Integrative GIS-AHP Techniques for Flood Susceptibility Analysis in Nashik, Maharashtra

Madhusudhan Reddy M.[1]*, Bhavani G.[1], Avinash Goud M.[1], Sushmanth J.[1], Sri Ramya N.[1] and Praveen S.[2]
1. Department of Civil Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad, Telangana, INDIA
2. Department of Civil Engineering, CVR College of Engineering, Hyderabad, Telangana, INDIA
*m.madhusudhanreddy@iare.ac.in

Abstract
This study delves into flood susceptibility analysis in Nashik, Maharashtra, employing Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP). Nashik, a rapidly growing city along the Godavari River, faces significant flood risks due to its unique geographical and hydrological characteristics. With a population exceeding 6 million and covering an area of 15,582 square kilometers, Nashik's vulnerability to floods is compounded by factors such as rapid urbanization and diverse river networks including the Godavari, Vaitarna, Bhima, Girna, Kashyapi and Darna. The study integrates various thematic maps, encompassing aspect, distance to river, elevation, flow accumulation, flow direction, drainage density, contour, Landsat 8 imagery, normalized difference vegetation index, land use and land cover, annual rainfall, roughness, slope, stream network and topographic wetness index. These maps aid in accurately identifying flood-prone areas by considering surface features, flow characteristics and hydrological parameters. The findings highlight regions with high drainage density, low elevation and proximity to major rivers as particularly vulnerable to flooding.

Additional factors such as land cover, rainfall intensity and terrain roughness significantly influence flood susceptibility. Through the integrative GIS-AHP approach, policymakers, urban planners and emergency response agencies gain critical insights for implementing proactive measures to mitigate flood risks. The study underscores the importance of spatial analysis and multi-criteria decision-making techniques in effective flood risk management and urban planning in Nashik. It emphasizes the comprehensive nature of the flood susceptibility assessment, incorporating a total of 11 parameters used in the AHP technique. By integrating these parameters into a cohesive framework, this research contributes to a better understanding of flood dynamics in Nashik and aids in developing strategies for resilient urban development and disaster preparedness.

Keywords: Flood susceptibility, GIS-AHP, Nashik, Maharashtra, Godavari river, Urban planning and Disaster risk management.

Introduction

Nashik, situated in the northern region of Maharashtra, is a city marked by rapid urbanization and significant growth. It is the third-largest city in Maharashtra by population, following Mumbai and Pune, with a populace exceeding 6 million spread over an area of 15,582 square kilometers. The city's geographical positioning on the western edge of the Deccan plateau, an ancient volcanic formation, plays a crucial role in its hydrological characteristics. At an average elevation of 945 meters above sea level, Nashik is a vital urban center with unique environmental and developmental challenges. The Godavari River, the second-longest river in India, originates from the Brahmagiri Mountain in Trimbakeshwar, about 24 kilometers from Nashik. This river flows through the heart of the city, making Nashik particularly vulnerable to flooding.

Apart from the Godavari, several other significant rivers including the Vaitarna, Bhima, Girna, Kashyapi and Darna, traverse the district, each contributing to the region's intricate flood dynamics. For instance, the Darna River, a minor right-bank tributary of the Godavari, rises north of the Kalsubai range and drains several talukas within Nashik. The Vaitarna River, originating from the Trimbakeshwar hills, receives substantial rainfall during the monsoon season, further heightening flood risks. Nashik has a long history of flooding, with severe events recorded in 1978, 1994, 2013, 2016 and 2019. These floods have caused extensive damage to property, infrastructure and agriculture, disrupting the lives of thousands of residents.

The 2019 floods, for instance, were particularly devastating, with heavy rainfall in August causing the Godavari River to overflow, leading to severe waterlogging and substantial infrastructure damage. Similar incidents in 2016 and 2013 also saw Godavari and its tributaries inundate vast areas, necessitating large-scale rescue and relief operations[1]. Given this context, it is imperative to develop a robust flood susceptibility analysis to better understand and mitigate these risks[22]. This study employs Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) to achieve this goal. The primary objectives are to characterize the surface features of Nashik, to analyze flow characteristics and to develop a detailed flood susceptibility map.

By integrating various thematic maps including those depicting elevation, drainage density, land use, land cover (LULC) and rainfall patterns, the current study aims to accurately identify areas at high risk of flooding. The integration of GIS and AHP methodologies allows for a comprehensive assessment that considers multiple criteria influencing flood susceptibility. These insights are invaluable for urban planners, policymakers and emergency response teams.

By understanding the area's most at risk, stakeholders can implement targeted flood management strategies, can design effective urban planning initiatives and can enhance disaster preparedness efforts[3-5]. Ultimately, this study aims to contribute to a safer and more resilient Nashik, capable of withstanding future flood events while safeguarding its population and infrastructure[10,11]. The geographical location map of Nashik is shown in figure 1.

Review of Literature

Conducting a thorough literature review for flood susceptibility mapping is essential for several reasons. First, it provides valuable insights into existing methodologies, data sources and analytical techniques used in similar contexts, aiding in the formulation of an effective research framework. Secondly, it helps to identify gaps and limitations in current literature, guiding researchers towards areas requiring further investigation or refinement. Additionally, a comprehensive review of past studies facilitates the integration of established best practices and theoretical frameworks into the research design, thereby enhancing the robustness and reliability of the findings. Several studies in similar contexts highlight different approaches and findings.

Sahana and Patel[29] compared frequency ratio and fuzzy logic models for flood susceptibility assessment of the lower Kosi River Basin in India. They found fuzzy logic to be more accurate in predicting flood susceptibility, despite the simplicity of the frequency ratio model and devised a hybrid method incorporating both models to produce an accurate flood susceptibility map. In the Ghaggar Basin, Haryana, India, researchers revealed high flood risk due to insufficient river channel capacity and emphasized integrating hydrological and socioeconomic data for flood hazard assessment[30]. Satellite imagery and census data were used to identify vulnerable areas and GIS mapping enhanced flood vulnerability analysis for local-level applications, assisting planners, insurers and emergency services.

Waterlogging poses significant challenges in urban areas, leading to damage and health issues. A study using AHP and GIS for waterlogging risk analysis in Patiala city, Punjab, assessed criteria like elevation, slope, land use and soil type to create a risk map[8]. This study identified five zones, aiding decision-makers in addressing flood risks. In Bijnor district, India, land suitability assessment for sugarcane cultivation used ten criteria such as rainfall, texture and slope[12]. The study employed fuzzy AHP in GIS to determine suitability, categorizing areas as highly, moderately, marginally suitable, or unsuitable. Most cultivable land was found to be highly suitable, emphasizing attention to areas needing improvement like Nagina, Najibabad and Bijnor sub-districts.

The Ghaggar river basin in northern India faces recurrent flash floods despite its semi-arid/arid nature. Due to limited flood-related data, identifying flood risk zones is crucial[9]. A study proposed graph theory for this purpose, utilizing spatial data like elevation, land cover and population, showing graph theory accurately identifying flood risk zones, surpassing AHP in accuracy. A study addressing the need for comprehensive flood risk assessment and management in Nashik District, Maharashtra, highlighted urbanization, climate change and inadequate infrastructure as key factors.

