Flood Susceptibility Mapping of the Middle Tapi Basin Using ArcGIS

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***Abstract*—Floods pose significant risks to human lives, infrastructure, and the environment. To mitigate the risks associated with flooding, accurate identification and mapping of flood hazards are crucial. To overcome this issue, the present study has been conducted around middle Tapi basin with the intention of delineating the flood risk and susceptibility with the use of remote sensing /(GIS) along with the Saaty's analytical hierarchy process (AHP) method. The digital elevation data and satellite images were taken from the Bhuvan website. The thematic maps were prepared using images. The precipitation data is taken from Indian Metrological Department website. The data collected from various sources was then used and with the help of ArcGIS model is developed. The area is classified in to 5 classes and a weighted overlay analysis is carried out. For the final flood susceptibility evaluation 10 sub-criteria were considered. Saaty's AHP method has been used to find weights of each of the parameter in which the topography has been assigned more weight for locating areas that are more prone to flooding. The other important parameters are hydrologic properties, land cover dynamics and permeability of the soil strata. The results of the study indicate that approximately 4,584 square kilometers (14.60% of the total area) is identified as very high to high flooding susceptibility zone. These high flooding susceptibility zones were predominantly located along the banks of rivers. It is also observed that an area of 9358.88 sq km (26.82% of total area) has low to very low flooding susceptibility.**

***Index Terms*—ArcGIS, Flood Susceptibility Mapping, MCDA Method, Saaty's AHP, Weighted Overlay.**

I. INTRODUCTION

Floods are among the most catastrophic natural calamities, causing serious destruction to property, infrastructure, and human life. To mitigate the risks associated with flooding, accurate identification and mapping of flood hazard is crucial. Geographic Information Systems (GIS) provides a useful framework for analyzing and mapping flood hazards by integrating data from various sources and spatial analysis technique. The flood hazard mapping provides a comprehensive understanding of flood hazard areas by combining topographic, hydrological, and meteorological data within a GIS environment. This enables better planning, disaster preparedness, and design response strategies to be adopted.

ArcGIS is a powerful tool for assessing and visualizing areas at risk of flooding. ArcGIS, provides advanced spatial analysis and mapping capabilities. The flood susceptibility mapping enables the identification and delineation of areas that are prone to flood events, helping in better understanding and managing flood hazards. Flood susceptibility mapping involves the integration and analysis of various geospatial data layers within ArcGIS. By overlaying and analyzing these layers, ArcGIS enables the identification of areas with specific characteristics that contribute to flood susceptibility. The output of flood susceptibility mapping is a spatial representation that highlights areas with varying degrees of flood susceptibility. The resulting map can be classified into different zones, such as high, moderate, and low susceptibility, providing valuable information for land-use planning, emergency preparedness, and disaster management. Additionally, ArcGIS offers visualization tools that allow for the effective communication of flood susceptibility information to stakeholders and the public

The current study has been conducted on the middle Tapi Basin, along the course of the Tapi River in middle part of India. It covers an area of 31,383 km^2 having length of approximately 360 Km. Agriculture is primary and major source of income of the people of the region. The overall temperature of the region varies from 10°C to 48 °C. The South-West rainfall is the major contributor to rainfall in this area. The annual average rainfall is found to be 713.05 mm.**[13]**

The past records of Ukai Dam indicate that the area was flooded during the years 1978, 1979, 1998, and 2006.

