Flood Hazard Mapping and Road Network Vulnerability Analysis of Kamrup and Kamrup Metropolitan Districts: Case Study of Assam Flood 2019

Bateswar Das

Research Intern at Council on Energy, Environment and Water (CEEW), Delhi; MSc Disaster Management, Tata Institute of Social Sciences; Email Id: *bateswardas8[at]gmail.com*

Abstract: ***Kamrup district is highly flood vulnerable due to riverine flood of Brahmaputra. The district is administrative center of Assam state and geopolitically significant for India to connect with North-East states. Majorly NH 17 and NH 27 passes through the district and connects the NE states with Assam and rest of India.Due to flood vulnerability the largest resource supply chain network of the country face damage and disruption. In this study flood vulnerability map was prepared using information and past flood data of Kamrup and Kamrup metropolitan districts following the Assam flood 2019. AHP-GIS based flood susceptibility zonation (FSZ) model was used to show the vulnerability and further NH17 and NH27 was super imposed on FSZ map to show the vulnerability in supply chain. The FSZ map was validated using AUC method which estimates the FSZ map in fair category, prediction and success rates are 0.620 and 0.718 respectively. The study creates scope of road network vulnerability assessment using AHP-GIS method in the hazard prone areas of the country in order to develop sustainable planning.***

Keywords: Flood susceptibility, Assam flood 2019, AHP-GIS based weighted overlay method, Transportation, Kamrup

1. Introduction

Flood is one of the most hydro-meteorologically common natural hazards which causes extreme damage and losses in any topographic environment. Extreme sedimentation to loss of ecosystem is the major issue as impacted by the flood event. Over the past few decades, the frequency of flood and its extent of destruction have increased significantly due to uneven distribution of rainfall,overflow of rivers, deforestation, urbanization, and unplanned human settlement along the coastal areas and riverbanks(Armenakis, Du, Natesan, Persad, & Zhang, 2017). The flooding is considered to be *natural environmental disaster* which causes large scale destruction in human civilization and in the ecosystem. The occurrence of flood is significantly excessive in riverine areas especially when rivers cross their storage capacity leading to river banks overflow and filling adjacent low lands causing environmental and socio-economic disasters to local inhabitants(Itodo & Duadu, 2012).

Therefore, it is important to create flood hazard mapping and monitor the flood plain in order to make sustainable development plan in the river basin. The increased intensification of flood worldwide shows that there is need of advancement for flood hazard risk mapping or flood susceptibility zonation (FSZ). Satellite Remote Sensing and GIS techniques have emerged as a powerful tool to deal with various aspects of flood management in prevention, warning, preparedness and relief management of flood disaster (Sani, Noordin, & Ranya, 2010).

2. Literature Study

Assam is geopolitically important for India to connect with Nort-East states of the country and NHs in the region plays significant role. Many studies are done in the Assam state over the flood risk mapping or flood zonation. At administrative level the work has been used, yet there are challenges. The studies have inherent challenges and limitations in identifying and quantifying hazard causing indicators, dealing with uncertainties and analyzing them (Sarmah, Das, Narendr, & Aithal, 2020). Flood vulnerability assessment of parts of Kamrup district in Assam is also studied to an extent. The vulnerability assessment reflects upon the poor flood management and impact on socio-economic livelihood(Das & Deka, 2021) . However, the studies do not emphasize on transport vulnerability of National Highways in the district which connect the district and state with rest of the country.

This study examines the transportation vulnerability usingflood susceptibility zonation (FSZ) model of the Kamrup district in Assam following Assam flood, 2019 where Guwahati and other major cities face urban flooding each and every year and there is need of proper floodplain management in order to develop sustainability.

3. Study Area

The Kamrup and Kamrup Metropolitan district in Assam is situated at 26°20′N , 91°15′Eapproximately which is extended over more than4500 square Km. It is located in the lower basin of Brahmaputra which has rapid flood incidents each and every year. Therefore, the Assam government and local administration need to work toward sustainable solution. Rapid urbanization of Guwahati and major cities in the district, sedimentation of River Brahmaputra and deforestation led to more river bank erosion causes flood in the region besides extreme rainfall. NH 17 and NH 27are the major national highway NH) network connect the district with the other parts of India and Assam state majorly. The above NHs are also important geopolitically for India to connect with NE states of the country. However, flood vulnerability in the district damages the transportation through NH and disconnects with major parts of the state Assam. Both NH17 and NH27 falls in the flood susceptible zone in Kamrup and Kamrup Metropolitan district. Rainfall induced flood and landslides are very common in the National Highway track in the districts.

The districts had annual average temperature 24°C with annual rainfall more than 2500 mm in 2019. The district is administrative center of Assamwith major cities and rainfall induced flood have been increased over the decade. River bank erosion mitigation and flood plain management can be done through proper development planning and resilience building through investment. For this purpose,the detailed study of flood risk or hazard zonation of Kamrup district and Guwahati urban area is required. This study focuses toflood vulnerability in these districts for better policy making using the AHP- GIS overlay method to create flood susceptibility zonation (FSZ).