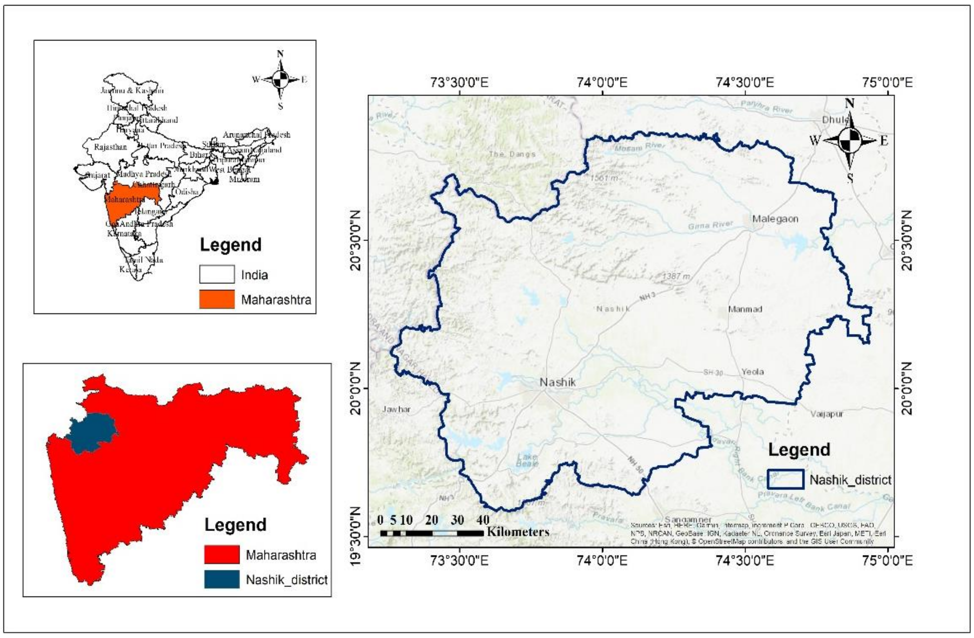


Fig. 1: Geographical location map of the Nashik, Maharashtra

Material and Methods

Focusing on vulnerable areas along the river Godavari and other rivers, the study integrated GIS and AHP methodologies, analyzing spatial data on terrain, hydrology, land use and infrastructure vulnerabilities to provide decision-makers with insights for proactive disaster preparedness and response[2].

The methodology for flood susceptibility analysis in Nashik involves a multi-stage approach (Figure 2). Data acquisition and preparation are conducted using multiple sources including Landsat-8 imagery from the USGS website, SRTM-DEM data for topographical information and rainfall data from the Indian Meteorological Department (IMD).

Landsat-8 data is utilized to generate thematic maps encompassing topographical features such as slope, elevation, roughness, contours, NDVI, LULC and the topographic wetness index (TWI). SRTM-DEM data facilitates watershed delineation, flow accumulation analysis, stream network identification, stream order, distances from rivers and roads and estimation of flow lengths. Annual rainfall data from IMD is used to create rainfall maps. These thematic maps are integrated to re-scale the data into five classes, identifying varying levels of flood susceptibility. The integration of these thematic maps results in the development of a comprehensive flood vulnerability map, highlighting areas at risk[15-18]. Methodology ensures a robust analysis for flood risk management in Nashik, utilizing GIS and AHP methodologies to provide a comprehensive assessment framework[31]. This approach aids urban planners, policymakers and emergency response teams in making informed decisions to effectively mitigate flood risks.

Results and Discussion

Surface characteristics of Nashik district: This study utilizes a colour infrared map (employing bands 4, 3 and 2) and a digital elevation model (DEM) derived elevation map of the Nashik district. These datasets are critical foundations for developing flood susceptibility maps in the region. The colour infrared map provides invaluable insights into land cover patterns, vegetation distribution and urban infrastructure. This information aids in understanding surface properties and potential flood pathways. The elevation map, categorized into five distinct elevation classes (ranging from the lowest to the highest point at 1596 meters), offers essential data regarding terrain variations and areas susceptible to flooding[21-23].

For this investigation focused on the Nashik district, fundamental datasets for GIS analysis were established using Landsat 8 (Level-2) data acquired from the USGS website and USGS-SRTM-DEM data. Employing GIS techniques like band compositing and mosaicking, a colour infrared map and an elevation map were generated as illustrated in figure 3.

