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Coastal Flood Susceptibility Mapping Using Multi-Criteria Decision-Making Approach and Analytical Hierarchy Process Model: A study of Tropical West Bengal Coast, India

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Abstract : *The coastline terrain is highly vulnerable to heavy storm surges, and the broader areas of the coastal plains are affected by the massive flood event. Large areas of the coastal Sundarbans were damaged, and many people died, and agricultural fields were inundated with salt water during the devastating cyclone Aila that hit West Bengal in 2009. It had 120 km/h gusts and a storm surge nearly 2 m high. More than five million people in the state are impacted by the cyclones. Therefore, the identification of cyclone-induced flood-affected areas is a crucial part to study to minimise the level of vulnerability and risk. This study considered the MCDM-based AHP method for identifying the coastal flood susceptibility areas. Here, eight factors were considered, i.e. rainfall, distance from the river, drainage density, topographic wetness index (TWI), surface slope, elevation, LULC, and soil types. Priority to magnitude has been decided based on expert decision. The final output of the susceptibility map was categorised into four classes, potential from low to very high. The study area is highly occupied by the moderate and high susceptibility zones. The moderate class covers the 3368.10 km2 area, which is 52% of the study area, and the high class covers 3128.76 km2 area which is 47% of the study area. The high susceptibility zone is located very close to the Bay of Bengal. The validation of the AHP model was performed by the ROC value i.e. 85.3% which indicates high precision and can be accepted to assess flood susceptibility studies in coastal Sundarban. The study revealed that proper and scientific land use plan and coastal area development plans can reduce the negative impact of floods in Tropical West Bengal Coast.*

Key words: *Coastal flood, tropical climate, flood susceptibility, MCDM approach, Analytical Hierarchy Process (AHP), RS-GIS*

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Introduction

The Indian Sundarban is highly vulnerable to tropical storms and their aftereffects, which include salt water intrusion, storm surge-induced flooding, and embankment breaches. The most destructive natural catastrophes in the world, tropical cyclones claim many lives and destroy a great deal of property. Significant increases in ocean temperatures brought on by global climate change result in a rise in the frequency and intensity of storms worldwide (Knutson et al., 2020; Ghosh and Mistri, 2023). Storm surges and high tides can cause a rise in water level that rapidly and suddenly brings floods in coastal locations. Extreme sea level rise causes coastal floods, which pose a serious risk on a national and international scale with far-reaching social, economic, and environmental repercussions (Haigh and Nicholls, 2017). The coastline terrain is highly vulnerable to storm surges and the border areas of the coastal plains are impacted by the massive flood events. Rising sea levels and stronger tropical cyclones are major contributors to the emergence of storm surge and coastal flooding risks (IPCC, 2007). It plays a vital role in the coastal dynamics and coastline changes, especially for salt marshes and mangrove forests. Loss and damage is a sibling scenario for local communities' which creates excessive casualties.

India receives a lengthy coastline (about 7,500 km), making the coastal regions of the Arabian Sea, Indian Ocean and the Bay of Bengal, excessively vulnerable to tropical and extra-tropical cyclones (Rahman and Salehin, 2013; Bhowmick et al. 2020). The Arabian Sea and the Bay of Bengal are homes for the maximum tropical storms, with the Bay of Bengal compared to the Arabian Sea (Kumar, 2020; Conitz et al. 2021).

The Purba Medinipur and South 24 Parganas districts comprise West Bengal's coastal plain, with a 158 km-long shoreline mostly dynamic in nature. Sundarban is one of the largest coastline areas in West Bengal (Javaid, 2021). While West Bengal's entire geographic area is 88,752 km^2, 111 blocks comprise 37,660 km^2 of flood-prone land identified during the past 41 years (from 1960 to 2000) (Irrigation & Waterways Department, West Bengal, 2020). People in West Bengal are compelled to be impacted by powerful and regular cyclone storms and floods covering its low-lying coastal region (Samanta 1997; Singh and Kumar 2017; Ciampa et al. 2021; Bhattacharya and Guleria, 2012) which is a very common phenomenon.

Large areas of the coastal Sundarban were damaged, many people died, and agricultural fields were inundated with salt water during the devastating cyclone Aila which has stricken to West Bengal coastal areas in 2009. It had 120 km/h gust and a storm surge nearly 2 m high (Debnath, 2013). More than five million people in the state got highly victimized. The Government of West Bengal and UNDP undertook a damage effect assessment, which put the death toll at 96. Devastation of homesteads identified serious losses. Around 5, 00,000 homes suffered completely or partially damaged, and considerably high quantity of croplands got badly massacred. Government relief camps evacuated more than 60,000 rescued lives (Pal and Ghosh, 2017). Sundarban and the surrounding area (Sagar Island) were damaged by Cyclone Bulbul also (2019). The water-inundated regions of the South 24 Pargana, East Medinipur, and North 24 Pargana districts changed from 99.922 km^2 to 149.22 km^2, 196.36 km^2 to 195.93 km^2, and 497.27 km^2 to 505.14 km^2 from pre-event to post-event, respectively during the cyclone-stricken days in 2019-2020s (Biswakarma et al. 2021). In total, 10.0172 km^2 of the vegetated area was harmed between the pre- and post-Bulbul periods being one worst calamity (Jaman et al. 2019). On May 20, Cyclone Amphan made landfall with strong winds and precipitation, a significant storm surge, and persistent wind velocity thrusting against civil life was of 170 kilometres per hour being momentary to evacuating

Table 1: Major tropical cyclones in the Bay of Bengal

Cyclone	Date of Occurance	Nature	Landfall	Storm surge height	Average wind speed (km/h)
Sitrang	25.10.2022	Severe cyclonic storm	Patuakhali in Barisal, Bangladesh Coast	2.4 m.	80-90
Yaas	23.05.2021	Very severe cyclonic storm	South of Balasore, Odisha coast	2-4 m.	140
Amphan	20.05.2020	Super cyclonic storm	Bakkhali, Indian Sundarban	5.45 m.	240
Fani	03.05.2019	Extremely severe cyclonic storm	Puri, Odisha coast	1.5 m.	215
Bulbul	10.11.2019	Very severe cyclonic storm	Sagar island and Frazerganj, Indian Sundarbans	1-2 m.	140
Titli	10.10.2018	Very severe cyclonic storm	Palasa, Andhra Pradesh	1.0 m.	150
Mora	30.05.2017	Severe cyclonic storm	Near Chittagong, Bangladesh coast	1.5 m.	110
Roanu	21.05.2016	Cyclonic storm	NW of Chittagong city, Bangladesh coast	3-5 m.	85
Mahasen	16.05.2013	Cyclonic storm	NW of Chittagong city, Bangladesh coast	2.0 m.	85
Phailin	04.10.2013	Extremely severe cyclonic storm	Near Gopalpur, Odisha coast	2.3 m.	215
Aila	25.05.2009	Severe cyclonic storm	Sagar island, Indian Sundarbans	2-3 m.	110
Akash	14.05.2007	Cyclonic storm	South of Chittagong, Bangladesh coast	1.5 m.	85
Sidr	11.11.2007	Extremely severe cyclonic storm	Barisal coast, Bangladesh coast	3 m.	216

Based on Literature studies

people (105 miles per hour) (118 mph) (Halder and Bandyopadhyay, 2022). Regarding devastation, cyclone Yass might not be as potent as cyclone '*Amphan*'. In contrast to 2020 (Sen, 2021), in West Bengal, 11,405.21 km^2 of coastal regions are overflowed by salty water due to Yass (Halder and Bandyopadhyay, 2022).

In the Indian Sundarbans, 54 out of 102 islands, 102 people live in life-threatening poverty (Chowdhury, 2021). This paper aims to identify the coastal flood susceptibility flood management and for the better agricultural development~~,~~ for enhancing livelihood of the coastal communities.

Based on Literature studies

Low-lying coastal settlements are among the most vulnerable to tropical storms. Effective coping techniques and mitigation tactics are thus vital to lessening the negative effects of cyclones. Hence, Flood prediction may be very helpful in averting loss and destruction. Flood-susceptible locations may be identified and flood damages reduced by scientific research of floods. With this aim in mind, this study conducted flood susceptibility analysis for Tropical West Bengal Coast using a combined multi-criteria decision making approach and analytical hierarchy process model.

A Succinct Outline of the Research Area

One of the world's largest delta areas is the Ganges–Brahmaputra delta (80000 km^2), with a heavily populated, low-lying, and extremely fragile coastal habitat created by the sediments and lithification as superposed deposited materials by the Ganges, Brahmaputra, and Meghna rivers (Kuehl et al. 1997, Ramesh et al. 2009, Stanley and Hait 2000). The Sundarbans mangroves, the greatest continuous stretch of diversified mangrove forest, are found in the delta (Hussain and Acharya 1994, Stanley and Hait 2000; Mondal et al. 2015). The delta is located 100 km. southeast of Kolkata, between latitudes 21°32' N and 22°20' N and 88°05' W and 89°05' W. It extends from the Hooghly-Matlah estuary to the Bangladesh border. Bangladesh makes up over 60% of this region (Fig. 1).