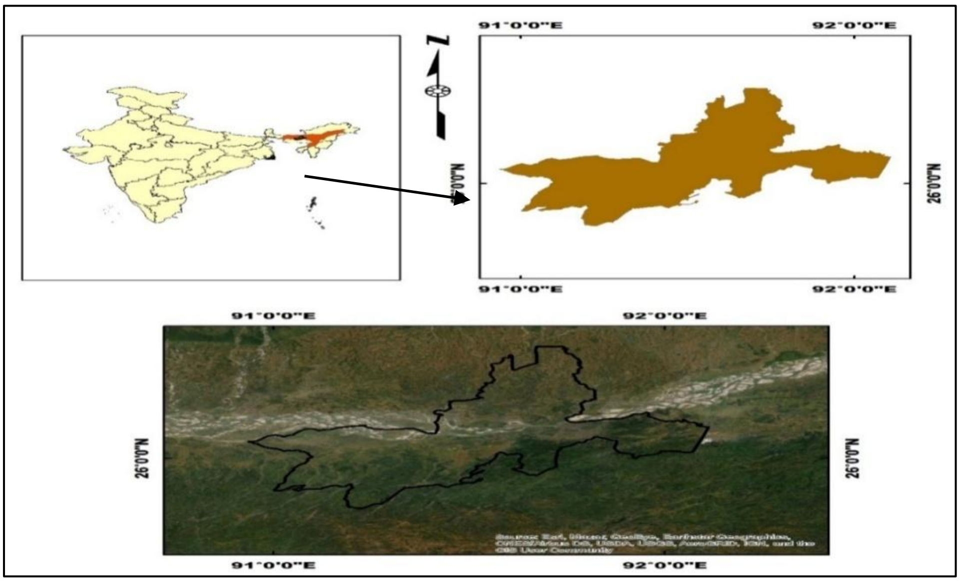


Figure 1: Kamrup including Kamrup Metropolitan district is shown in the map with the base map in ArcMap

4. Methodology

The study is done in two major steps which are, 1) Preparation of datasets using ArcMap after collection of data collected from different sources; 2) AHP- GIS based integration is done through overlaying and 3) finally model evaluation was done using area under curve (AUC) method.All the steps are completed in ArcGIS tool. The methodology for the study is in detailed shown in the below figure. The integrated map represents the Flood Susceptibility Zones (FSZ) of Kamrup District in lower Brahmaputra valley.

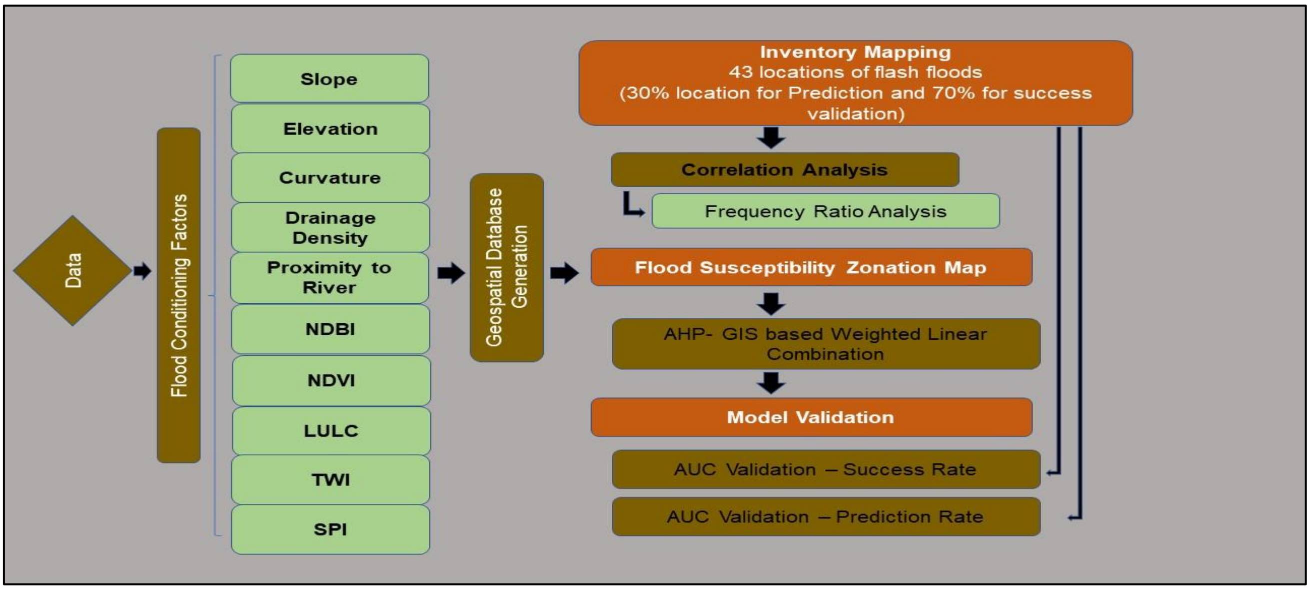


Figure 2: Flow chart represents the methodology used in the study to prepare flood susceptibility zonation (FSZ) map

4.1 Flood Inventory Map

In the flood vulnerability assessment, past flood locations data are significantly important to estimate future potential flood event. It is also required to evaluate the FSZ map for validation purpose(Rahmati, Pourghasemi, & Zeinivand, 2016). In this study total 43 flood location from various news sources, past literatures and Assam State Disaster Management Authority website were used to prepare the flood inventory map. Further, 30% of the total flood locations were used for prediction and 70% data were used for testing the success rate of final FSZ map.