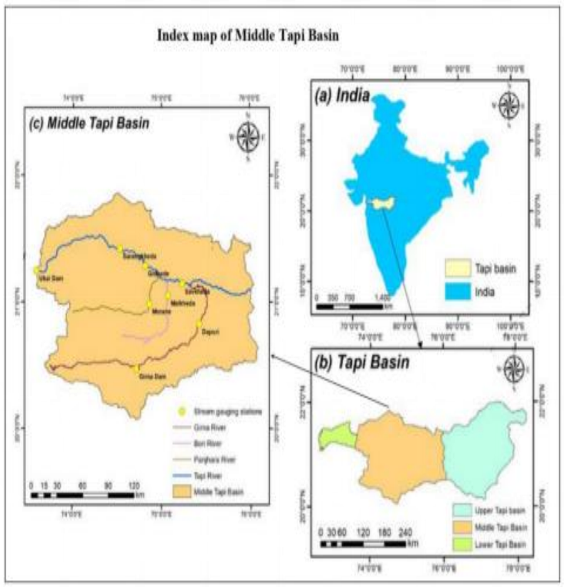


Figure 1: Index map of Middle Tapi Basin

II. LITERATURE REVIEW

The literature study is based on the flood susceptibility mapping using the perspective of geoinformatics, employing GIS based tools such as HEC-RAS, HEC-HMS, ArcGIS, Erdas Imagine along with multi criteria decision analysis (MCDA) tool **[1]** and other parameters and a weighted overlay model was employed to excite the prototype.

Amare et.al. (2018)[2], analyzed the study area around Adigrat town to spatially delineate the flood hazard and risk using geo-spatial and multi-criteria decision analysis (MCDA) methods for the issue of urban floods events.

Yashon et.al. (2014) [3], aims to preparation of flood maps and the estimation of flood risks in rapidly developing urban areas. The study focuses on the Eldoret Municipality in Kenya and utilizes an integrated approach combining AHP and GIS analysis techniques. The flood risk hazard mapping incorporates various factors that contribute to flooding. The mapping process employs a multi-parametric approach. Additionally, an UFRI is evaluated based on the degree of susceptibility and exposure in that area. The precision of the results is validated by comparing them with actual flood depth compution, showing a low difference of 0.01 m and a high difference of 0.37 m in different flood-affected areas.

Subhasish et.al. (2022) [4], conducted a study using the AHP method. Initially, 12 factors influencing direct floods were chosen and assessed. The importance of these factors were then evaluated by the AHP method to evaluate their importance in identifying flood-prone areas. The results revealed that LULC, NDVI, and distance from road and river were the high influencing criteria contributing to flash flood susceptibility. A flood susceptibility map was subsequently generated, classifying the study areas into five susceptibility zones. These findings can be valuable for authorities in effectively managing and reducing potential damages in highly flood-prone areas.

Abd Nasir et.al. (2014) [5], analyzed the limitations of flood forecasting by proposing a solution that combines the GIS and AHP. The main objective was to predict flood susceptible zones in the State of Perlis, Thailand. Five criteria considered to influence flood generation were chosen. The integration of the model into a GIS system enables the generation of a flood forecasting map.

Maurya et.al. (2016) [6], concluded that middle Tapi basin patterns display substantial geographical and temporal diversity, with most regions exhibiting a declining trend in total annual rainfall. Also, by calculating rainfall variability index for middle Tapi basin, the overall variability in the annual total amount of precipitation was assessed **Pramodkumar et.l. (2000) [7],** concluded the floods of high magnitude are rather frequent and prevalent in Tapi river.

Literature shows various parameters selection for flood risk, flood hazard, flood susceptibility and flood vulnerability by authors **[2][3][4][5]** varied according to the study area requirement to identify flood-prone areas using the Analytic Hierarchy Process (AHP) method. The weights of flood affecting factors were then determined using the AHP method to evaluate their importance in identifying flood-prone areas. A flood map was subsequently generated, classifying the study areas into very high, high, medium, low, and very low susceptibility zones. The integration of the model into a GIS system enables the generation of a flood forecasting map.

III. SYSTEM DEVELOPMENT

A. Data Collection: The relevant data such as DEMs, hydrological data, rainfall data, land use/land cover information, soil data, and historical flood records are collected. The data sources are various satellites, (like Landsat, Bhuvan), Governmental organizations and non-governmental agencies.

B. Preprocessing: The collected data is then prepared and analyzed. This involves cleaning and organizing the data, as well as converting it into a suitable format for ArcGIS.