Data Sources & Methodology

Data Source

This research work has been schematized based on both primary and secondary data. At the preliminary level field data was collected through a questionnaire survey during the field visits, and secondary data was collected from published research articles, newspapers paper clippings, and surfing Google. For making the digital maps, the satellite data has been gathered from Earth-Explorer (https://earthexplorer.usgs.gov/), SRTM-DEM, Landsat data, Rainfall data which was received from IMD Pune gridded data site (http://www.imdpune.gov.in), and Soil data was collected from FAO site (India partnership). Some additional data has been collected by reviewing the relevant articles, thesis and irrigation and waterways department of West Bengal.

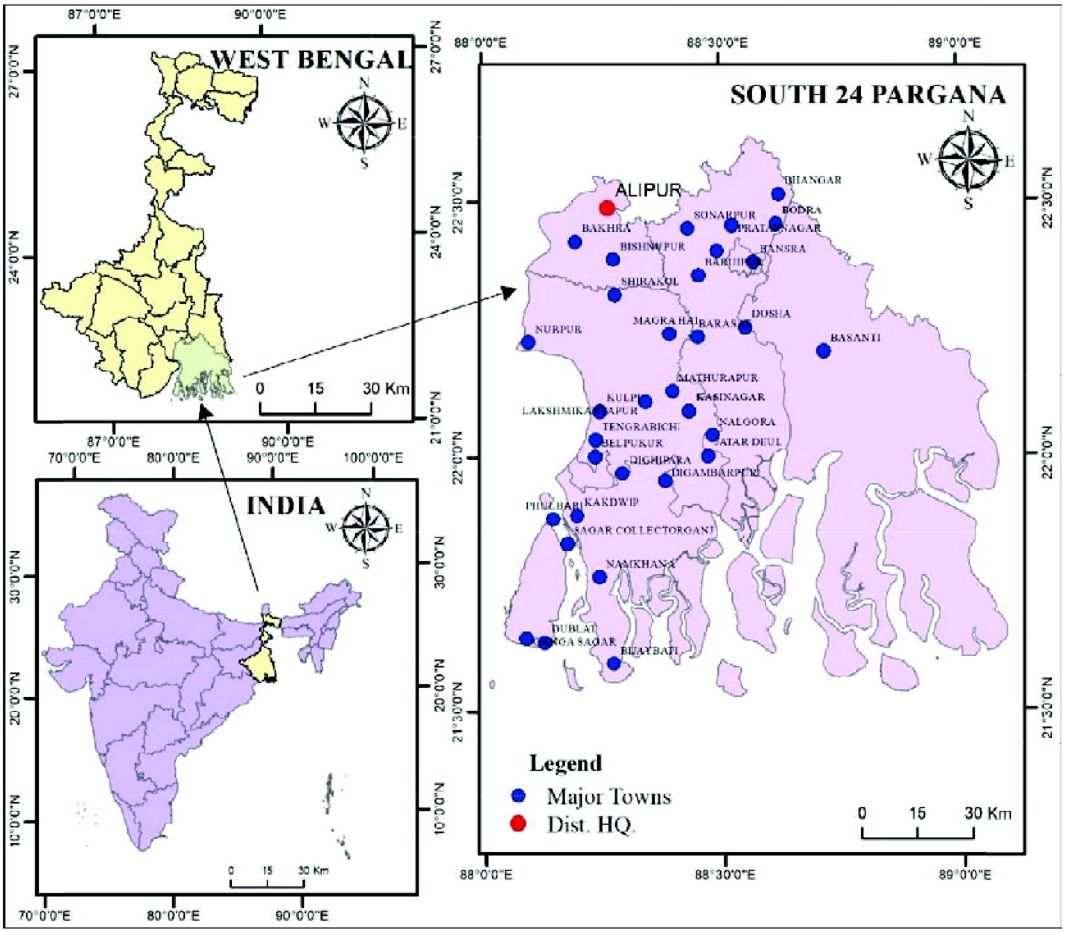

Fig. 1: Geographical personality of the study area and location of cyclone effaced sites in South 24 Parganas

AHP Method (Analytical Hierarchy Process)

The helpful and popular multi-criteria decision-making process known as AHP and was first introduced by Saaty in 1980. Usually, criteria are ranked to establish the factorizing and dominating factor based on experienced judgements (Das 2017; Hammami et al. 2019). AHP assists decision-makers in pair-wise comparisons between the selected elements, with the preidentified scale ranging from 1 to 9. The approach is calculated for each criterion (Wi) by finding the eigen vector corresponding to the greatest eigen value of the matrix and normalizing the components' sum to unity, i.e. 01 presented in (equation 1). For the preparation of the AHP Excel sheet, the eight map attributed data was needed, and which is prepared using the ArcGIS platform. After calculating

Table-2: Detailed description of the data used for identifying the flood susceptibility zones and their sources

Data Type	Details of Data	Available Format	Extracted Layer	Generated Layer	GIS Format
SRTM DEM USGS Earth Explorer (EE)	Entity ID: SRTM1N21E087V3, SRTM1N21E088V3, SRTM1N21E089V3, SRTM1N22E087V3, SRTM1N22E088V3, SRTM1N22E089V3, Spatial resolution-30m Publication date: 2014-09-23	TIFF	Contour; elevation	Distance from River, Drainage density, TWI, Elevation, Average slope,	Raster
Landsat-8 USGS EE	Path: 138 Row: 044 Row: 045 Date Acquired: 2023/03/06	TIFF	LULC (TCC)	LULC	Raster
Rainfall IMD-Pune	IMD Pune Gridded Rainfall data (1991-2022)	Binary	Point data	Total annual rainfall	Raster
Soil Texture FAO, UNESCO	FAO UNESCO soil map of the World (DSNW)	ESRI Shapefile	Soil texture	Soil texture	Raster

the weight using the AHP Excel sheet, it was run in the machine environment for the susceptibility mapping based on techno-algorithmic software output.

$$\sum_{i=1}^{n} wi = 1 \qquad \text{………………….. Equation 1}$$

The AHP model has been developed through four stages of functions, i.e., assignment of weight, pairwise comparison matrix, weight normalization, and consistency ratio (CR) check (Hammami et al., 2019). For the present study, a total of eight parameters were selected that are intended to regulate the flood susceptibility in the coastal Bengal, India. Here, expert opinions, field expertise, and multiple literature reviews are used to assign weights to each parameter. A high weight parameter resembles a high impact, and a low weight indicates a minor influence over flood susceptibility.

Table 2 shows the pairwise comparison matrix of coastal flood occurrence factors, where parameters are arranged in a hierarchical order and assigned values according to their relative importance (Table 3). Scores of pairwise comparisons are normalized to prepare the standardized comparison matrix for flood susceptibility mapping. Consistency of the AHP method is then measured by the following equations.

$$CR = \frac{CI}{RI}$$ .... Equation 2

Where,

$$CI = \frac{\lambda \text{ max} - n}{n - 1}$$ Equation 3

Where, *CR* denotes consistency ratio, *CI* indicates consistency index, *RI* is random index, λ max is principal eigenvalue in the matrix and n is the number of parameters.

ROC andAUC curve

The ROC and AUC curves are among the most accepted performance and computational metric for validating the AHP model. Before output of the flood susceptibility map, it was further run with the help of accurate positive and actual harmful data under GIS environment for the validation of the flood susceptibility map, and then the ROC curve was prepared. True positive or accurate harmful data is a point feature made with the help of primary and secondary information. If the output value comes to be above 85%, the MCDM result will be accepted scientifically as per the designing algorithm of the technique. The nature of the random guess is a unity proportion of no excess like same amount of false positive is indicative of true positive. Here, the deviation of false positive vs true positive is a successful departure of the validation of the model and if it runs more than 0.80 within the 0-1 range means an amount of false positive corresponds to a deviating value of true positive making the change of high validation.

Results and discussion

Relationship between Influencing Factors and Coastal Flood

For identifying the flood susceptibility zones of coastal area, eight factors were considered, i.e. rainfall, distance from the river, drainage density, and topographic wetness index (TWI), slope, elevation, LULC, and soil types.