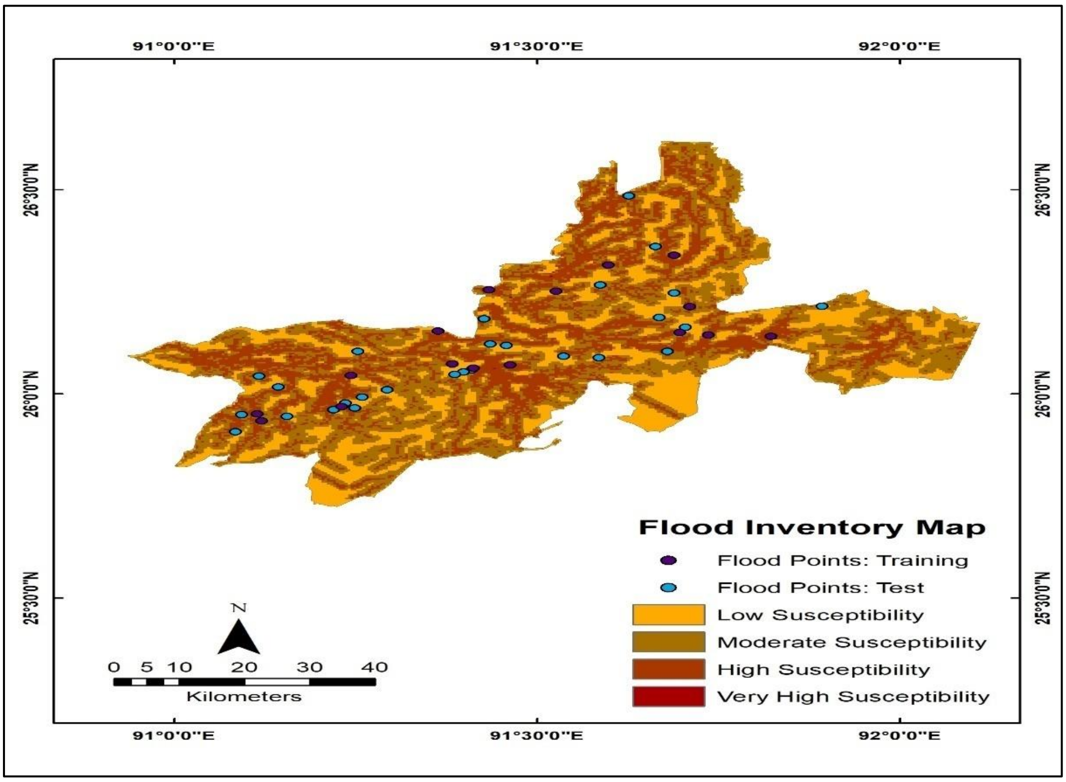


Figure 3: Map showing past flood locations for testing and training in validation

4.2 Dataset Preparation of Flood Conditioning Factors

It is better to have an understanding of various causing factors for the flood. This helps in further choosing the factors of the causality of flood in the region. There are several factors influence the flood in Brahmaputra River basin. The causality factors are mostly chosen following the various studies done in the context of Assam flood(Das & Deka, 2021). Maps of the conditioning factors are shown below (Figure 3) which were reclassified image using *Natural Break* method in ArcGIS tool.

1) Elevation

The criteria of elevation besides surface slope, curvature is more important to delineate the flood hazard or to map the flood zonation. The downstream at lower elevation creates suitable flood condition as to sedimentation and surge in river flow during monsoon. It is important to understand the elevation and slope variation for development purpose on river basin(Souissi, et al.). In this study the elevation variation is shown in five classes from very low to very high-range using Cartosat-1 DEM data of 30 m spatial resolution.

2) Slope

The slope map is associated with elevation and one of the important criteria. The slope is measured in degrees. As Assam is located in the North Eastern hilly area, there is steep slope to a large extent as well. However, the lower slope degree signifies the flat surface or low elevation area(Meraj, Romshoo, Yousuf, Altaf, & Altaf, 2015). Therefore, low elevated flat surface is more inundated during flood and in this study the slope map is classified in five ranges from very low slope to steep slope which were represented by the slope degree using the same Cartosat-1 DEM data.

3) Curvature

The curvature map helps us to understand the geomorphological characteristics in any topographic region(Pourghasemi & Rahmati, 2017). The curvature is analyzed as three categories. The negative curvature value is considered as concave surface curvature, positive value is convex curvature and zero value is considered as flat surface curvature.

4) TWI and SPI

The Topographic Wetness Index (TWI) and Stream Power Index (SPI) were calculated using the Cartosat-1 DEM data of 30m resolution which shows the wetness of the river basin and the stream power of Brahmaputra River in the region. TWI also has importance in the control of surface runoff as more wet area has greater runoff compare to less wet area and SPI is important to measure the erosive power due to surface runoff or river discharge. However, the Kamrup district is situated in lower basin region where the erosive power of the river Brahmaputra is very less compared to upper riparian region.

$$TWI = \ln A_s / \tan\beta$$

$$SPI = A_s \times \tan\beta$$

Where, A_s is specific catchment area (m^2/m) and β is slope (in °) as referred in the study (Veerappan & Sumaira, 2020; Beven & Kirkby, 1979).

5) Proximity to River

Proximity to river was calculated using the Euclidean Distance tool in ArcGIS which presents the proximity of the river basin area to the natural drainage. Natural Drainage here includes all the streams and rivers which are in the study area and the proximity for a distance of up to 1000m (1 km) was derived which was later reclassified into five classes of 100m, 300m, 500m, 700m and 1000m. The nearest region to river or less distance from the river means higher flood prone region as we study from the map.

6) Drainage Density

Drainage density can be defined as the length of river channels per unit area of the basin which controls flow accumulation of river channel pathways(Arora, Pandey, Siddiqui, Hong , & Mishra, 2019). The drainage density is important for flood susceptibility zonation (FSZ) as the higher density value means more susceptible to flood. The drainage density was calculated using Cartosat-1 DEM data of 30m resolution using Kernel density tool from Hydrology toolbar in ArcGIS.

7) Built-up Index (BUI)