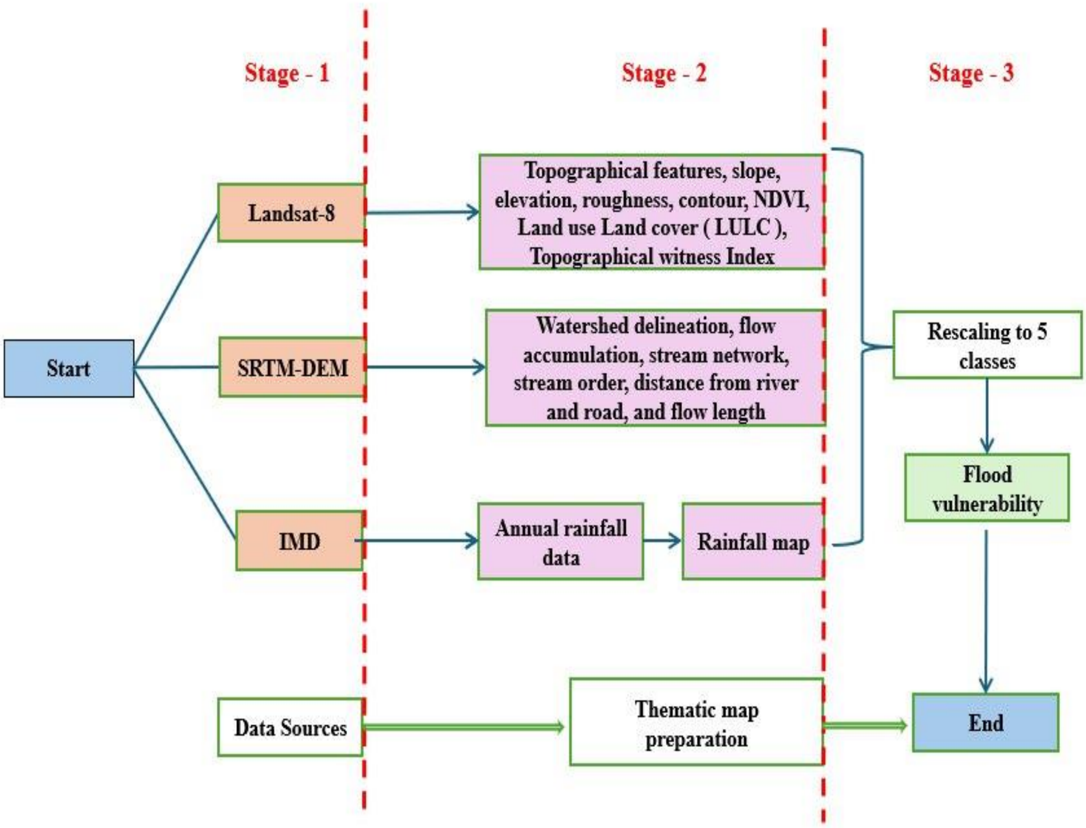


Fig. 2: Methodology adopted for flood hazard mapping of Nashik

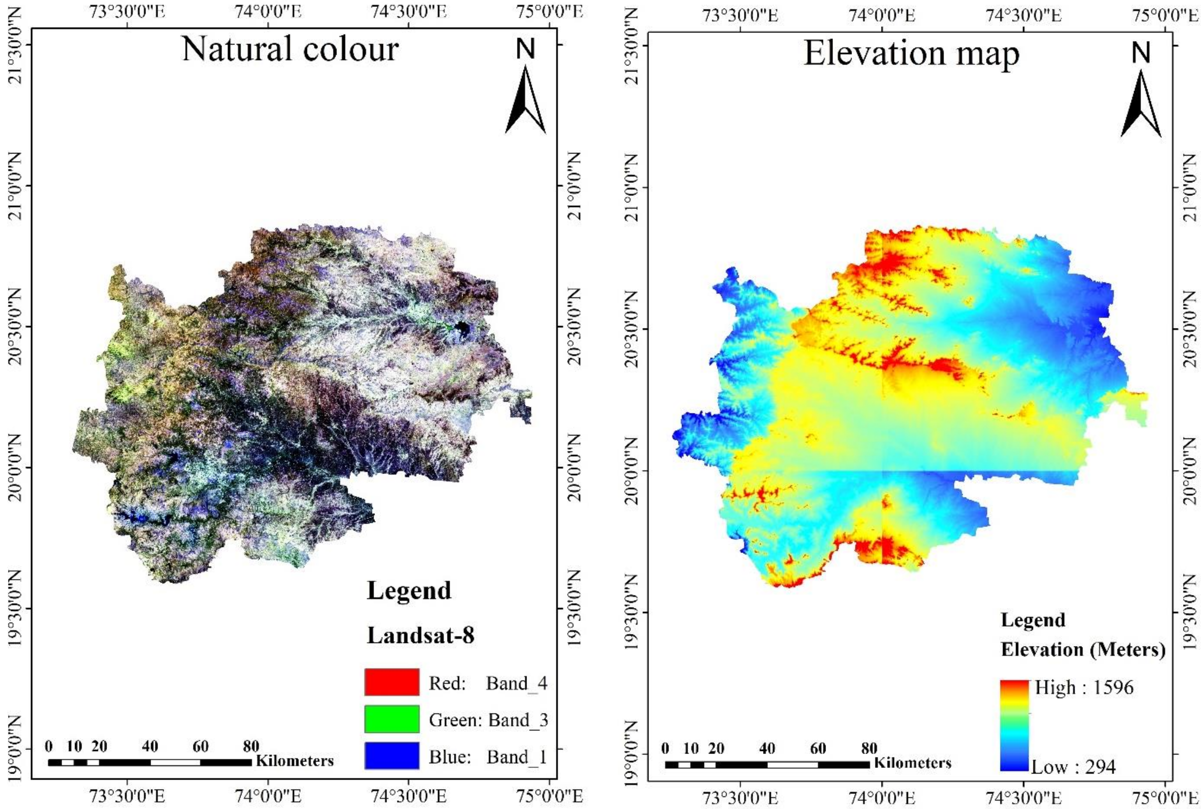


Fig. 3: Surface features representing the Landsat-8 and elevation maps of the Nashik

Flood susceptibility mapping is crucial for understanding and mitigating flood risks in any region including Nashik district. Key surface features such as slope, aspect, contours, roughness and hillshade play a vital role in accurately developing these maps. The slope of a terrain significantly influences water flow and flood susceptibility. In Nashik district, the slope is measured in degrees and classified into five groups: 0-250, 260-620, 630-1500, 1600-3500 and 3600-32000. Gentle slopes (0-250) are more prone to flooding as water tends to accumulate in these areas. Moderate slopes (260-620) have a reduced risk, while steep slopes (630-1500, 1600-3500) further reduce flood risk due to rapid water runoff. Very steep slopes (3600-32000) are least susceptible to flooding but may pose other hazards like landslides.

Aspect, the direction a slope faces, affects exposure to sunlight, wind and rainfall, influencing vegetation and soil moisture, which are critical for flood risk assessment. In Nashik, aspect is classified as Flat (-1), North (0-22.5), Northeast (22.5-67.5), East (67.5-112.5), Southeast (112.5-157.5), South (157.5-202.5), Southwest (202.5-247.5), West (247.5-292.5), Northwest (292.5-337.5) and North (337.5-360). Northern aspects, receiving less sunlight, may retain more moisture and may be more susceptible to flooding, while southern aspects are drier and are less prone to flood. Contours, indicating elevation changes, are crucial for understanding drainage patterns and flood risks.

In Nashik, contours are measured in meters and classified into five groups: group 1 (6000-8500 meters), group 2 (up to 9000 meters), group 3 (up to 10000 meters), group 4 (up to 12000 meters) and group 5 (up to 15500 meters). Lower contour areas are more likely to experience flooding due to water accumulation, while higher contour areas may act as barriers to water flow, influencing flood dynamics. Surface roughness, affecting water flow velocity and direction, is calculated for Nashik and divided into five classes. class 1 (0.12-0.36), class 2 (0.37-0.44), class 3 (0.45-0.52), class 4 (0.53-0.60) and class 5 (0.61-0.86). Lower roughness values (Class 1) indicate smoother surfaces where water flows quickly, potentially leading to downstream flooding.

Higher roughness values (Classes 4 and 5) indicate more obstacles, slowing water flow and reducing flood risk in upstream areas but potentially increasing it downstream due to delayed runoff[6]. Hillshade maps represent the spatial distribution of light and shadow over a terrain, crucial for visualizing topography and understanding flood risks. In Nashik, the hillshade effect, measured and illustrated, shows the distribution of light and shadow, with a maximum value of 254. High hillshade values indicate areas of intense sunlight exposure, affecting soil moisture and vegetation, thus influencing flood susceptibility. Shadows can indicate lower areas where water might accumulate.

By integrating these thematic maps slope, aspect, contour, roughness and Hillshade into a GIS, it is possible to comprehensively assess flood risks in Nashik district. For example, areas with gentle slopes, northern aspects, low contours and low roughness are identified as high-risk flood zones. Conversely, regions with steep slopes, southern aspects, high contours and high roughness are deemed low risk zones. The detailed analysis of these surface features enables more accurate flood susceptibility mapping, aiding in effective disaster management and mitigation strategies.

By understanding and mapping these features, Nashik district can better prepare for and can respond to potential flood events, protecting lives and property. The results highlight the importance of considering multiple surface features for a comprehensive flood risk assessment. Thematic maps representing the of slope, aspect, contour and roughness are illustrated in figure 4 and hillshade is illustrated in figure 5.