Rainfall

Rainfall is the primary source that influences the flood of low-laying areas (Tehrany et al., 2013; Consoer and Milman, 2018). Thus, rainfall is very important parameter for influencing the flood being most obvious scenario in low-laying areas prone to high inundations. The study

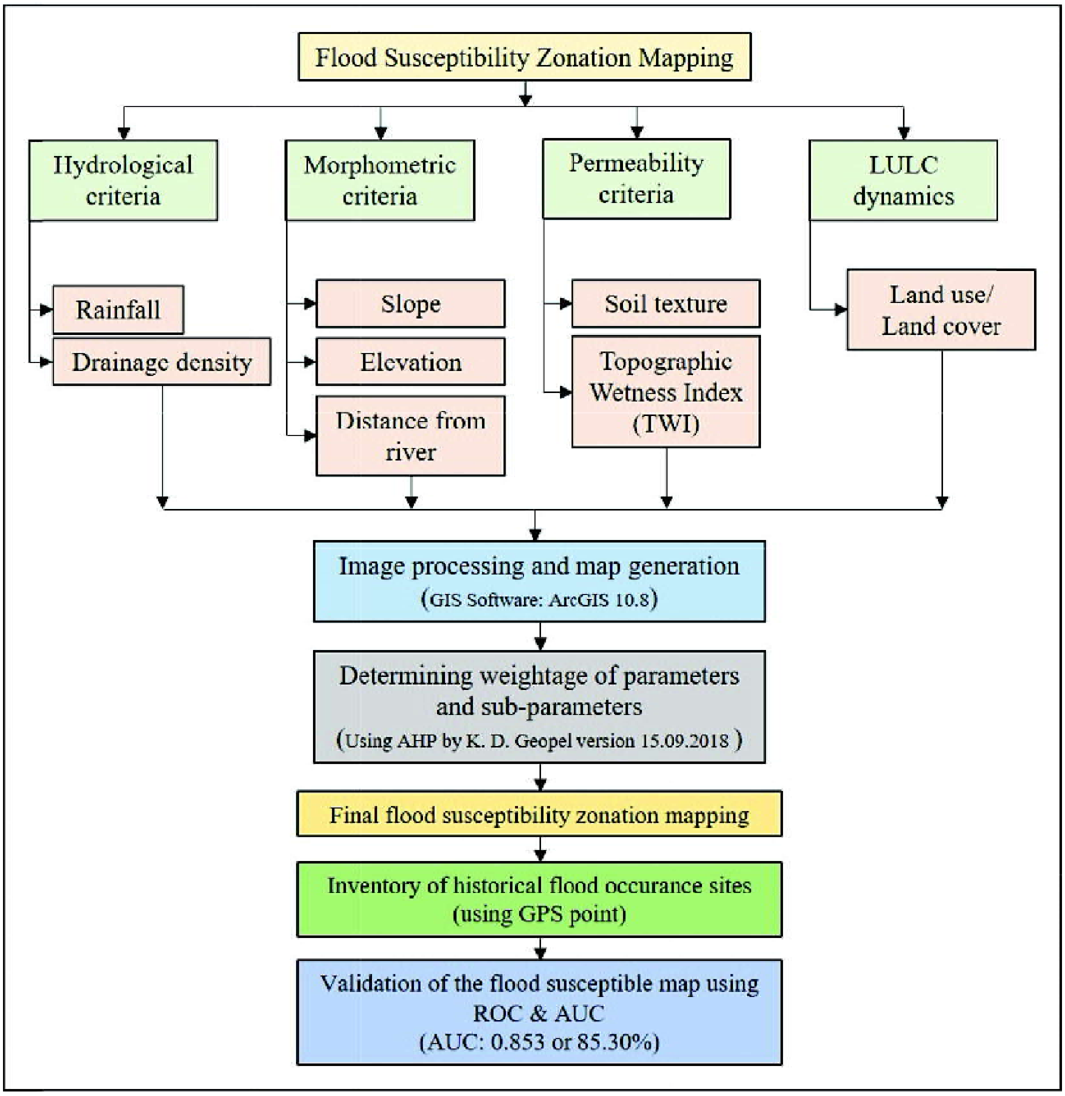

Fig. 2: Methodological flow chart of the current study for execution of AHP model under MCDM approach

area is characterized by 9 to 13 m m.s.l. height on an average. The average annual rainfall for the last 33 years (1990-2022) has been analyzed here to visualize the nature and characteristics of flood creating the phases of inundations. The maximum rainfall is more than 1800 mm, and it is a very high rainfall compared to other rainfall zones in the entire Zone, which covers1248.94 km^2 area designated as a high flood-prone area.

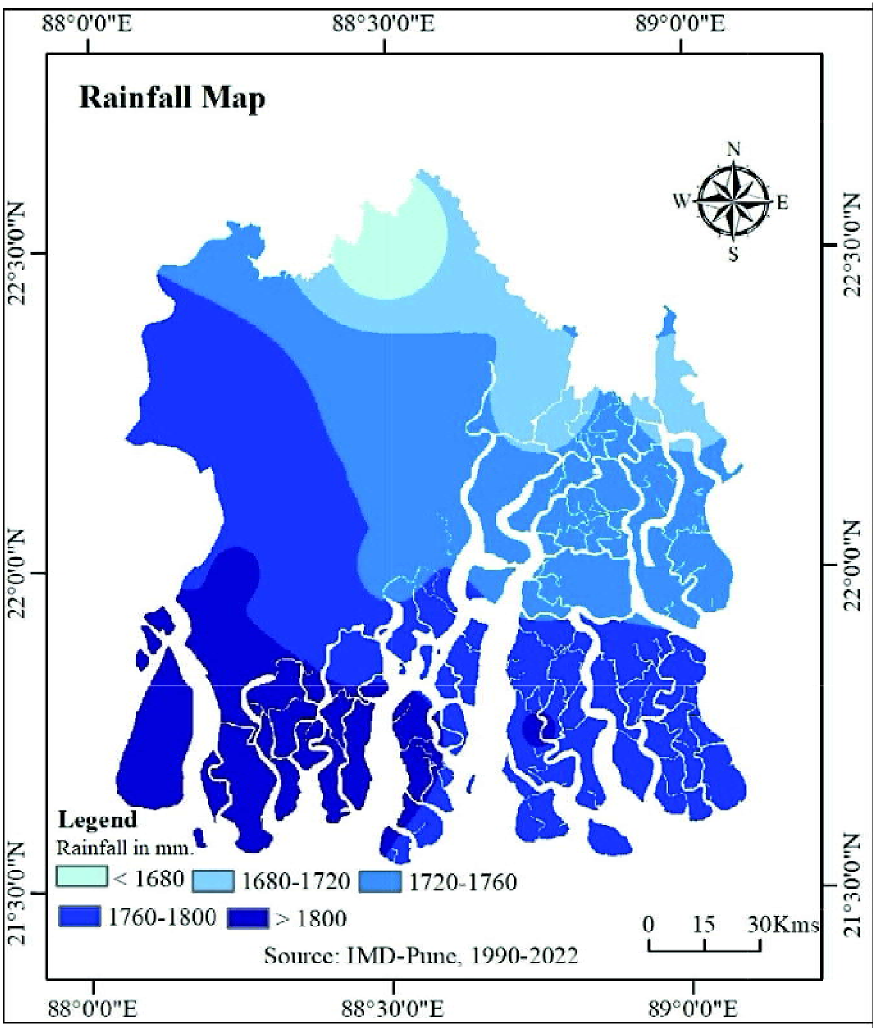

Fig. 3: Spatial distribution of rainfall in South 24 Parganas as most influential flood induction parameter.

The 1760 –1800 mm rainfall covers an area of 2743.63 km^2 and both zones collectively almost covered 54% of the areas out of the total study area. 2434.96 km^2 areas are covered by the 1720-1760 mm rainfall occurrence (nearly 34%) zone. This area is moderately affected. 818.67 km^2 and 260.43 km^2 areas are covered by low and deficient rainfall (1680-1720 mm & <1680 mm). It was witnessed that the high rainfall zone is located in the proximal belt to Bay of Bengal, and the flood susceptibility is maximum in this area. Through the use of AHP method, the perceived weightage value based on expert judgment and being most techno-centric for the rainfall was found being very high (Table 2) is reasonably a main factor of rainfall induced calamity in the entire study area.