Built-up index was used to show the impact of urban settlements in the flood conditioning of the study area. In many cases urbanization is considered to be influencing factor of flood which distort river flow and helps in sedimentation(Bhatti & Tripathi, 2014). The BUI index was extracted from Landsat 8 images using ArcGIS tool. In the first step normalized difference vegetation index (NDVI) and normalized difference built-up index (NDBI) was extracted using Landsat 8 satellite image of 30 m spatial resolution. Built-up index was used which especially shows the extent of built-up region compare to non-settlement region after extracting the vegetation index from the NDBI map. The NDVI and NDBI were obtained using the formula,

$$NDVI_{landsat\text{-}8} = (NIR - Red) / (NIR + Red)$$

$$NDBI_{landsat\text{-}8} = (SWIR - NIR) / (SWIR + NIR)$$

Where, NIR is Near infrared band, SWIR is short wave infrared band and Red is the specific spectral band. The NDVI and NBDI can help to understand the influence of vegetation in prevention of the flood probability as well as influence of built-up area in influencing flood occurrence. Further, built-up index was calculated following the formula,

$$BUI_{landsat\text{-}8} = NDBI_{landsat\text{-}8} - NDVI_{landsat\text{-}8}$$

8) Land Use and Land Cover

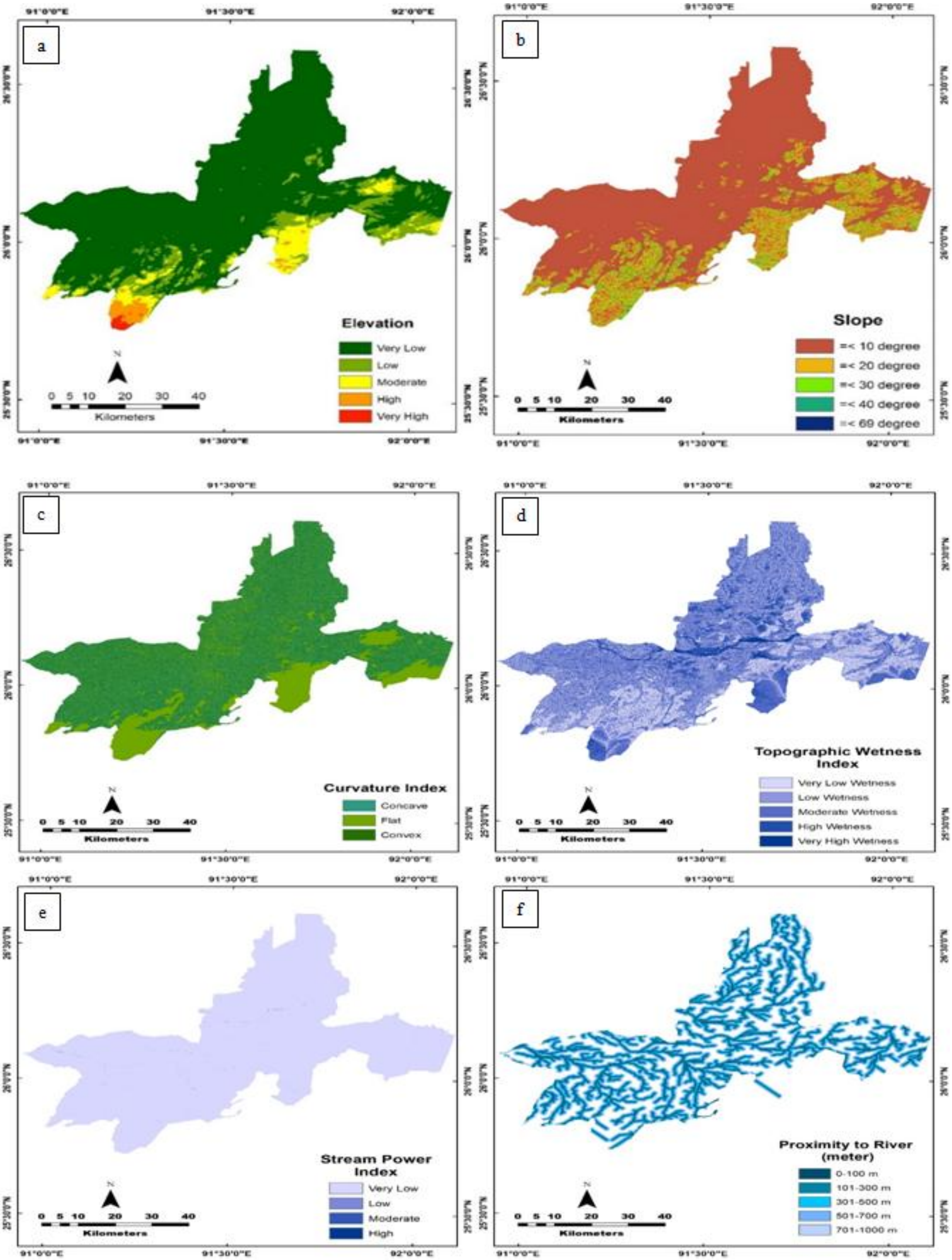
For flood susceptibility mapping,land use and land cover (LULC) is most essential parameter to understand the activities in the region and types of LULC to be affected by the flood frequently. Different types of land use impact on some hydrological processes such as infiltration, evapotranspiration, runoff generation. The study area has very few activities in the context of LULC. The LULC map was collected from ESRI Global LULC map with 10 m resolution derived from ESA Sentinel-2 satellite image which is very useful and accurate as it is used in many studies which was resampled to 30 m resolution to make similar with other datasets and extracted for the study region.

9) Rainfall

Rainfall is the primary factor in this study as the flood is caused mostly in rain season or it is studied as rain-induced flood. In this study the rainfall map was generated from the data source tropical rainfall measuring mission (TRMM) using inverse weighted distance method(Bartier & Keller, 1996). The map is produced for annual total rainfall as the flood event occurred in the time span of 2019-2020. Though, highest rainfall happened in the study region during June-July of the year.

Table 1: Specifications of data type and different sources.