C. Terrain Analysis: Generate derivatives from the DEM to analyze the terrain characteristics that influence flooding. This includes computing elevation, slope, distance from river, and drainage density. These derivatives help in understanding the flow patterns of water across the landscape.

D. Hydrological Analysis: Perform hydrological modeling to simulate the flow of water within the study area.This includes precipitation, drainage density. This can be achieved by using tools such as the Flow Direction, Flow Accumulation, IDW and Stream Order tools in ArcGIS. The modeling process helps in identifying the major channels and flow paths.

E. Data Integration: Combine the various datasets, such as land use/land cover, soil types, and rainfall intensity, with the terrain and hydrological derivatives. This integration helps in understanding the relationship between these factors and flood susceptibility.

F. Weighting and Classification: Assign weights to each factor based on its relative importance in flood susceptibility. This can be calculated by AHP method or statistical analysis. The area is then classified into appropriate categories (e.g., low, moderate, highly vulnerable) based on flooding pattern.

G. Overlay Analysis: Overlay the weighted and classified factors to obtain a composite flood susceptibility map. This is achieved using tools such as Weighted Overlay or Map Algebra. The overlay process combines the individual factors and assigns a flood susceptibility value to each location.

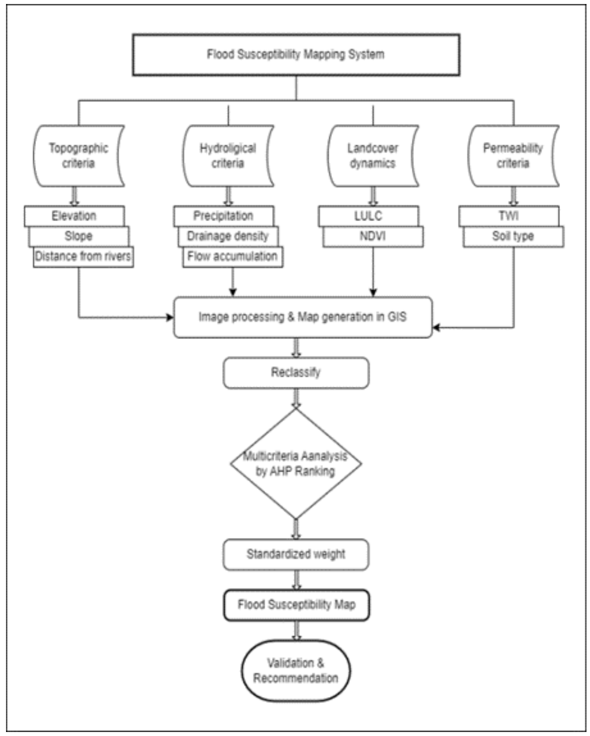


Figure 2: Schematic of the procedure used for flood susceptibility mapping in a Middle Tapi basin.

H. Validation and Refinement: Validate the flood susceptibility map by comparing it with historical flood records or field observations. The weights are adjusted on the basis of validation results and the area is classified.

I. Visualization and Reporting: The flood susceptibility map is then displayed for visualization of the stakeholders. It represents various symbols to represent different levels of flood susceptibility. A report for documenting the methodology, data sources, and results of the analysis is prepared for further study and references.

IV. RESULTS AND DISCUSSION

The flood susceptibility map is created by combining the results for each criterion across five different classes. The pairwise Comparison Matrices (PCMs) are generated to estimate the relative importance of each criterion using the AHP method.

The final flood susceptibility map is then developed using a lambda max value of 10.54 and a consistency ratio value of 0.04 (verified to be less than the accepted threshold of 0.1).