Proximity to the River

Due to heavy and torrential rainfall occurrences, the flat topography is exposed to be highly vulnerable due to location of numerous water bodies such as ponds, dams, and lakes (Reager et

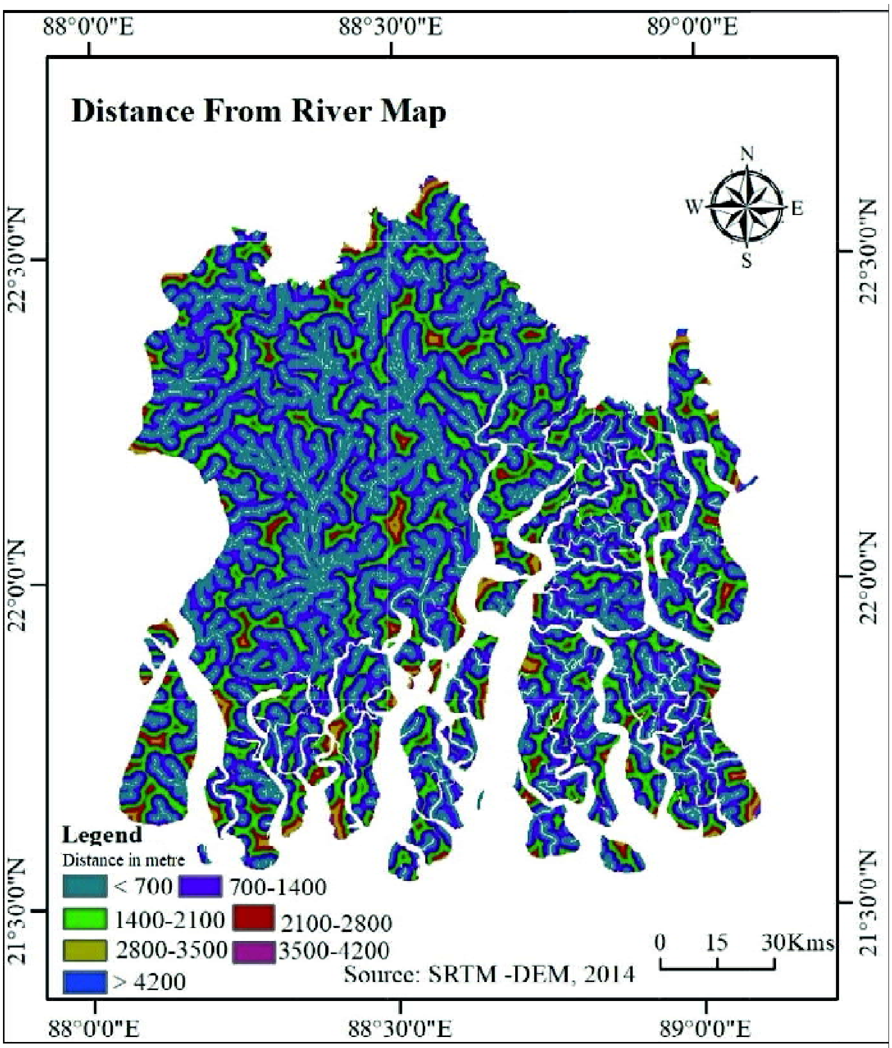

Fig. 4: Distance and Proximity to River as a MCDM parameter promoting flood occurrences

al., 2014; Greeo and Martino, 2016; Dhiman et al. 2019). South 24 Pargana is a recipient downstream region covered by many tributaries. Out of the total area, 2904.67 km^2 is located within the 700 m proximal distance of the river. The 2653.801 km^2 area is situated between 700 and 1400 m. Almost 75% of the area (out of the total) is located within 1400 m and due to this reason, South 24 Pargana is a highly flood-prone area. Also, the rainfall is more effective in this area compared to other areas. 1413.96 km^2 is 2100 to 2800 m compared to other areas here, and the flood occurrence chance is moderate. The 456 km^2 site is between 2800 and 4200m, and the flood occurrence change and the effect is low.

Drainage Density

Drainage density is one of the significant influencing factors for floods (Ogden et al. 2011; Handayani et al. 2020; Komi et al. 2016), that states the fact of river length per unit of area (km/km^2) (Magesh et al. 2012). The line density analysis tool was used to generate the drainage density layer. Based on the output value, the area has been divided into seven zones based on drainage density. The minimum value of Dd. is < 0.15, covering 419.21 km^2 areas of this entire study area. The maximum Dd. value is > 0.9, which covers 27.62 km^2 area. 6454.80 km^2 (86%) area is covered between 0.15 and 0.6 Dd. For the papered flood susceptibility map, the drainage density map has been attributed a weight of 16%, according to AHP predesigned methodology. The ideology indicates that in reality for a per unite area if the length of the river being a drainage linkage, under the line density tool of MCDM based GIS environment, comes to be more it will hold huge surges and as the rivers are highly sedimented associated with 1-1.5^{o} of as slope characters, they are readily over flashy and promotive to flood.

Topographic Wetness Index (TWI)

The TWI specifies the location and dimensions of the saturated area vulnerable to overland flow (Wilson and Gallant, 2000; Looring, 2013; Narendr et al. 2021). The map was prepared using the SRTM-DEM data. The study area was divided into five classes according to the TWI. Logically the higher TWI value is more than 20, which covers 8.58 km^2 of the study area, and the low TWI value is less than 8m, which covers 2956.75 km^2 areas. 3096.503 km^2 area is situated between 8 & 12, and it covers the maximum area and extent of the study area. The full extent of South 24 Pargana is under the 12 TWI value; therefore, the flood occurrence chance is high in this area. Considering the meaning of TWI most literatures have cited it as the quantification of topographical control on hydrological processes. Not only this, it also indicates forest quality being a promotive diffusion factor and situationally speaks of the saturation-excess-overland flow. As the intermittent streams changes in deluge an algorithm needs to be fitted to correspond heavy high tides and cyclone flushes. The TWI thresholds are normally 5.95-10.35 impacted by stream length change, saturated geological beds and inducive soil characters that determines steady water

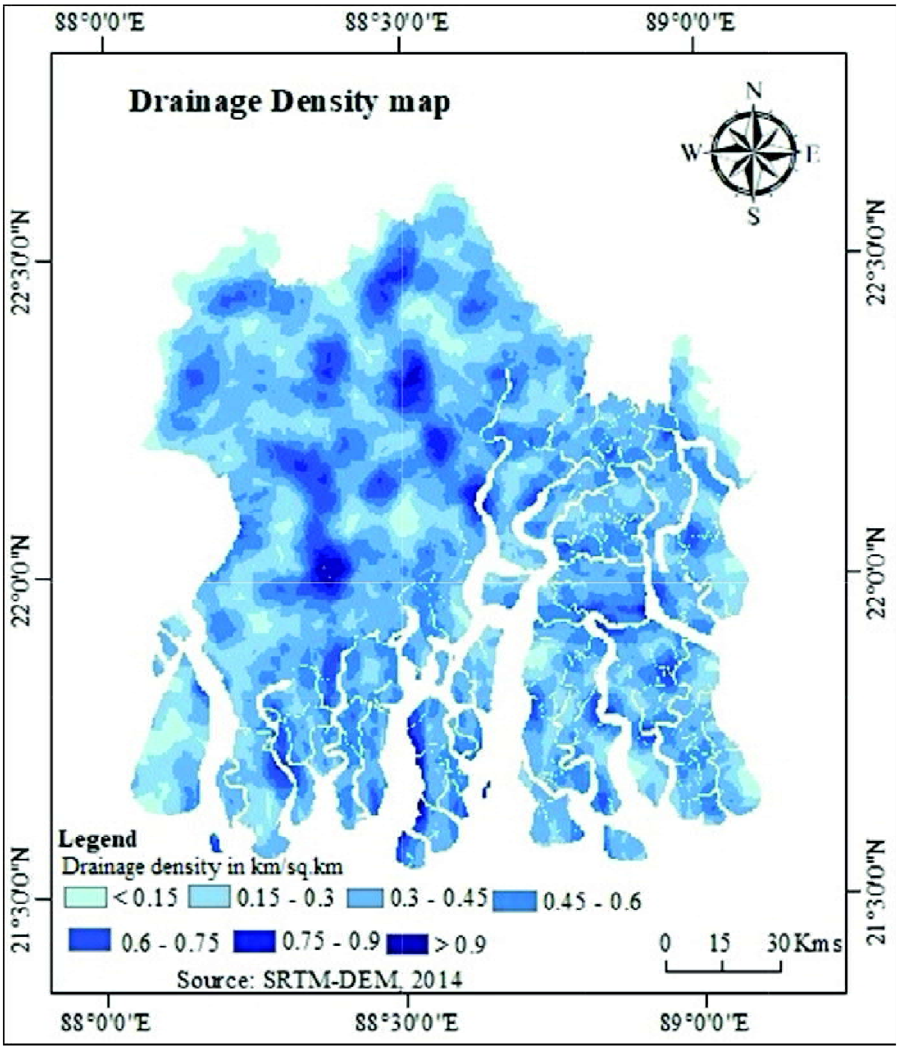

Figure-5: Drainage Density as positive MCDM parameter to Flood

holding with higher and over saturation. Here, the value is averagely 8-10 even 16, surely it is conformable to the above mentioned geo-environment situations and promotive cum provokable factor to flood in extra tropical exigencies (Fig. 6)

Slope

Flood production and redistribution of flood water are impacted mainly by topography. The slope percentage is one of the essential indicators that highly influence floods known to us very