Factor	Data Type	Data Source	Resolution	Year of Data Source
Elevation	Digital Elevation Model (DEM) data	Cartosat-1 DEM from Bhuvan portal of NRSC	30 m	2019 (derived from Cartosat-1 satellite launched in 2005)
Slope				
Curvature				
Drainage Density				
Proximity to River				
TWI				
SPI				
NDVI, NDBI & BUI	Landsat 8 satellite image	USGS Earth Explorer	30 m	2019
LULC	ESA Sentinel- 2 satellite image	ESRI Global LULC Map	10 m	2019-20
Rainfall Data	Gridded Raster Data	Climatic Research Unit (University of East Anglia) and NCAS website	0.5°	2019
Road Network Data	Vector data	Open Street Map (Wiki)	-	latest


a
Elevation
Very Low
Low
Moderate
High
Very High
0 5 10 20 30 40
Kilometers
b
Slope
=< 10 degree
=< 20 degree
=< 30 degree
=< 40 degree
=< 69 degree
c
Curvature Index
Concave
Flat
Convex
d
Topographic Wetness Index
Very Low Wetness
Low Wetness
Moderate Wetness
High Wetness
Very High Wetness
e
Stream Power Index
Very Low
Low
Moderate
High
f
Proximity to River (meter)
0-100 m
101-300 m
301-500 m
501-700 m
701-1000 m

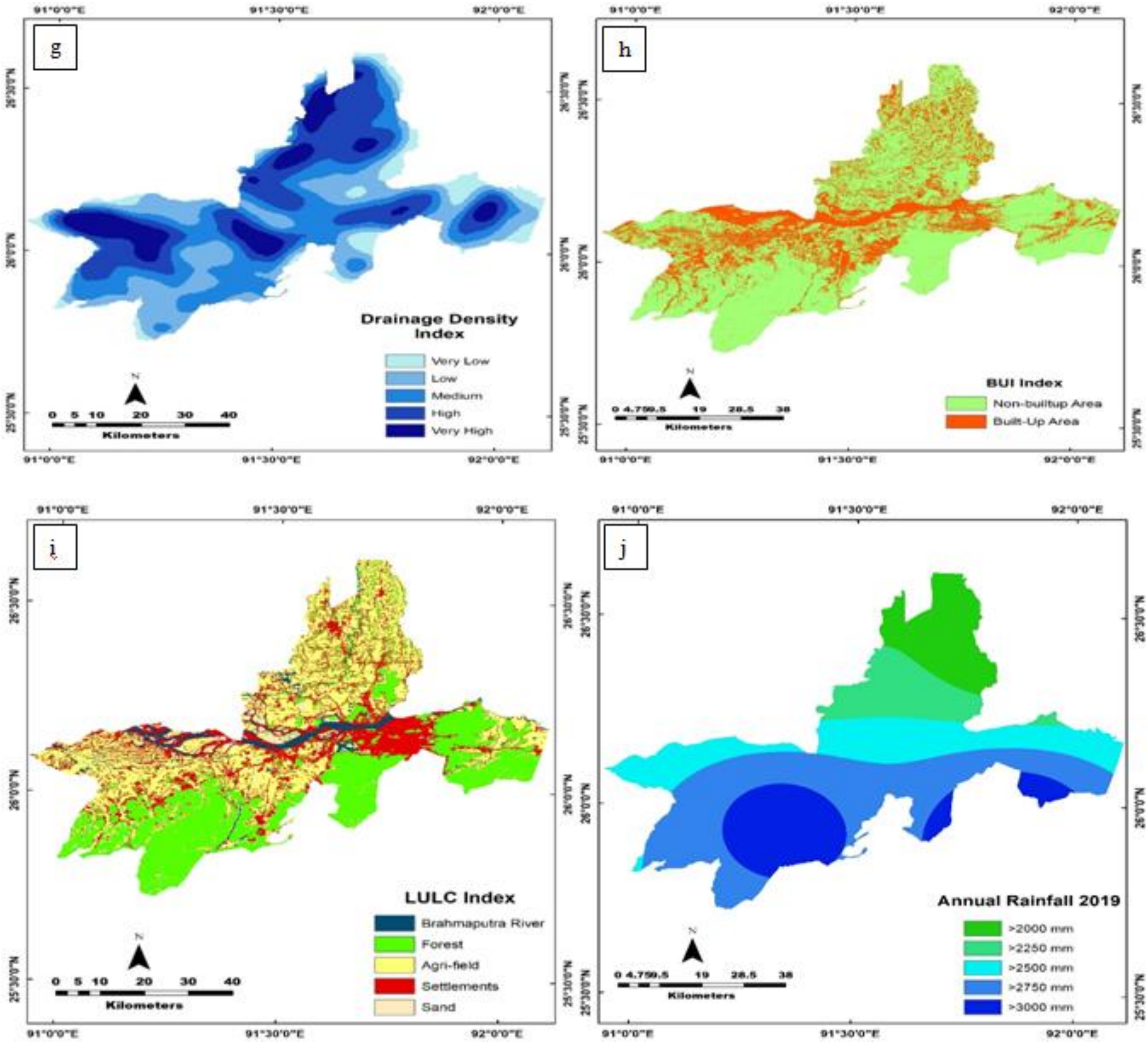


Figure 4: Map showing flood conditioning factors- a) elevation, b) slope, c) curvature, d) TWI, e) SPI, f) proximity to river, g) drainage density, h) BUI, i) LULC, j) annual rainfall 2019.

4.3 Correlation Analysis using Frequency Ratio

In flood susceptibility modeling it is important to show the correlation between the flood contributing factors and flood occurrence. To show the probabilistic relation between dependent and independent variable frequency ratio (FR) model was used which is a simple geospatial model which is calculated for each class of each independent factor(Razavi Termeh, Kornejady, Pourghasemi, & Keesstra, 2018). FR was calculated using the following formula,

$$FR = \frac{A/B}{C/D}$$

Here, A is number of flood location in each class and B is the number of total flood location. C is the pixel number in each class and D is the total number of pixels in research area(Ha, et al., 2021).

4.4Model Validation

Area under curve (AUC) is one of the most commonly used evaluation method for the performance of a binary classifier system or model based on dependent and independent factors. AUC method was used to evaluate the FSZ success and prediction rate where 70% and 30% randomly selected past flood location data were used respectively. The AUC validation results are generally classified in following ways: 0.90–1 (excellent), 0.80–0.90 (good), 0.70–0.80 (fair), 0.60–0.70 (poor/satisfactory) and 0.50–0.60 (unsatisfactory)(Pradhan & Kim, 2017).