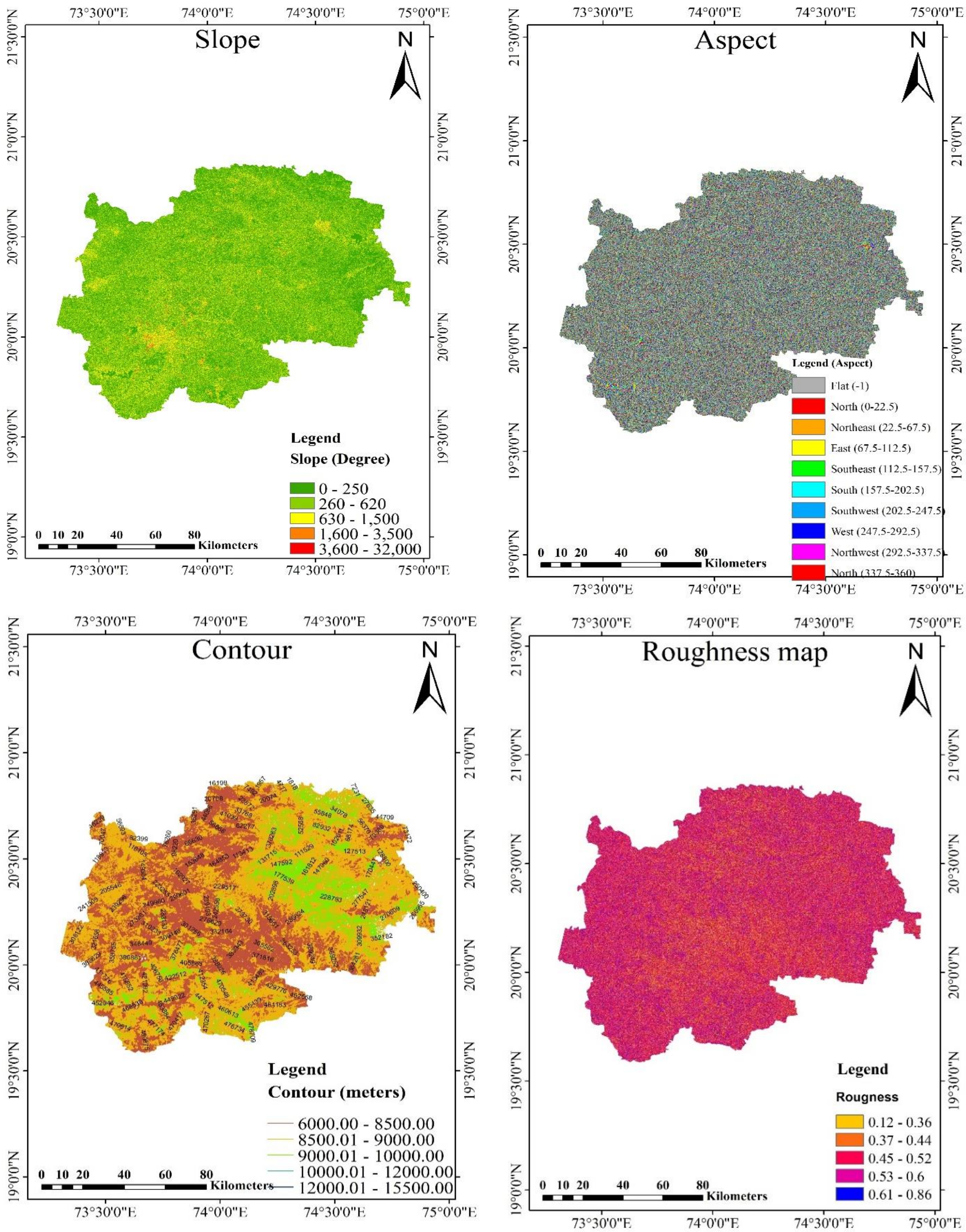


Fig. 4: Surface characteristics of Nashik representing slope, aspect, contour and roughness

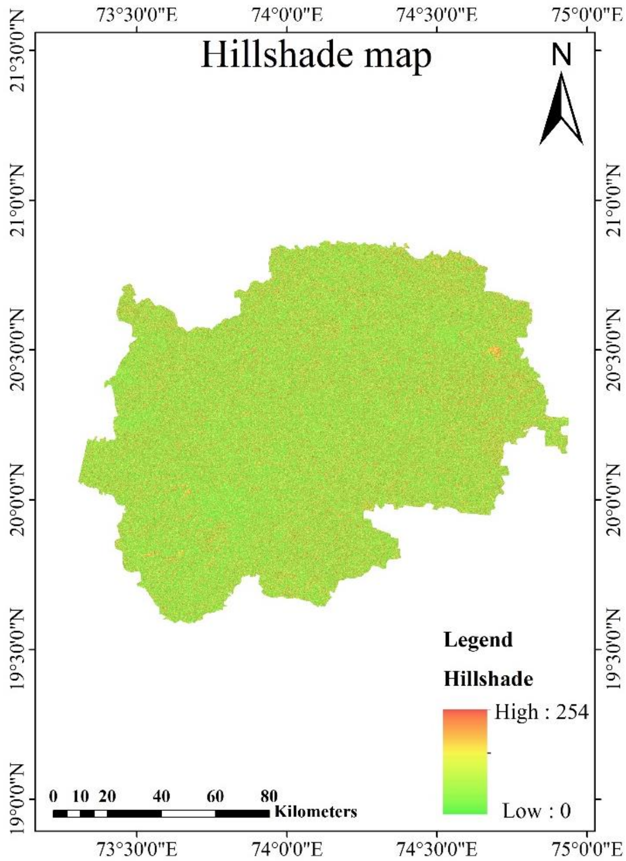
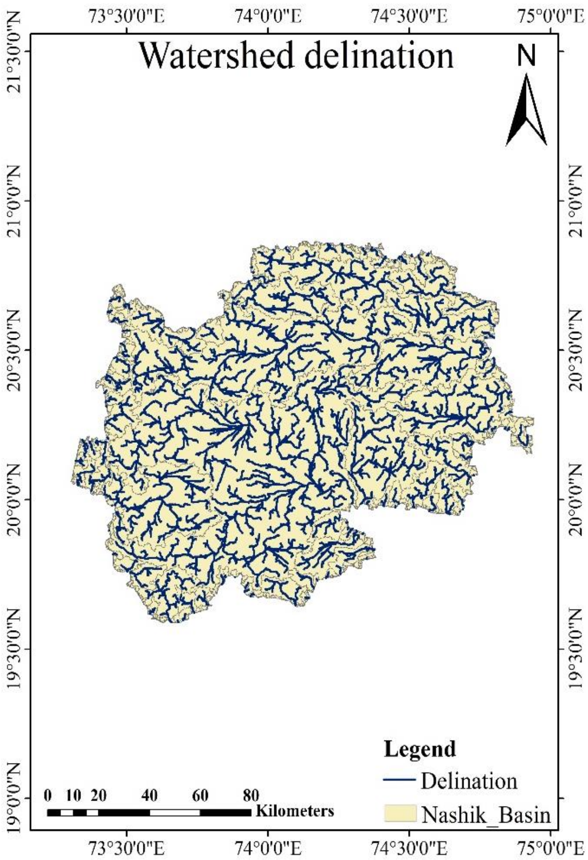


Fig. 5: Hillshade representing the spatial distribution of light and shadow over the Nashik region



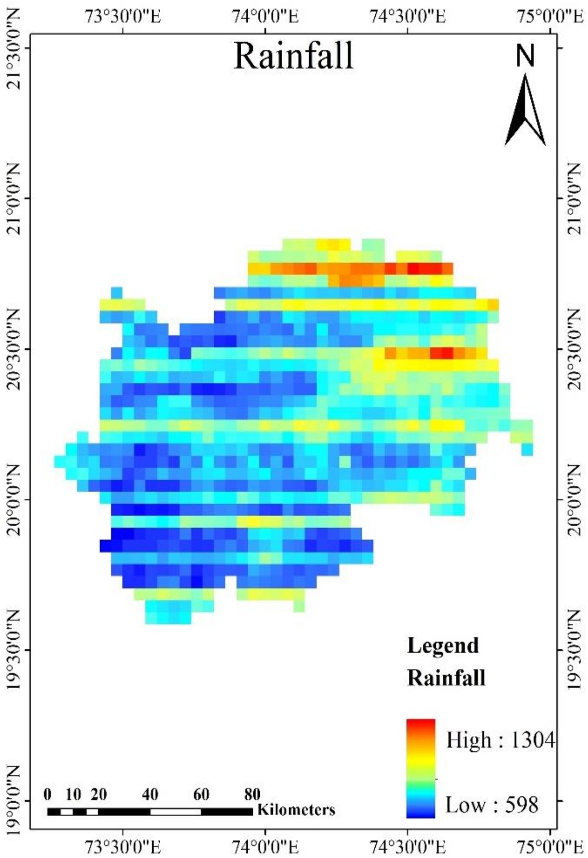


Fig. 6: Thematic maps representing spatial distribution streamline delineation and annual rainfall map of the Nashik

Flow characteristics of the rivers in the Nashik: Key surface features such as streamline delineation and annual rainfall maps are essential for accurately developing flood susceptibility maps. Using Landsat-8 data, the flood susceptibility mapping of Nashik district has been enhanced through the creation of detailed streamline delineation and annual rainfall maps. To develop the streamline delineation, basin and flow accumulation were first created using GIS, followed by converting the raster into a new raster, resulting in a clear delineation of streamlines[19,20]. These delineations help to identify the primary water flow paths and accumulation zones, which are critical in understanding how water will move across the landscape during heavy rainfall events, thereby highlighting potential flood-prone areas.