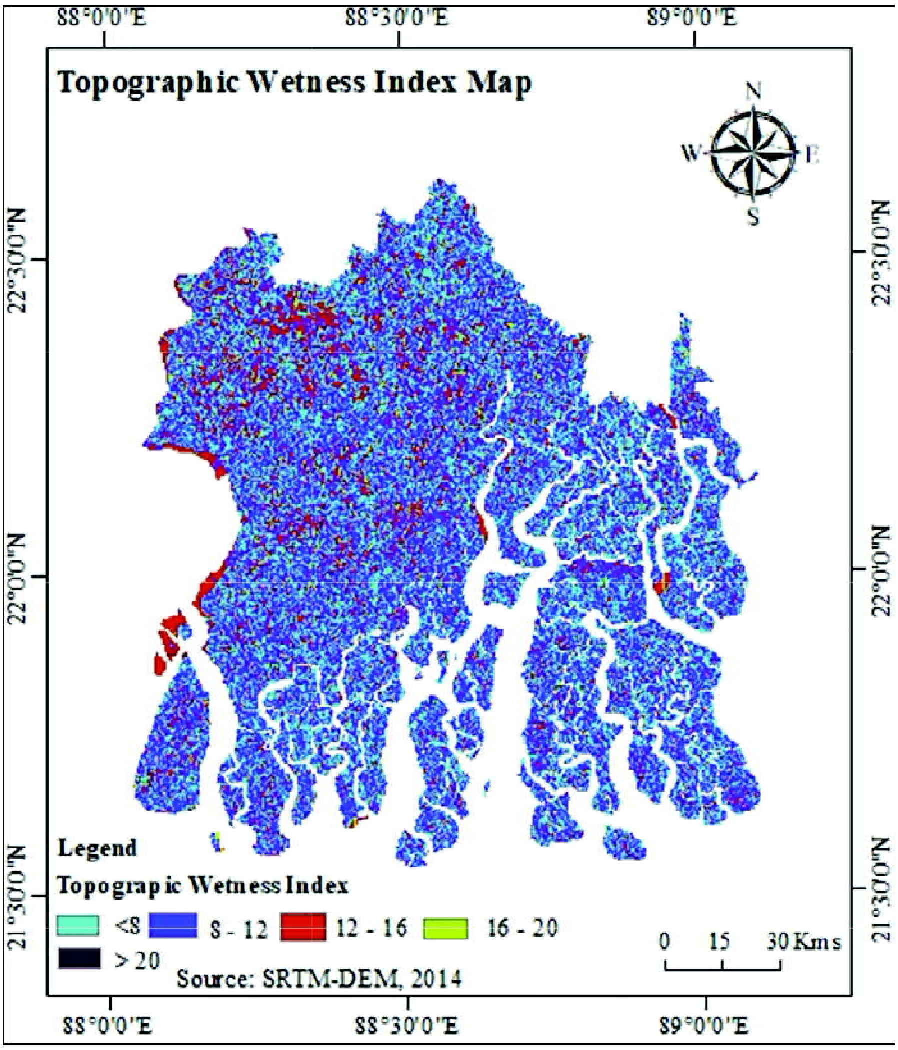

Fig. 6: Topographic Wetness Index Being a Fourth Dominant Flood Impacting Factor

obvious (Parrott et al. 2009; Youssef et al. 2011). Low-slope areas are more vulnerable to flooding since they are more likely to be submerged, and a surface with a high slope is less susceptible to flood risk as floodwater drains downslope readily (Chen et al. 2015). As a result, this element significantly impacts how much surface runoff and infiltration occurs, which in turn influences how sensitive a region is to flooding (Rahmati et al. 2016). The study area is divided into six zones in terms of slope characters (Fig.7). 7107.83 km^2 (almost 95%) area is under the 3 degree pitch means less than 3° pitch control and subject to be inundated frequently.

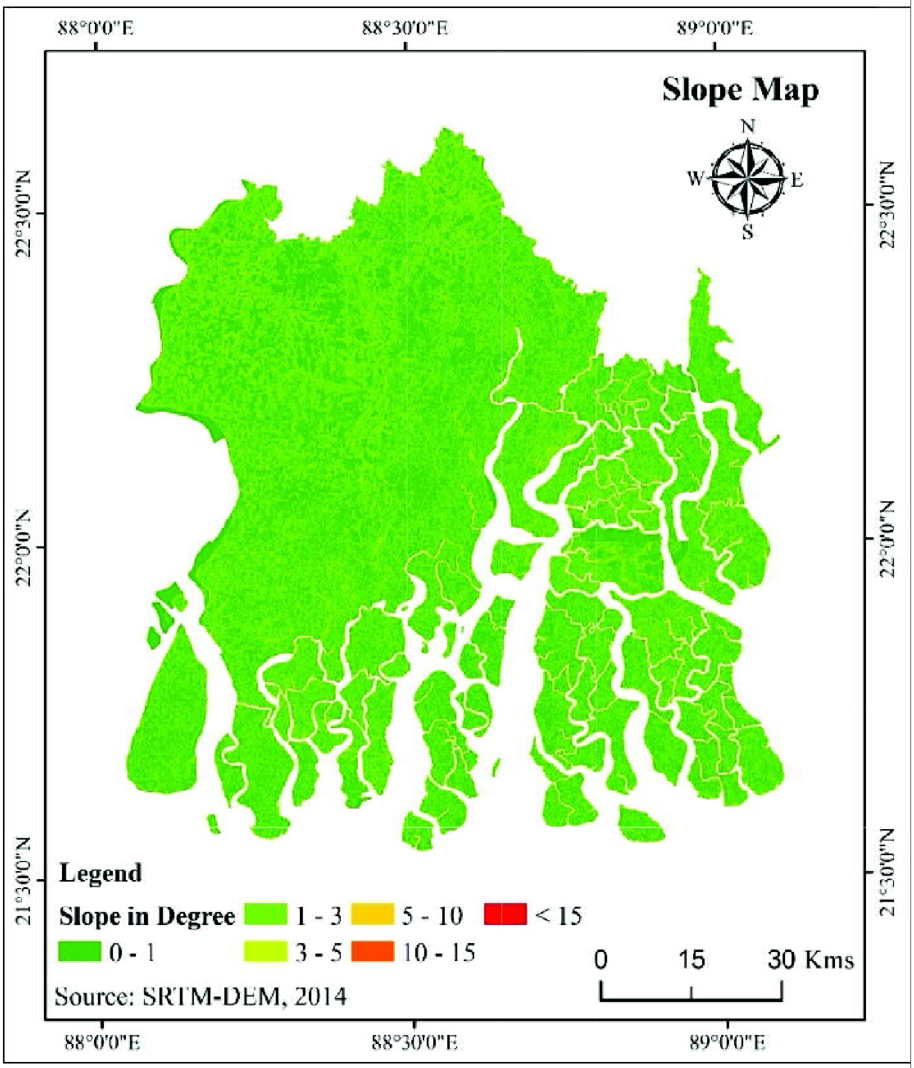

Fig. 7: Surface Slope Characters as Provoking Flood Occurrence Parameter

Elevation

Water frequently flows from high elevation to lower elevation. Therefore, the flood quickly submerges the low-elevation areas most effectively when rains (Fernández. et al. 2010). The elevation plays a vital role in determining the flow of water, which is the leading cause of flood. In this study area, the maximum height is > 36m, and the minimum is < 9m. The 98% area is under the elevation of 18m that is 7334.96 km^2. Reasonably, the flood occurrence rate is high, and inevitable. Using SRTM-DEM, the elevation map has been prepared and divided into five zones based on the elevation characters (Fig. 8).