4.5 AHP- GIS based Weighted Linear Combination (WLC)

In the context of FSZ, one of the most useful methods for integration of different parameters related to flood is weighted linear combination or weighted overlay. Different factors are generated from Digital Elevation Model (DEM)

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data, LULC data from the satellite images, aerial photographs are prepared for the flood risk assessment including road network, population data, river dam and embankment data can be used. The parameters are overlayed in ArcGIS based on assigned weights to create flood zonation map. In order to assign weight expert-basedanalytical hierarchy process (AHP) is used and further combined by **weighted linear combination (WLC)** where continuous criteria (factors) are standardized to a common data model in raster layer with a common resolution (Anueyiagu, Anyanwu, Njoku, & Okorondu, 2021). The combination of AHP and GIS techniques are very useful method to determine the significant factors or decision in policies. Use of this method in Urban Flood Risk Indexing (UFRI) is highly acknowledgeable. However, there are some challenges and researchers still could not reach to consensus regarding the issues of weighting in AHP method. The contentious areas include: (i) the method for capturing experts' opinions using the pairwise comparison method; (ii) the method for aggregating individual expert ratings (in cases where consensus ratings are not used); and (iii) the method for standardizing the criteria or factors involved in the analysis which are subjective in each case. Moreover, AHP has given attention by the experts as its emphasis on the structure of providing preferences on different parameters by different policymakers(Ouma & Tateishi, 2014).

Use of AHP is diverse since it is used for flood vulnerability mapping as well. There are certain criteria or factors of the flood hazard which are given weights along with the alternatives of the particular criteria using the pairwise comparison. The weights are generated in between 0-9 following *Saaty's*scale and the AHP method is used to prioritize the factors or criteria based on the output. The output validation is observed based on the consistency ration (CR) which is acceptable less than 0.1 or 10%. In this study the influence percentage was calculated using AHP method (CR= 9%) where scale between 1-5 were given by expert knowledge based on importance of each class of each factor.

Table 2: The weightage provided to the conditioning factorsincluding scale for every classes.

Causal Factors	Class Range	Scale	Influence Percentage (weight)
TWI	2.63988018 - 6.430490266	1	8
	6.430490267 - 8.325795308	2	
	8.325795309 - 10.47955104	3	
	10.47955105 - 13.58095929	4	
	13.5809593 - 24.60818863	5	
SPI	0 - 243,188.0471	1	10
	243,188.0472 - 1,215,940.235	2	
	1,215,940.236 - 3,161,444.612	3	
	3,161,444.613 - 9,079,020.424	4	
	9,079,020.425 - 20,670,984	5	
Slope (in °)	0 - 10	5	10
	10.00000001 - 20	4	
	20.00000001 - 30	3	
	30.00000001 - 40	2	
	40.00000001 - 68.13751984	1	
BUI	(-0.865731597) - (-0.150375598)	1	10
	(-0.150375598) - 0.199089274	3	
Annual Rainfall	> 2000 mm	1	12
	> 2250 mm	2	
	> 2500 mm	3	
	> 2750 mm	4	
	>3000 mm	5	
Elevation	(-8)-30.8235294	5	8
	130.8235295 - 297.4117647	4	
	297.4117648 - 513.9764706	3	
	513.9764707 - 824.9411765	2	
	824.9411766 - 1,408	1	
Curvature	(-16.12816238)- (-0.114384136)	3	7
	(-0.114384136) - 0	2	
	0 - 17.72954178	1	
LULC	Water	5	13
	Vegetation	2	
	Agri-field	1	
	Settlement	4	
	Sand	3	
Drainage Density	0.111028202 - 0.28498321	1	12
	0.28498321 - 0.367259227	2	
	0.367259227 - 0.437781527	3	
	0.437781527 - 0.520057545	4	
	0.520057545 - 0.710467756	5	
Proximity to River (m)	0 - 191.9742293	5	10
	191.9742294 - 391.7841414	4	
	391.7841415 - 591.5940535	3	
	591.5940536 - 791.4039656	2	
	791.4039657 - 999.0495605	1	

5. Results and Discussion

5.1 Flood Susceptibility Zonation Map and Vulnerability to National Highway 17, 27

The final integrated flood susceptibility zone map was prepared using the above discussed method. The integration is subjective based weighted. It was generated based on expert's knowledge with relative literature review. Literatures are very supportive to make understanding and importance of the conditioning factors. Literature can support the validation of the weights as well(Allafta & Opp, 2021). The final flood susceptibility map was classified into low, moderate, high and very high susceptibility zones.