1. *Normalizd Pairwise comparison matrix*

Parameter	E	S	FA	P	DR	DD	TWI	LULC	ST	NDVI	Vp	Cp
E	1	2	2	2	2	3	3	2	3	4	**2.26**	**0.19**
S	1/2	1	1	3	2	3	3	2	4	5	**2.01**	**0.17**
FA	1/2	1	1	2	2	3	3	2	4	4	**1.89**	**0.16**
P	1/2	1/3	1/2	1	2	2	3	2	3	4	**1.37**	**0.11**
DR	1/2	1/2	1/2	1/2	1	2	3	3	4	4	**1.34**	**0.11**
DD	1/3	1/3	1/3	1/2	1/2	1	2	2	3	4	**0.92**	**0.08**
TWI	1/3	1/3	1/3	1/3	1/3	1/2	1	1	2	3	**0.64**	**0.05**
LU/LC	1/2	1/2	1/2	1/2	1/3	1/2	1	1	2	3	**0.76**	**0.06**
ST	1/3	1/4	1/4	1/3	1/4	1/3	1/2	1/2	1	2	**0.44**	**0.04**
NDVI	1/4	1/5	1/4	1/4	1/4	1/4	1/3	1/3	1/2	1	**0.32**	**0.03**

Table 1: Pair-wise comparison matrix by AHP

2. Check for Consistency

$$CI = (\lambda max - n)/(n - 1)$$

CI = (10.54 − 10)/(10 −1) , CI = 0.06

$$CR = CI/RI$$

CR = 0.061/1.49 , CR = 0.04 <0.1

If the Consistency Ratio (CR) is equal to or less than 10%, the weights are considered acceptable. However, if the CR exceeds 10%, it indicates that the subjective judgments need to be reviewed and revised.

3. Discussion

A. *Digital Elevation Model (E):*

The 30 m DEM dataset has been downloaded from Bhuvan portal. After merging the tiles of present study area and by using Clip geo-processing tool the DEM is created. The low elevation regions have been assigned the highest ranking as flood prone areas, which contribute 30.98% (< 177m elevation) of the study area. The hilly area accounts for 4.94% (>657 m) of the total area and is located towards the South-west region.

B. *Slope(S):*

Steeper slopes are more susceptible to surface runoff, while flat terrains are susceptible to water logging. The slope created is mainly classified into 5 classes, from 0 to 89%. The slope varies with high slopes (86°-90°) in the mountainous areas having area of 15.46%, and gentle to moderate slope (0°-30°) in the plain terrain with area of 8.91%.

C. *Flow Accumulation (FA):*

High values of the accumulated flow showed areas of concentrated flow, which subsequently made them more susceptible to flooding. It is formed during the simulation of runoffs by determining the flow direction.

D. *Annual Rainfall (P):*

During the monsoon period, the region receives heavy rainfall, leading to a substantial increase in the water levels. Around 6.1% of total area receives the rainfall of >1732mm while 19.15% area receives rainfall between 1351mm - 1732mm.

E. *Distance from River (DR):*

The flood severity depends on the distance of the location from the bank of the river. For the study area, it is observed that near the river network (<500 m) the area is highly susceptible to flood, while the effect of this parameter significantly decreases for distances >600 m.

F. *Drainage Density (DD):*

High drainage density levels are beneficial for runoff and, as a result, suggest a reduced flood risk. Around 19.64% of the study area has higher drainage density.

G. *Topographic Wetness Index (TWI):*

It is a terrain-based parameter that represents the potential for water to accumulate and saturate the landscape based on its topography. A higher TWI value represents higher chances of flooding in that area. In study area, nearly 11.42% of total area has higher TWI values.

H. *Land use Land cover (LULC):*

The hydrological cycle is mainly influenced by changes in land usage and land cover. Out of total basin area, 68.63% of the area covers agricultural land while 24.74% of the area has forest cover. Built-up area is around 3.48%