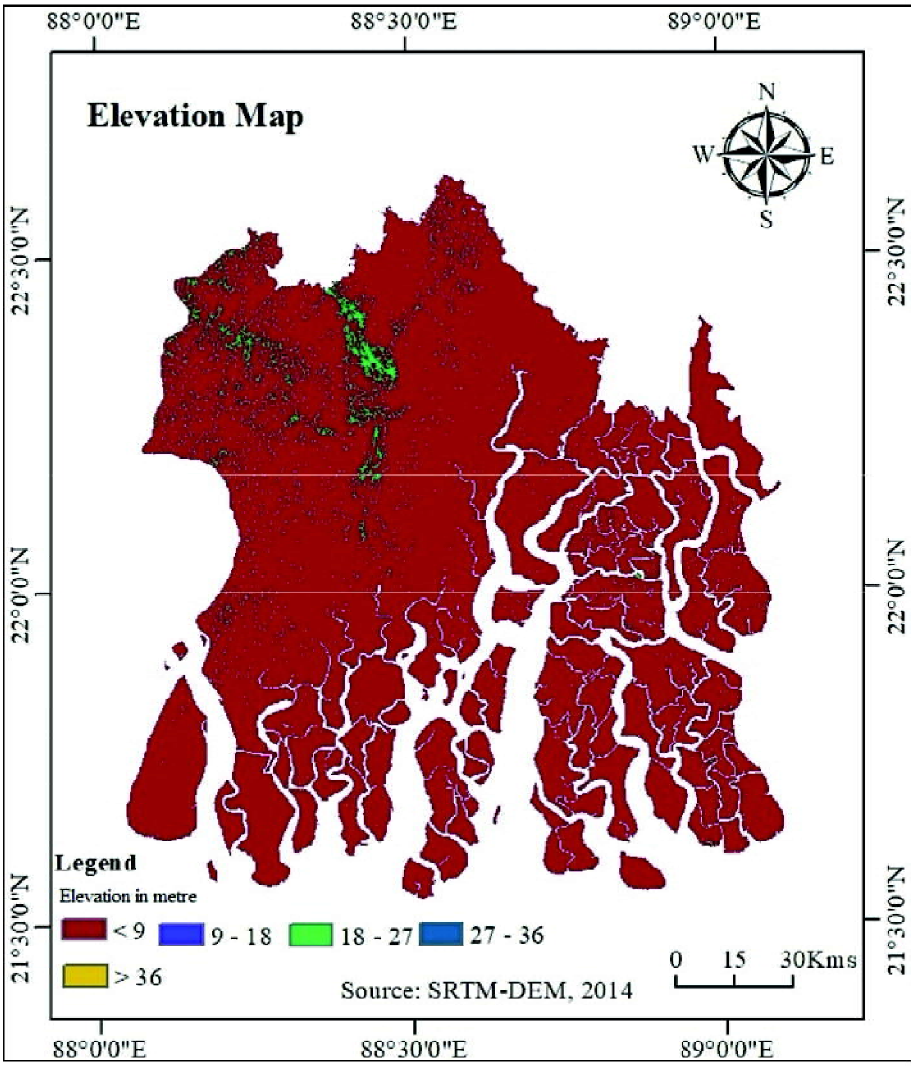

Fig. 8: Elevation Map of the Study Area

Land Use & Land cover (LULC)

To detect whether a place is susceptible to being waterlogged by flooding, the land use/ land cover is the significant factor (Nuissl et al. 2009). The infiltration rate is influenced by land use & land cover (Kourgialas and Karatzas 2011). Due to the unscientific use of land and the growth of urbanization, the flood occurrence rate is high being so rational thinking of realistic geo-environment (Tehrany et al. 2014). The land use/cover map was prepared using a satellite image of 2023 (Landsat 8). The study area is highly covered by vegetation and mangrove forest, which is 5126.17 km^2. The settlement area is significantly less than others due to fragile and hostile environment. The total area covered by the settlement is 746.78 km^2 proportionately very low. The agricultural land and water body covers 1396.62 km^2 & 213.94 km^2 area respectively. In connection to the logical viability to assign weightage to this criterion is that less the covered

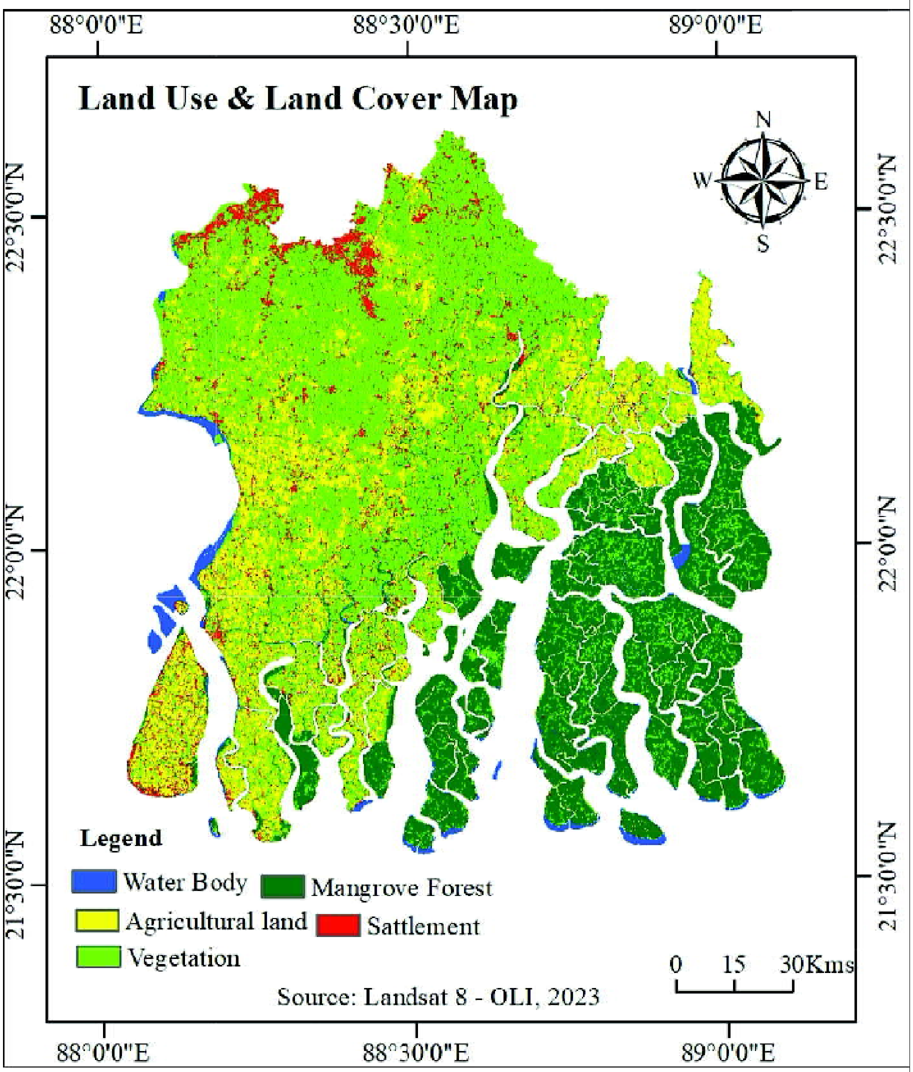

Fig. 9: Land Use/Land Cover Map of the Study Area

area more is the chances of groundwater infiltrations and higher the paved area more is chances of overland flow and deterministic to flood. As pave mentation is low and other criteria are more pronounced thus the average value of MCDM is only 4 indicating less effective than rainfall-slope-elevation-TWI association. (Fig. 9)

Soil Type

Soil types are direct factor in causing or controlling flood of any area. The texture and structure of the soil are influenced by the flood rate during the post occurrence phase of the

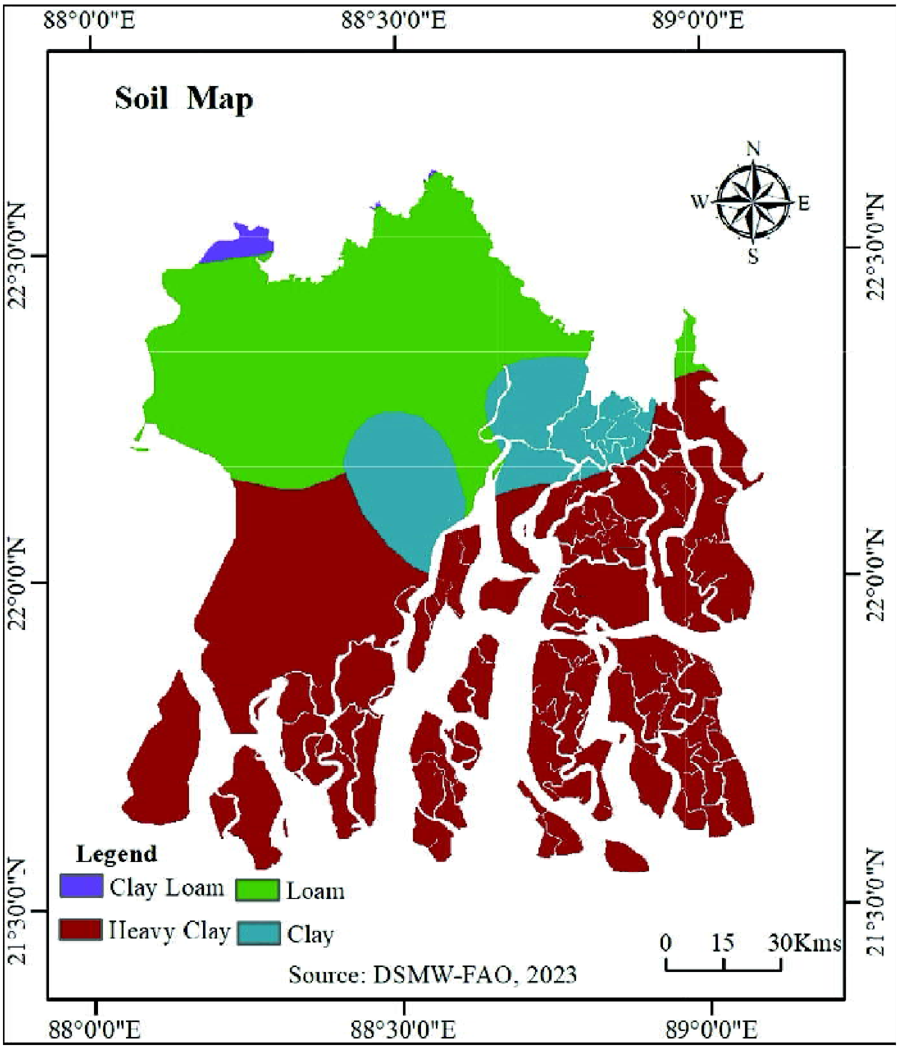

Fig. 10: Soil Types of the Study Area

study area. Soil controls the rate of runoff. The study area is dominantly covered by the heavy clay type of soil texture associated with alkaline that retards infiltration and covers 3793.56 km^2 areas, which is nearby the Bay of Bengal. 2239.67 km^2 areas are covered by the Loam soil texture, which is comparatively away from the oceanic fathom of the Bay of Bengal and this is basically a high-elevation area. Except for these, another two types of soil textures identified are clay loams and viscous clay flats which covered 45.75 km^2 and 784.63 km^2 area of the study area respectively. Due to clayey marshy flats and alkali complexes associated with supersaturated subsurface pedons the magnitude of flood has increased to its extremity and weighted in MCDM approach but less influential than rainfall-slope-elevation-TWI criteria neither inclusively or mutually or exclusively as viewed in table 2 & 3.