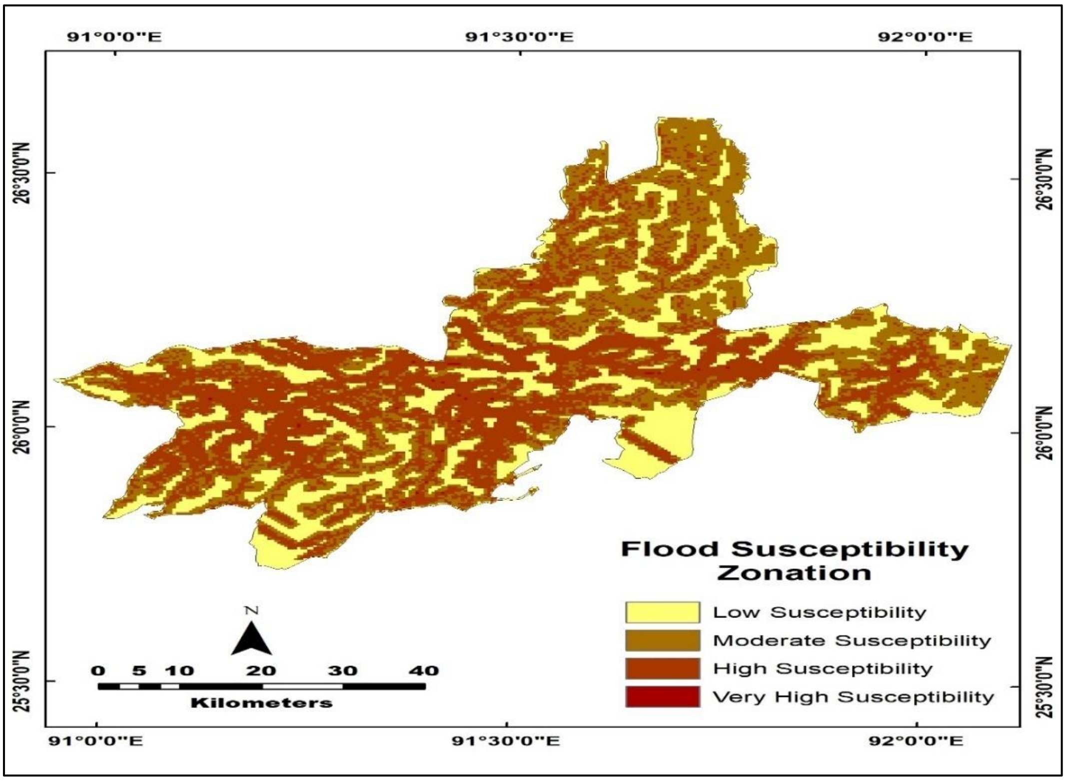

Figure 5: Flood susceptibility zonation (GSZ) map prepared using AHP-GIS weighted linear combination

The below map is the presentation of transportation vulnerability during riverine flash flood in Kamrup and Kamrup metropolitan districts in Assam. The major flood prone areas are nearest to the river and mostly settlement areas are situated on the bank of river which creates more damage and losses each and every year. But, damages of transportation connectivity are not studied much in Assam. Both the NH 17 and NH 27 which are main connectivity source to other parts of the country and north-east region becomes vulnerable due to Brahmaputra River flood as we see major areas of NH fall under high susceptibility zones in the case study of Assam flood 2019. Riverine and rain-induced flash floods are quick and creates more damages in short period of time(Ruin, Creutin, Anquetin, & Lutoff, 2008).

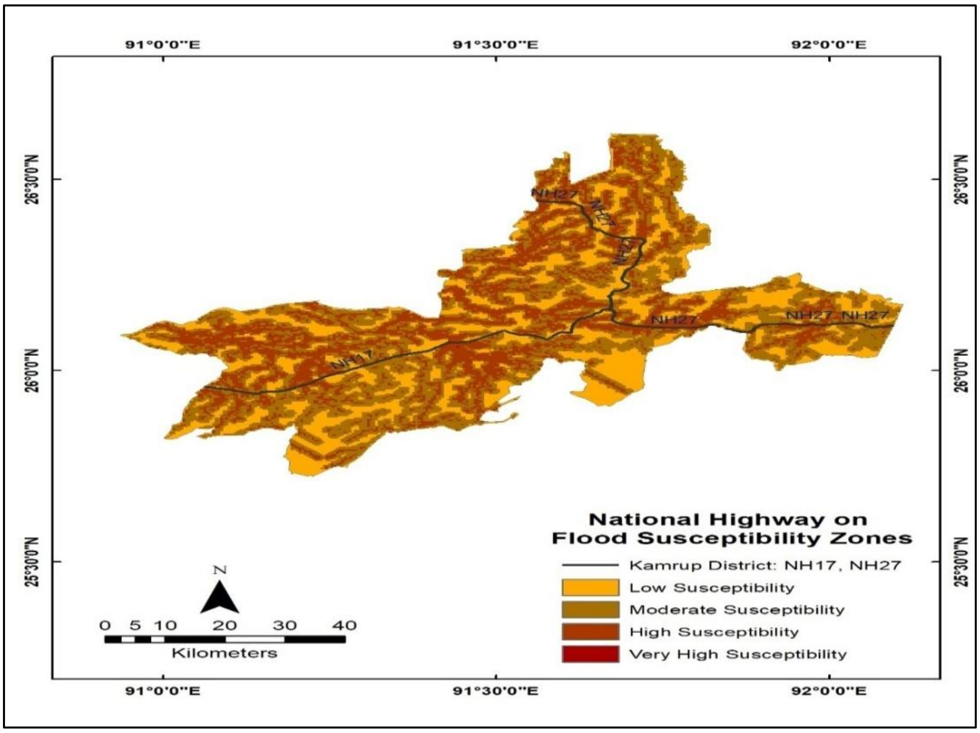

Figure 6: National Highway vulnerability map over FSZ. Major percentage of NH 17 and NH 27 falls over high flood zones which are the primary connectivity between North-East India and mainland India

5.2 Frequency Ratio Analysis

The FR technique was used to show the correlation between flood locations and flood conditioning factors. Figure 8 indicates that the highest topographic wetness index has the highest FR value (3.451). High Twi indicates more run off and flash flood in settlement and agricultural area. Following that, settlement area has more impact on the flood occurrence (3.22). while the water bodies and river have no influence on flood occurrence. It indicates the flood occurrence due to rainfall and human settlements stressors. Elevation above 800 m has significantly less impact on flood occurrence.

5.3 Validation of the susceptibility model

AUC estimation was done for prediction and success rate where the estimated values are 0.620 and 0.718 respectively. Though the prediction rate has been poor but satisfactory based on 30% past flood data, the success rate has givenfair estimation to show the validity of the flood susceptibility model.

