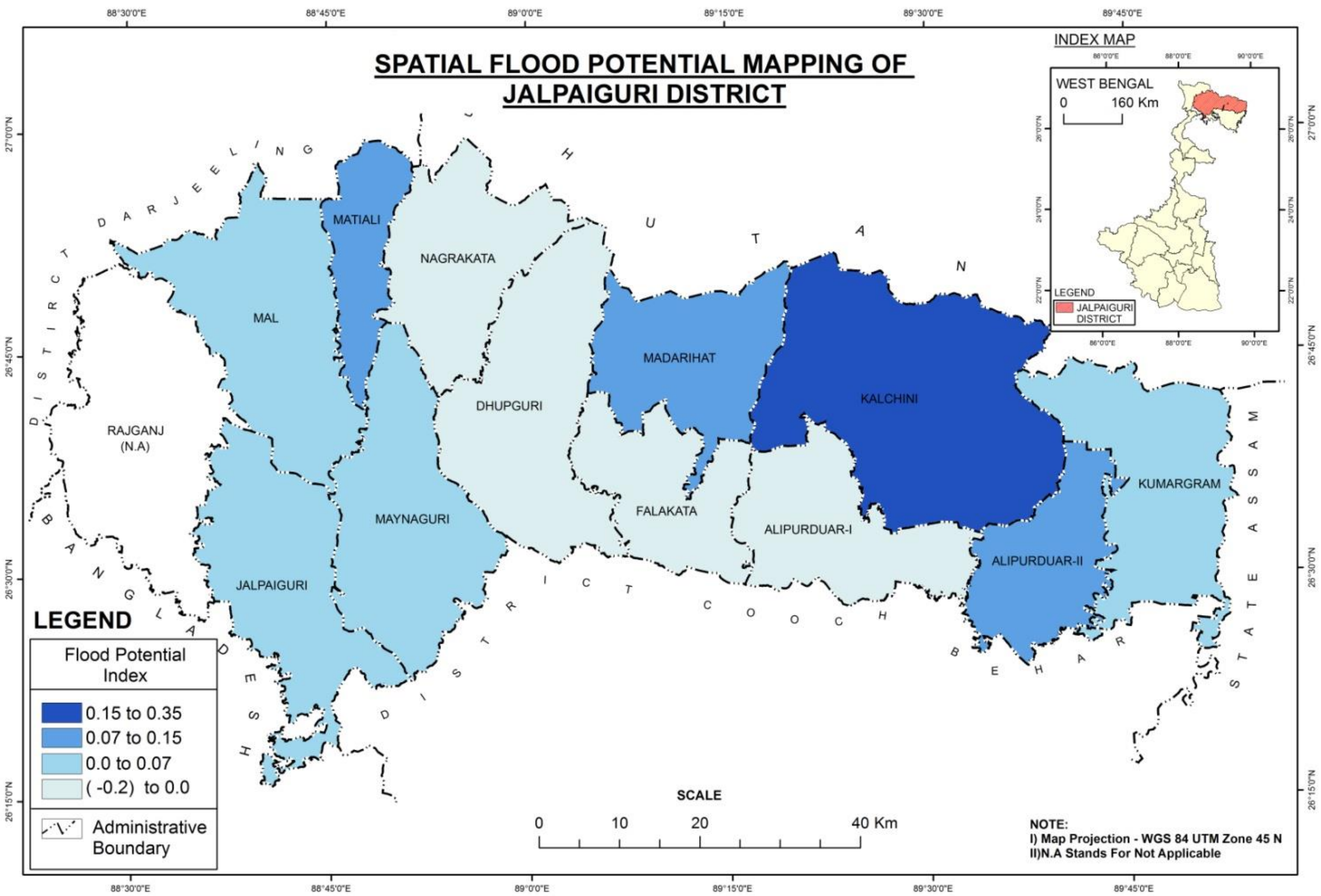

Figure 5. Spatial flood potential mapping of the Jalpaiguri District.

4 Conclusion

In recent years, increasing human occupancy in flood prone areas makes flood more hazardous and devastative. In this situation, identifying flood potential areas is necessary to manage the effects of high flood situations because flood potential indices indicate prior concerns of these areas. To find out the proper Spatial Flood Potential Index (*SFPI*) and Spatial Flood Potential Mapping (SFPM), this technique is helpful to the geographers and planners.

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