Table-2: Matrix and normalized principal Eigen vector for assigning the weightage of parameters in the AHP method

Matrix		Rainfall	Distance from river	Drainage density	TWI	Slope	Elevation	LULC	Soil Types	Normalized Principal Eigenvector
		1	2	3	4	5	6	7	8	
Rainfall	1	1	1	2	3	4	5	6	7	28.24%
Distance from river	2	1	1	1	2	3	4	5	6	22.12%
Drainage density	3	1/2	1	1	1	2	3	4	5	16.27%
TWI	4	1/3	1/2	1	1	1	2	3	4	11.65%
Slope	5	1/4	1/3	1/2	1	1	1	2	3	8.24%
Elevation	6	1/5	1/4	1/3	1/2	1	1	1	2	5.85%
LULC	7	1/6	1/5	1/4	1/3	1/2	1	1	1	4.27%
Soil Types	8	1/7	1/6	1/5	1/4	1/3	1/2	1	1	3.35%

**Using AHP by K. D. Geopel version 15.09.2018 (adopted by present authors)*

Spatial Distribution of Flood Susceptibility Zone

Floods have a long history in West Bengal, which is a part of the Bengal Delta. While floods in the northern part of the state typically happen early in the wet season and are violent and usually short duration floods in the southern part of the state typically happen later than the wet season (Basu et al. 2017) i.e. late September. The only coastal areas in the state are in the farthest southern expansion, and they frequently experience severe flooding and diurnal inundation. The border between the South 24 Parganas and North 24 Parganas districts includes a significant chunk of the coastal zone (Bandyopadhyay et al. 2003). In the ArcGIS environment, the eight layers were created as already expressed to make the susceptibility layer by comprehending weighting approach-based layering in the AHP method. The flood susceptibility map aids in identifying areas at risk by flooding as supposed already by flooding. Historical flood data supports the accuracy of the methodology which is really lacking here due to lower paucity of time and explorations here (Table 2 &3) (Fig. 11).

The final output of the susceptibility map was divided into four classes, potential from low to very high (fig. 11). The moderate and high susceptibility zones highly occupy the study area

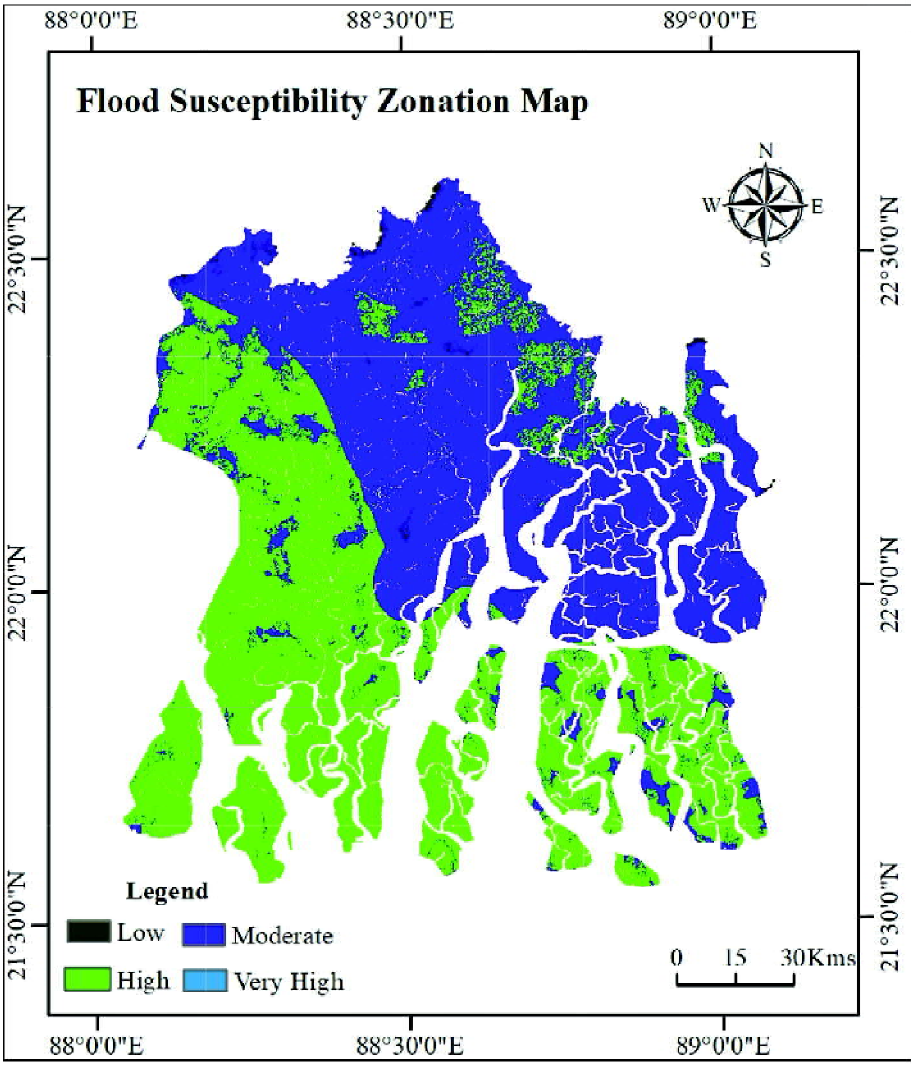

Fig. 11: Flood Susceptibility Zone Map

Table-3: Weights and Area Calculation of different parameters in AHP Method (MCDM)

Multi Criteria Parameter (MCDMP)	Classes	Weights %	Scale (out of 5)	Area (sq.km)
Rainfall magnitudes(mm)	< 1680	28	2	260.42
	1680 to 1720		3	818.67
	1720 to 1760		4	2434.95
	1760 to 1800		4	2743.63
	> 1800		5	1248.94
Proximity to the River (m)	< 700	22	5	2915.67
	700 to 1400		5	2664.80
	1400 to 2100		4	1424.95
	2100 to 2800		3	369.86
	2800 to 3500		2	89.40
	3500 to 4200		2	25.05
	> 4200		1	16.90
Drainage Density(km/sq.km)	< 0.15	16	5	419.21
	0.15 to 0.30		4	1753.26
	0.30 to 0.45		4	2997.66
	0.45 to 0.60		3	1703.87
	0.60 to 0.75		2	490.95
	0.75 to 0.90		2	109.60
	> 0.90		1	32.07
Topographic Wetness Index (Numerical value)	< 8	12	5	2956.75
	8 to 12		4	3096.50
	12 to16		3	1333.87
	16 to 20		2	108.98
	> 20		2	10.53
Slope Factors (^{o}d)	0 - 1	8	5	4211.37
	1 to 3		5	2896.46

Multi Criteria Parameter (MCDMP)	**Classes**	**Weights %**	**Scale (out of 5)**	**Area (sq.km)**
	3 to 5		4	286.26
	5 to 10		3	55.90
	10 to 15		2	30.52
	> 15		2	26.12
Altitude (m)	< 9	6	5	7168.55
	9 to 18		4	296.96
	18 to 27		3	25.10
	27 to 36		3	10.01
	> 36		2	6.01
Land Use Land Cover Scenario	Water Body	4	3	217.94
	Mangrove		2	2143.75
	Agricultural Land		3	1399.62
	Settlement		4	751.78
	Vegetation		3	2993.54
Soil texture (categorical)	Clay Loam	4	2	186.50
	Loam		4	2420.42
	Heavy Clay		4	3954.31
	Clay		3	945.40

Source: calculated by authors based on expert opinion of AHP model

(Table 2 & 3). The moderate class covers 3368.10 km^2 area, 52% of the study area, and the high course covers 3128.76 km^2 area, 47% of this area. The high susceptibility zone is located near the proximal belts of Bay of Bengal, with innumerable distributing emptying to the sea. In this area, the rainfall is also high. The prepared map presents the spatial distribution of flood Susceptibility.