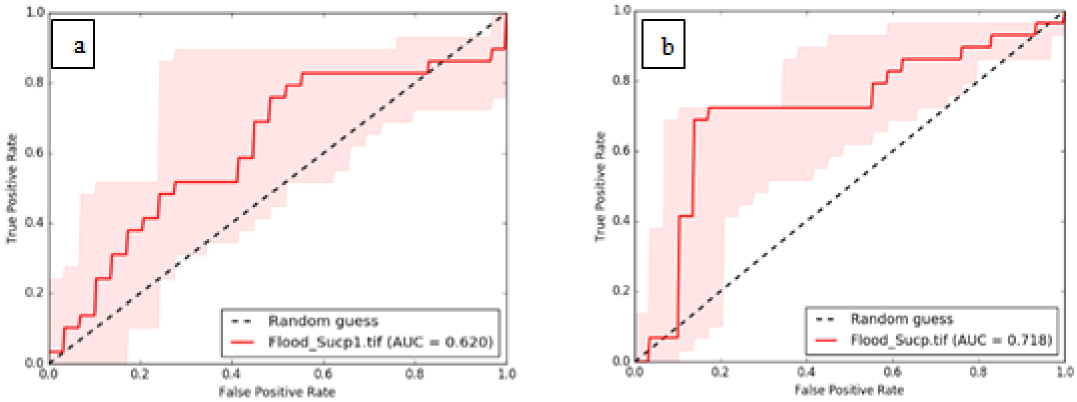

Figure 7: AUC validation estimated value- a) prediction curve, b) success curve.

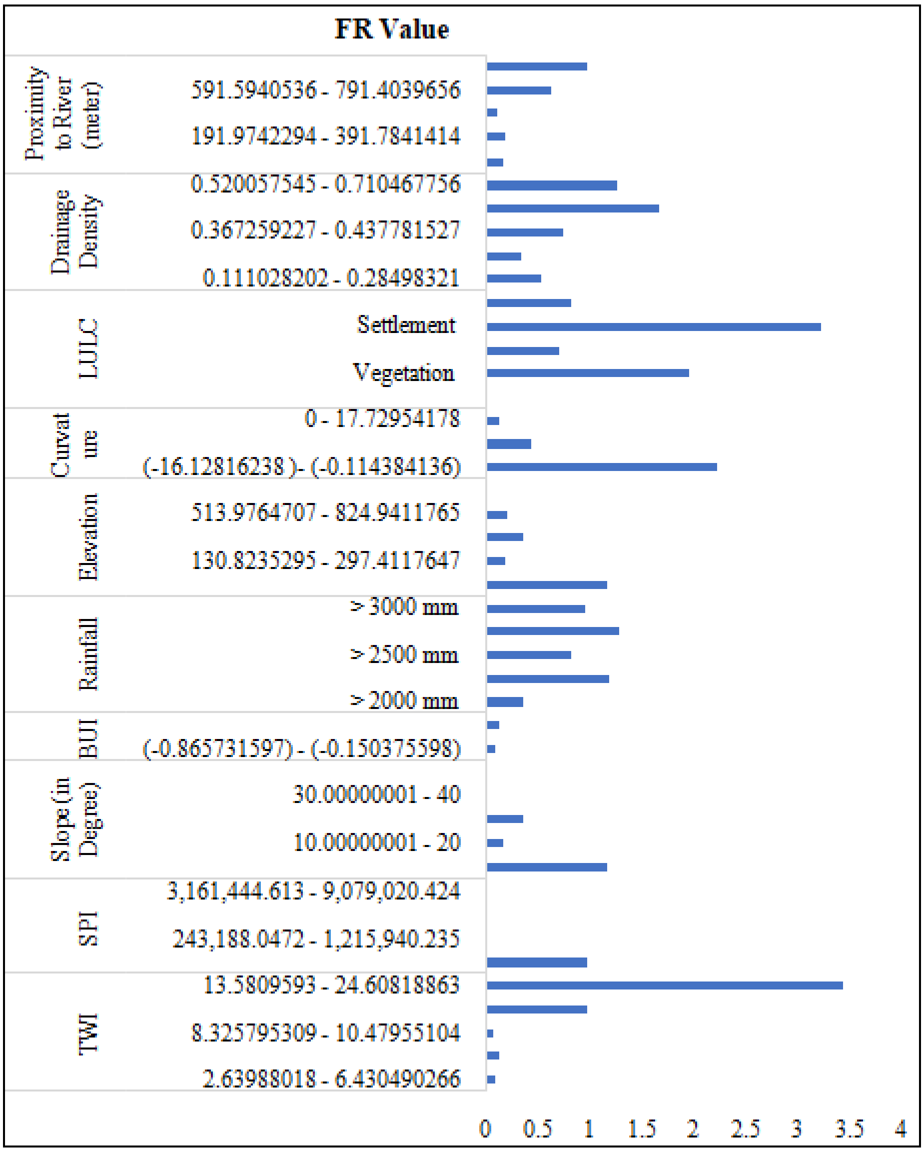

Figure 8: Frequency analysis of flood occurrence on conditioning factors

6. Conclusion

The conclusion can be drawn from the FSZ map is the NH passes through high flood susceptible zone makes the transportation and resource supply chain vulnerable. There is proper need of road and settlement development planning in the lower basin of Brahmaputra River or in Kamrup districts which is administrative part of the state and important for NE India. The AHP-GIS multi-criteria method used in this study is effective and creates scope for further studies of road network vulnerabilities in the various parts of the state or country. The AUC model is useful validation tool used in this study and shows further scope for research validation and applicability in geospatial vulnerability assessment due to extreme events. The study further creates scope of risk assessment of the national highway network in the country which are largest source of country wide supply chain network during emergency in the country.

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Author Profile

Bateswar Das, a post-graduate in Disaster Management from Tata Institute of Social Sciences. I have been working on nature and human-induced disaster risk analysis, sustainable development through nature-based innovative ideas in the field of climate change adaptation and extreme events. I have interest to work and explore in the field of sustainable agriculture, urban planning and water resource management using geoinformatics. I also write in the field of climate risk reduction, socio-economic vulnerabilities and policy recommendation.