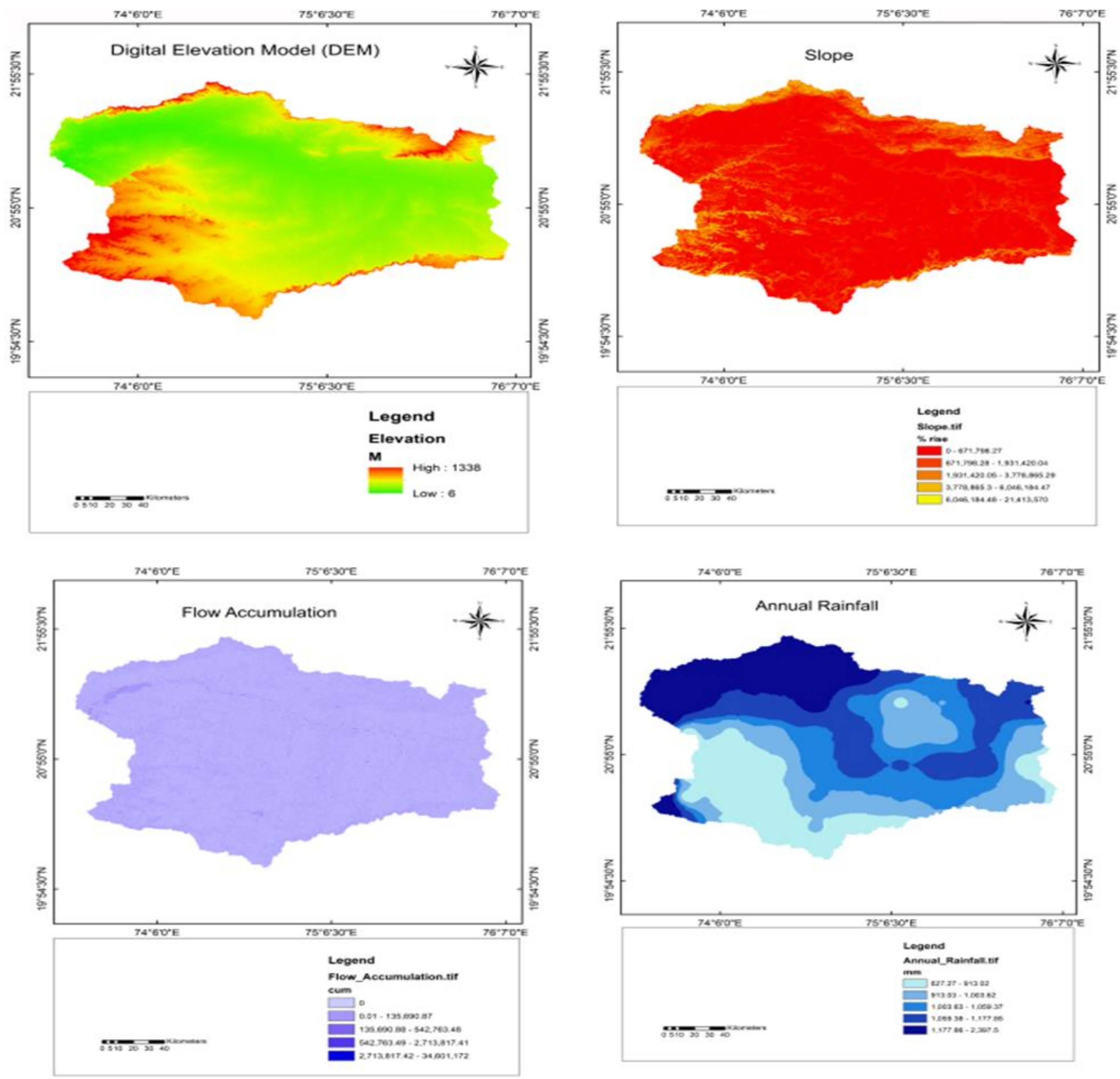
I. *Soil Type (ST):*

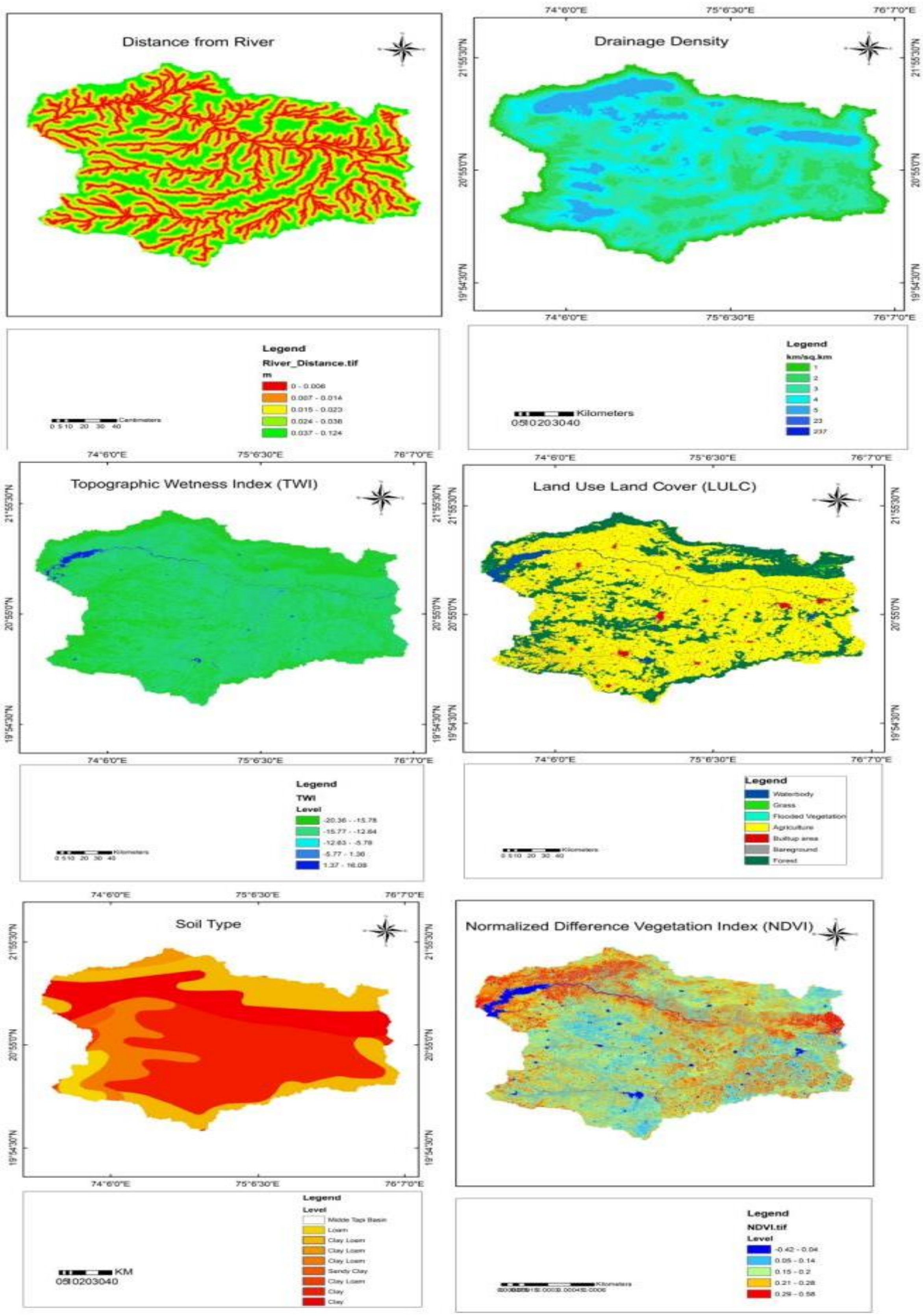
The soil type affects the infiltration and the surface runoff. There are four types of soil found in basin: loam, clayey loam soil, sandy clay, and clayey soil.
Because of the clayey soil (nearly 58.54%) has greater runoff than loam and sandy loam soil, so the rating level is assigned correspondingly.