The area where a bit of high tending slopes is attained; the rainwater induced runoff is very low and slower. Leadingly, rainfall, proximity to the river and drainage density play the major role and the soil types and land use/land cover are less critical criteria compared to slope which is so monotonously and extensively flat and promotive to extensive expansion of flood than variability. TWI and Elevation play moderate roles in the spatial distribution of floods.

Identification and Ground Truthing of Flood Scenario

South 24 Pargana is a highly flood-prone area in West Bengal. In last 15 years, there are more than 10 major floods ever noticed (Pal. et. al, 2022). Around 14:00 hrs. on May 25, 2009, a severe cyclone named "Aila" made landfall in West Bengal's coastal regions, mainly both of 24-Parganas (North & South). The storm hit with the speed of 120–130 Kph (I & W Dept., GoWB). About 125 of the 308 sluice gates were entirely damaged, allowing salinity to enter and drown the islands were the worst scenario in both the districts.1,05,075 hectares of arable lands in South 24 Parganas were completely submerged under salt water. Rice fields and individual ponds were salted and became ecologically lost except but existence. The Government was on high alert followed by the Aila's massive destruction (Chakraborty, 2015). Photo plate 2.1 A is showing how destroyed houses in *Patharpratima* of South 24 Parganas were found as residue after the catastrophes of Amphan cyclone & Cyclone Yass even abolished the restructuring homes at Gosaba in the South 24 Parganas district of Sundarban region in West Bengal. The area has been submerged by chest-high water, forcing the residents to go on a harrowing journey to the newer shelters carrying their children and animals and movable aesthetics (photo plate 1B). During the Amphan a total of 3274.326 km^2 area was affected (Haldar et. al, 2021).

The infrastructural damage rate was very high within a 2 km area of the coastal line from Bakkhali, Namkhana, Gosaba, Pakhiraloy, Sajnekhali, etc. During the flood, they stay in the nearest shelters or flood relief camp, which is provided by the Govt. of West Bengal and by the local people committees. Natives are highly suffering from running their agricultural works and thereby productivity by limited inputs, during flood and almost in every year the agricultural land is submerged and infected by the salty sea water and white encrustation which damages the quality of land makes their land to be barren one. So, during post flood days, they confront food shortage and they are compelled to importing their food from neighboring districts. During inundations, fishing is detained and creates setback to their economically weak lifestyle. In the near coastal belts maximum houses are *kuccha* and that aggravates high vulnerability.

In the period of the Yass cyclone a total of 2314.78 km^2 was affected by submergence of flood water in South 24 Pargana. By this event, 432.25 km^2 of vegetation, 26.14 km^2 of grassland, 3.94 km^2 of Scrub land, 67.49 km^2 of water body, 34.19 km^2 of built-up land, 43.58 km^2 of virgin vegetation, 1367.77 km^2 of agricultural land and 339.15 km^2 other (Haldar and Bandyopadhyay, 2022) type of land-use land-cover areas were severely affected.

This area is infested of flood and high frequency of inundations that results into increasing numbers of homeless and jobless victims. This study area is receiving high magnitude of annual average rainfall. Where the rainfall intensity is very high, the flood occurrence chances and their impacts are found to be very high, presented by the flood susceptibility map (Figure 11). The next important factor is Distance from the River. The Figure 4 shows South 24 Pargana is covered by many rivers mainly distributaries and many of the most minor tributaries are having intriguing patterns of high bifurcations. So, the distance from the river plays an essential role in flooding in

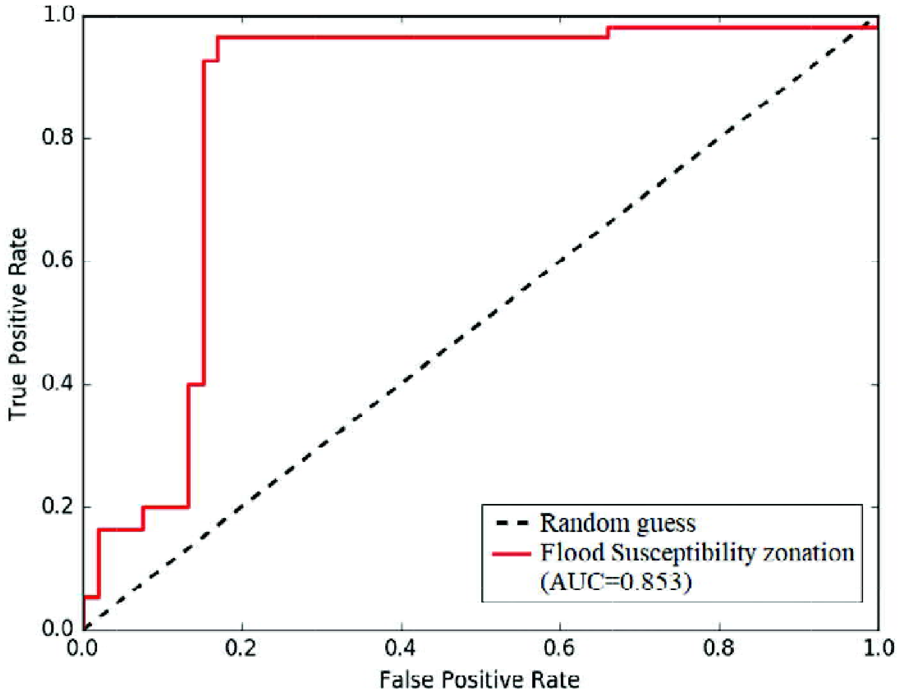

Fig. 12: Validation of the flood susceptibility map through ROC curve

this area. And the drainage density and TWI are also crucial for making this area prone to inundation. Although a flood is a natural disaster, its impact is serious on human activities. It is very important to determine the acceptance rate of the study, therefore through the AHP method, the final output has been checked by Receiver Operating Curve known as ROC curve using ArcGIS. This study produces an acceptation magnitude of 0.853, which means 85% of accuracy and the AHP model can be accepted in designing flood susceptibility zonation map (Figure12).

Positive measures

After field investigation and on preparing the map layouts using DEM & satellite images and analysis of the present study provides some important remedial suggestions, which will help the people for better mitigation of flood in this area in future being the novelty of the present study.

Public Behavioural Management

Human activities are the main mitigation method for flood management. Human activities can control the flood effect in this region as follows

Photo plate-1: Effect of Amphan & Yaas (a) Houses damaged during post Amphan Cyclone in Patharpratima, South 24 Parganas (b) Houses damaged during the post Yaas Cyclone in Gosaba, South 24 Pargana.

Control the settlement growth within 2km from the coast line

At present the growth rate of settlement in the coastal area of south 24 Pargana is high due to tourism activities. When planning new settlements or expanding existing ones, avoid building in areas that are highly susceptible to flooding, may decide mindfully for the government departments especially coastal areas. Identification of floodplain zones of the coastal areas, and other high-risk regions, and initiating discouraged construction in these locations are very much needed.

Increasing plantation

In south 24 Pargana, especially Sundarban and the coastal area have become plant less in recent times due to high urbanization. Collaboration between a variety of stakeholders, including local government, environmental agencies, and local community people, is necessary to control flood consequences through plantations. Building a more durable and sustainable approach to flood control is achievable by integrating vegetation-planting efforts with other flood mitigation measures, such as appropriate infrastructure and early warning systems.

Proper land use practice

The coastal area is an important economic zone for the tourism industries, and because of that this area can't maintain the proper land use planning. Therefore, the effect of the flood is high near the coast line areas. The settlement which is located within 1.5 km of the coastal line is highly vulnerable. Proper land use planning can control the flood impact and they develop their livelihood. Illegal settlements can be noticed here due to flunky and temporary income benefits like hut-cum-shops which have built near the beaches are seriously affected by the flood and inundation.

Conclusion

Flood is a natural calamity, but their impact depends on the human nature and their activities. The coastal area of South 24 Parganas is a tourism based economic hub, therefore the population is increasing day by day in this area and found with unscientifically developing. In this area, the development of tourism and industry that have partly abolished mangrove forests along the coasts and as a result, the intensity of floods is increasing. This paper presents the flood intensity rate in different areas of South 24 Parganas and their influencing factors. Based on the field visits and consulting different data, like SRTM-DEM, 2014, Landsat 8 OLI-2023, rainfall data from IMD-Pune, soil texture data from FAO- India a precise scenario is framed in this regard. This study mainly presented the fact that this area is mostly affected by heavy rainfall. Population and settlements are unabatedly growing near the rivers and near beaches of the Bay of Bengal. Using the AHP method this study analysed the flood susceptible area in south 24 Pargana as the most desired objective. With better economic facilities and livelihood, schemes for enhancement of standard of living can bring a change.

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Conflict of Interest

The authors state no conflicts among and between the interests of various concerns to the best of their known-how.

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