In addition to streamline delineation, the annual rainfall map for the year 2022 was developed using rainfall data collected from the IMD. Rainfall in Nashik is measured in millimeters, with a maximum recorded rainfall of 1304 mm and a minimum of 598 mm across the district. Thematic maps of streamline delineation and annual rainfall maps are illustrated in figure 6, these measurements are vital for assessing flood susceptibility as regions with higher annual rainfall are more prone to flooding[13]. The variation in rainfall across the district helps in identifying areas that receive excessive rainfall and are therefore more likely to experience flooding. By integrating these features streamline delineation and annual rainfall maps into the flood susceptibility mapping, a comprehensive assessment of flood risks in Nashik district is achieved. Areas with dense streamlines and high annual rainfall are identified as high-risk flood zones whereas areas with fewer streamlines and lower rainfall are considered low risk.

Flow density and distance from River: Measuring the flow characteristics of flow accumulation, flow direction, stream network/density and Euclidean distance is essential in developing accurate flood susceptibility maps for any region. In the context of Nashik district, these characteristics were measured using Landsat-8 data. Figure 7 illustrates the spatial distribution of all these themes, providing a comprehensive view of the region's flood susceptibility. Flow accumulation, which represents the amount of water flowing into each cell in a grid, is a critical factor in flood risk assessment. This was developed using GIS by determining the sum of all cells that flow into each down-slope cell. In Nashik district, flow accumulation values range from a minimum of zero to a maximum of 5,321,064.

High flow accumulation areas are more likely to experience flooding as they indicate zones where water converges. Flow direction is another crucial parameter, indicating the direction water will flow out of each cell. This was mapped and grouped into five classes based on flow size: class one (1-2), class two (2.1-8), class three (8.1-32), class four (33-64) and class five (65-130). Understanding flow direction helps in predicting the pathways water will take during heavy rainfall, which is vital for identifying flood-prone areas. The stream network and its density are also important in flood susceptibility mapping. The stream network was developed to provide details on of line density, illustrating where streams are most concentrated.

In Nashik, the stream network was grouped into five classes: class one (0-0.209), class two (0.21-0.41), class three (0.42-0.62), class four (0.63-0.83) and class five (0.84-1.05). High-density stream networks indicate regions where water flow is more frequent and intense, increasing the likelihood of flooding. Euclidean distance, which measures the distance from the road, is calculated using GIS. It is grouped into five classes: class one (0-1100), class two (1200-2100), class three (2200-3200), class four (3300-4300) and class five (4400-5300). The Euclidean distance map helps to identify areas farther from infrastructure, which might be less monitored and maintained, potentially increasing flood susceptibility. By integrating these flow characteristics into the flood susceptibility mapping of Nashik district, a comprehensive assessment of flood risks is achieved. High-risk flood zones are identified in areas with high flow accumulation, dense stream networks and specific flow directions that converge water flow[32-34].

Conversely, regions with low flow accumulation, sparse stream networks and greater Euclidean distances from roads are considered of lower risk. The detailed analysis of these flow characteristics enables more accurate flood susceptibility mapping, aiding in effective disaster management and mitigation strategies. Understanding these features allows Nashik district to prepare better for to respond to potential flood events, protecting lives and property. The results emphasize the importance of considering flow accumulation, flow direction, stream network density and Euclidean distance in comprehensive flood risk assessments.

NDVI and TWI mapping: Measuring the flow characteristics of NDVI and TWI is essential in the context of flood susceptibility mapping for any region. Using Landsat-8, these indices were calculated for Nashik district. Figure 8 illustrates the spatial distribution of these themes. The NDVI is calculated using equation 1 and grouped into four categories: water body, land, shrubs and vegetation[23]. NDVI quantifies vegetation health and density by analyzing spectral reflectance, with values ranging from -1 to 1. Higher NDVI values indicate dense vegetation, which can reduce runoff and mitigate flood risk, while negative values highlight non-vegetated surfaces more prone to flooding[27].

$$\mathrm{NDVI} = \frac{\mathrm{B5}-\mathrm{B4}}{\mathrm{B5}+\mathrm{B4}} \quad (1)$$

TWI is another crucial parameter, evaluating the terrain's susceptibility to water accumulation and flow[25,26]. TWI is calculated using the equation 2, based on factors such as slope and catchment area and is grouped into five classes for Nashik district: class one (-12 to 2.6), class two (2.7-4.6), class three (4.7-6.7), class four (6.8-9.8) and class five (9.9-

27). Higher TWI values indicate areas more prone to water accumulation, correlating with higher flood risk[38,39].

This index helps in understanding soil moisture conditions and spatial variability in soil properties, essential for categorizing areas into different flood susceptibility classes[7,26]. Flood susceptibility mapping plays a critical role in mitigating the impact of floods in the region.

$$\mathrm{TWI} = \mathrm{Ln}\,\frac{a}{\mathrm{tab}\,(\beta)} \qquad (2)$$

Integrating these parameters into the flood susceptibility mapping of Nashik district provides a comprehensive assessment of flood risks. High-risk flood zones are identified in areas with low NDVI values indicating sparse vegetation and high TWI values indicating significant water accumulation potential[24,27].