J. Normalized Difference Vegetation Index (NDVI):

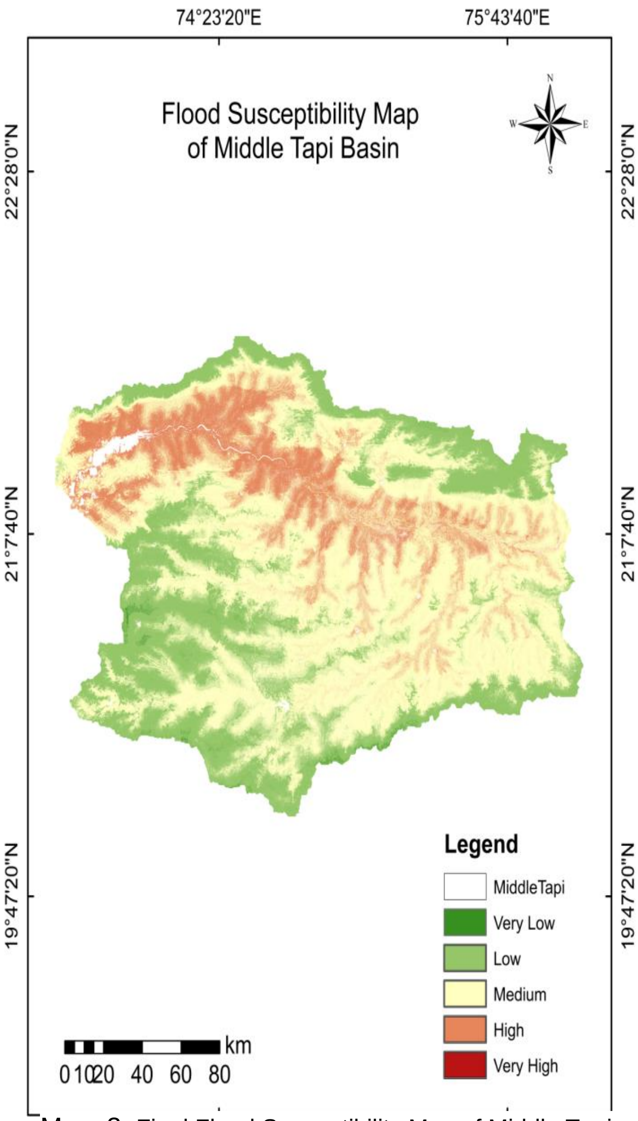
It has a negative relationship with flooding. By calculating the normalized difference between NIR and red bands, NDVI gives an indication of the presence and vigor of vegetation in a given area. Higher NDVI values typically correspond to healthier and denser vegetation, while lower values indicates sparse or stressed vegetation.

Map 1: Thematic map of elevation, slope, flow accumulation, precipitation





Map 2: Thematic map of distance from river, drainage density, TWI, LULC, soil type, NDVI



Map 3 :Final Flood Susceptibility Map of Middle Tapi Basin areas

Table 2: Area coverage of flood susceptibility classes

Sr. No	Level of Risk	Flodded Area (sq.km)	Flooded Area %
1	Very low risk	80.25	0.255
2	Low risk	9278.63	29.565
3	Medium risk	17439.70	55.572
4	High risk	4581.35	14.599
5	Very high risk	2.84	0.009
	Total	**31382.76**	**100.000**

V. CONCLUSION

The GIS-based multi-criteria AHP method provides a systematic approach to decision-making that incorporates both qualitative and quantitative factors for identifying flood hazard zones in the Indian state of Maharashtra. In the present work, for the final flood susceptibility evaluation, the grouping of these criteria is based on their relative level of impact on the resulting floods. Then all the floods influencing the raster layer are pre-processed within the ArcGIS software and then reclassified into the 5 classes for generating the ultimate flood susceptibility map. Among the MCDA methods, Saaty's AHP method has been used to find weights of each of the criterion. As a result, approximately 4,584 square kilometers, accounting for around 14.60% of the total area, is identified as being in very high to high flooding susceptibility zones. These zones are predominantly located along the banks of rivers. This indicates that a significant portion of the area with high flood susceptibility is situated in close proximity to river channels, making it more vulnerable to flooding events. on the other hand, an area of 9358.88 sq km (26.82%) has low to very low flooding susceptibility. If more number of parameters are used the GIS-based AHP technique gives a better and reliable flood susceptibility area mapping.

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