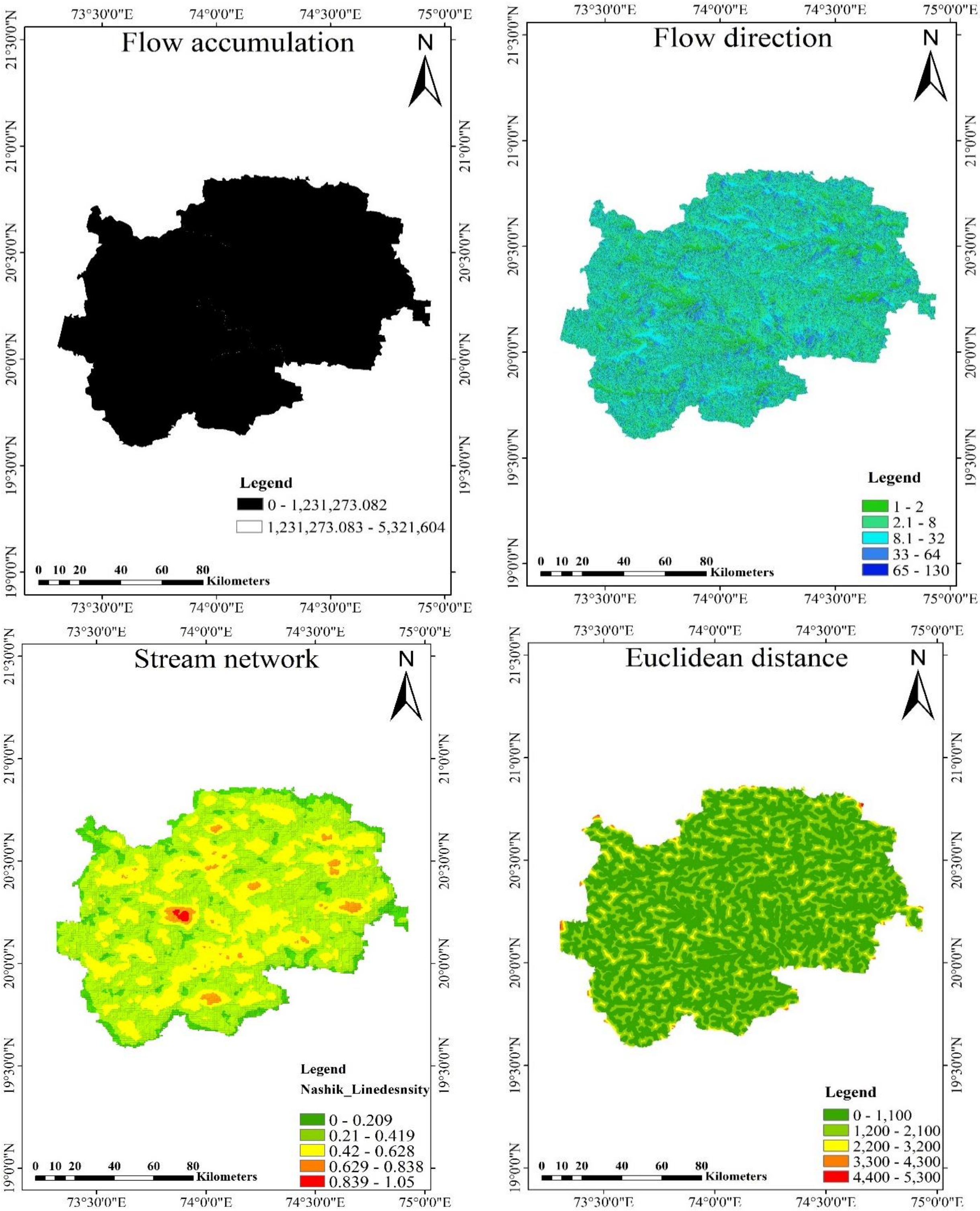


Fig. 7: Thematic maps representing flow characteristics in terms of flow accumulation, flow direction, stream network and distance from the road (Euclidean distance).

Conversely, regions with high NDVI values and lower TWI values are considered lower risk. This detailed analysis enables more accurate flood susceptibility mapping, aiding in effective disaster management and mitigation strategies[24]. Understanding these features allows Nashik district to prepare better for to respond to potential flood events, protecting lives and property.

Land Use Land Cover mapping: A cornerstone of flood susceptibility mapping is the LULC map. Leveraging the power of GIS, a detailed LULC map for Nashik district was meticulously crafted using supervised image classification techniques applied to Landsat-8 data. This thematic map, presented in figure 9, meticulously categorizes the land into various classes. These classifications include not only the expected broadleaf forests and cropland, but also delve deeper into nuanced categories like mixed forests, shrubland, barren land, fallow land, wasteland, water bodies, plantations and even needleleaf forests. Each of these land cover types plays a unique and crucial role in flood risk assessment.

The varying flood susceptibility stems from the inherent properties of each land cover type. Built-up areas, for example, are often dominated by impermeable surfaces like concrete and asphalt. These surfaces have minimal water infiltration capacity, leading to increased runoff and consequently, a heightened risk of flooding. In stark contrast, forests and plantations function as natural sponges. Their dense vegetation boasts a high capacity for water absorption, significantly reducing flood potential by mitigating runoff and promoting infiltration[14]. By meticulously mapping the spatial distribution of these diverse land cover types, the LULC map transforms into a powerful tool for flood risk management and mitigation strategies.

Empowered by this comprehensive LULC map, Nashik district can make transition from reactive flood management to proactive mitigation strategies. Areas with high concentrations of built-up land can be targeted for improved drainage infrastructure or creation of green spaces to absorb rainwater and lessen runoff. Conversely, existing forests and crucial natural flood barriers can be prioritized for conservation efforts. This data-driven approach allows Nashik district not only to prepare for potential floods but to actively reduce their impact, ultimately safeguarding lives, property and the overall well-being of the community.

Integrative GIS-AHP technique for flood susceptibility assessment: Implementing AHP techniques within GIS provides a robust method for assessing flood susceptibility and creating effective risk management strategies. AHP functions as a structured decision-making tool, assigning relative weights to various spatial data layers based on their influence on flood susceptibility[26,35].

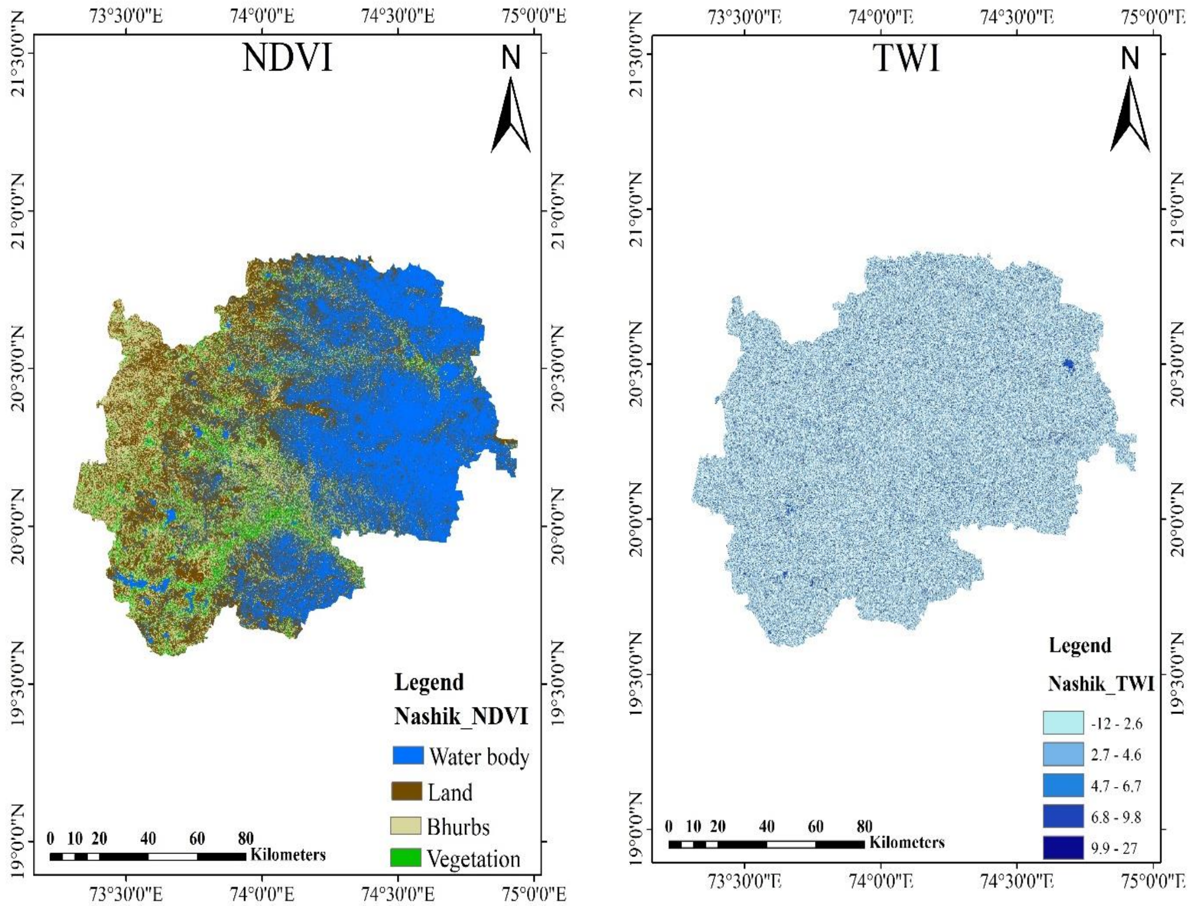


Fig. 8: NDVI and TWI maps representing the natural vegetation and moisture content over the Nashik

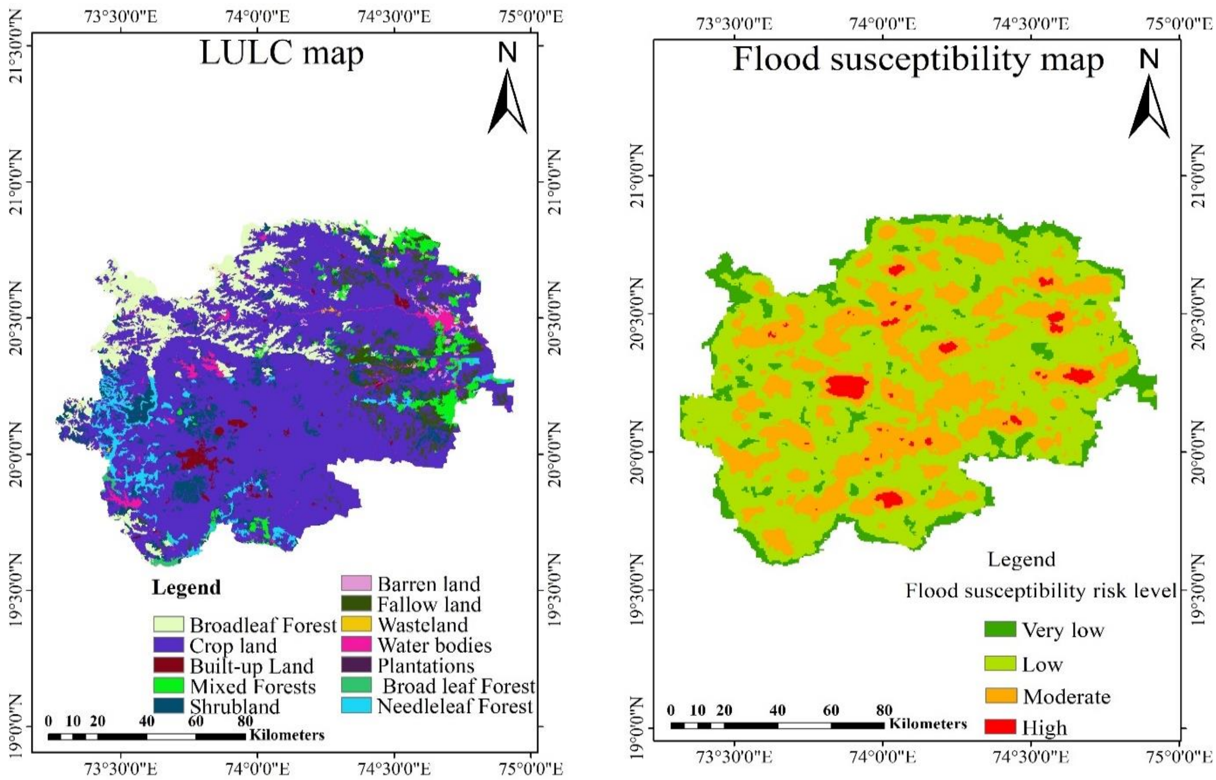


Fig. 9: LULC and flood susceptibility maps representing the landforms and flood risk zone over the Nashik

This process involves pairwise comparisons where the importance of each factor is evaluated relative to others, resulting in a hierarchical structure that reflects their respective impacts. The significance of each factor is determined through these comparisons, with criteria organized hierarchically and rated on a scale from 1 to 9 to indicate varying degrees of importance (Table 1). The comparison matrix for 'n' criteria is condensed into a summarized matrix, with criteria weights represented as coefficients (a_{ij}, where i, j = 1,2,3,…n) in equation 3.

$$A = \begin{bmatrix} a11 & a12 \ldots\ldots & a1n \\ a21 & a22 \ldots\ldots & a2n \\ an1 & an2 \ldots\ldots & ann \end{bmatrix}, a_{ii} = 1, a_{ij} = \frac{1}{a_{ij}}, a_{ij} \neq 0 \quad (3)$$

Despite the inherent subjectivity in AHP's hierarchical structuring, its robustness makes it a widely recommended approach for regional studies[7,36]. The process involves multiplying the weighted values of input raster layers by their corresponding cell values[37]. To facilitate weighted overlay analysis, all layers undergo reclassification, rasterization and resampling to ensure uniform pixel size and labeling. This research utilized GIS with the weighted overlay technique (WOT), incorporating ten input layers for overlay analysis using the mathematical equation 4:

$$RI = \sum W_i R_j \quad (4)$$

where 'W' represents the weight allocated to each layer and 'R' indicates the rank assigned to each theme within a layer. The variable 'i' denotes the number of layers while 'j' denotes the number of themes within each layer.

$$RI = W1 \times R1 + W2 \times R2 + W3 \times R3 + W4 \times R4 + W5 \times R5 + W6 \times R6 + W7 \times R7 + W8 \times R8 + W9 \times R9 + W10 \times R10 \quad (5)$$

where W1×R1, W2×R2 ………… W10×R10 are the weightage and ranking of LULC, elevation, TWI, slope, precipitation, NDVI, distance from river, aspect, drainage density and soil type respectively.

In the context of implementing AHP techniques using GIS, the AHP methodology employs fundamental scales derived from Saaty[28] as illustrated in table 1, to assign weights to each vulnerability theme according to predefined standards. The flood susceptibility map, shown in figure 9, categorizes vulnerability into five classes where higher values indicate lower susceptibility and lower values indicate higher susceptibility.

The allocated weights, as shown in table 2, provide insight into the percentage distribution across each vulnerability theme. This GIS-AHP approach for flood susceptibility analysis in Nashik district, integrates drainage density, emphasizing a comprehensive methodology that incorporates both hydrological and spatial factors. By combining AHP-derived weights with GIS-based WOT method, the mapping process gains depth, enabling a thorough understanding of the region's vulnerability to potential flooding. Each factor was assessed based on its significance and assigned numerical ratings on a scale of 1 to 5. Subsequently, weights and ranks were given to each factor class, with higher values indicating a greater influence on flood occurrence.

Table 1
The core scales of AHP

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favor one element over another.
5	Strong importance	Experience and judgement slightly strong one element over another.
7	Very strong importance	One element favored very strongly over another.
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation.
2, 4, 6 and 8 are used to express intermediate values		

Table 2
Ranking and weighting of susceptibility classes across various thematic maps.

Creation	Unit	Susceptibility class	Ratings	weight (%)
LULC	Level	Very High	5	11
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	
Elevation	meters	Very High	5	13
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	
TWI	%	Very Low	1	11
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
Slope	degrees	Very High	5	11
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	
Precipitation	mm/year	Very Low	1	10
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
NDVI	Level	Very High	5	10
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	
Distance from River	meters	Very High	5	9
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
Aspect	Level	Very High	1	9
		High	2	
		Moderate	3	

		Low	4	
		Very Low	5	
Drainage density	m/km	Very Low	1	8
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
Distance from Road	Level	Very High	5	8
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	

Conclusion

Nashik, located in northern Maharashtra, is the third-largest city in the State with a population of over 1.8 million. It is experiencing rapid urbanization, leading to increased flood risks. Positioned at an elevation of 945 meters on the western edge of the Deccan plateau, Nashik's unique topography influences its hydrological dynamics. The Godavari River, originating from Brahmagiri Mountain and other significant rivers such as the Vaitarna, Bhima, Girna, Kashyapi and Darna, contribute to the city's flood susceptibility. Nashik has a history of severe floods including major events in 1978, 1994, 2013, 2016 and 2019. The 2019 floods, for instance, caused widespread damage, highlighting the urgent need for effective flood susceptibility analysis.

This study utilizes GIS and the AHP to develop a detailed flood susceptibility map for Nashik. Key datasets used include colour infrared maps and DEMs to analyze surface features such as slope, aspect, contours, roughness and hillshade. For instance, areas with slopes greater than 15 degrees were identified as having higher runoff potential. Flow characteristics like flow accumulation, flow direction, stream network density and Euclidean distance to rivers were measured, providing a clear understanding of water movement during heavy rainfall. Areas with flow accumulation values above 500 were marked as high risk.

The study also incorporated indices such as the NDVI and TWI to assess vegetation health and water accumulation potential. Regions with NDVI values below 0.2 indicated sparse vegetation, making them more prone to flooding. The TWI analysis revealed areas with high wetness potential, crucial for flood prediction. LULC maps were created using supervised image classification techniques, categorizing the land into various classes such as urban, agricultural, forest and water bodies. The LULC analysis showed that urban areas, constituting 30% of the land, are at higher flood risk due to reduced infiltration. By employing AHP within GIS, weights were assigned to various spatial data layers, allowing for a structured decision-making process.

The flood susceptibility map produced identifies high-risk zones with a susceptibility index ranging from 0 to 1, where values above 0.7 indicate high flood risk. This comprehensive assessment provides invaluable insights for urban planners, policymakers and emergency response teams, aiming to enhance disaster preparedness and implement targeted flood management strategies, ultimately contributing to a safer and more resilient Nashik.

References

1. Arandhakar S., Chaudhary N., Depuru S.R., Dubey R.K. and Bhukya M.N., Analysis and implementation of robust metaheuristic algorithm to extract essential parameters of solar cell, *IEEE Access*, **10(1)**, 40079-40092 **(2021)**

2. Babu P.A., Nagaraju V.S. and Vallabhuni R.R., Speech emotion recognition system with librosa. In 2021 10th IEEE international conference on communication systems and network technologies (CSNT), 10th IEEE International Conference on Communication Systems and Network Technologies (CSNT), 421-424 **(2021)**

3. Bhukya L., Kedika N.R. and Salkuti S.R., Enhanced maximum power point techniques for solar photovoltaic system under uniform insolation and partial shading conditions: a review, *Algorithms*, **15(10)**, 365-372 **(2022)**

4. Cheruvu A., Radhakrishna V. and Rajasekhar N., Using normal distribution to retrieve temporal associations by Euclidean distance, In 2017 International Conference on Engineering & MIS (ICEMIS), IEEE, 1-3 **(2017)**.

5. Devi M.D., Juliet A.V., Hariprasad K., Ganesh V., Ali H.E., Algarni H. and Yahia I.S., Improved UV Photodetection of Terbium-doped NiO thin films prepared by cost-effective nebulizer spray technique, *Materials Science in Semiconductor Processing*, **127(3)**, 105673-78 **(2021)**

6. Gade M.S.L. and Rooban S., Run time fault tolerant mechanism for transient and hardware faults in alu for highly reliable embedded processor, In 2020 International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE), IEEE, 44-49 **(2020)**

7. Gokceoglu C., Sonmez H., Nefeslioglu H.A., Duman T.Y. and Can T., The 17 March 2005 Kuzulu landslide (Sivas, Turkey) and landslide-susceptibility map of its near vicinity, *Engineering Geology*, **81(1)**, 65-83 **(2005)**

8. Gorai S., Dhir A. and Ratha D., Waterlogging Risk Assessment of Patiala City, Punjab Using Analytical Hierarchy Process and GIS Analysis: A Case Study, International Conference on Hydraulics, Water Resources and Coastal Engineering, Singapore: Springer Nature Singapore, 237-246 **(2021)**

9. Gorai S., Ratha D. and Dhir A., Prediction of flood risk zone of Ghaggar river basin, India using graph theory technique, *Geocarto International*, **37(25)**, 9425-9452 **(2022)**

10. Goud B.S., Srilatha P. and Shekar M.R., Effects of mass suction on MHD boundary layer flow and heat transfer over a porous shrinking sheet with heat source/sink, *Int. Journal of Innovative Technology and Exp. Engineering*, **8(10)**, 263-266 **(2019)**

11. Jagadha S., Gopal D. and Kishan N., Nanofluid flow of higher order radiative chemical reaction with effects of melting and viscous dissipation, *Journal of Physics*, Conference Series, IOP Publishing, **1451(1)**, 012003 **(2020)**

12. Jamil M., Ahmed R. and Sajjad H., Land suitability assessment for sugarcane cultivation in Bijnor district, India using geographic information system and fuzzy analytical hierarchy process, *Geo Journal*, **83(1)**, 595-611 **(2018)**

13. Janakiramaiah B., Kalyani G., Prasad L.V., Karuna A. and Krishna M., Intelligent system for leaf disease detection using capsule networks for horticulture, *Journal of Intelligent & Fuzzy Systems*, **41(6)**, 6697-6713 **(2021)**

14. Jayanthi N., Lakshmi A., Raju C.S.K. and Swathi B., Dual translation of international and Indian regional language using recent machine translation, In 2020 3rd International Conference on Intelligent Sustainable Systems (ICISS), IEEE, 682-686 **(2020)**

15. Kalyani G., Janakiramaiah B., Karuna A. and Prasad L.N., Diabetic retinopathy detection and classification using capsule networks, *Complex & Intelligent Systems*, **9(3)**, 2651-2664 **(2023)**

16. Kumar C.L., Jayakumar V. and Bharathiraja G., Optimization of welding parameters for friction stir spot welding of AA6062 with similar and dissimilar thicknesses, Materials Today: Proceedings, **19(1)**, 251-255 **(2019)**

17. Kumar K.U., Babu P., Basavapoornima C., Praveena R., Rani D.S. and Jayasankar C.K., Spectroscopic properties of Nd3+-doped boro-bismuth glasses for laser applications, *Physica B: Condensed Matter*, **646(1)**, 414327 **(2022)**

18. Kumar N.R., Goud S.J., Srilatha P., Manjunatha P.T., Rani S.P., Kumar R. and Suresha S., Cattaneo–Christov heat flux model for nanofluid flow over a curved stretching sheet: An application of Stefan blowing, *Heat Transfer*, **51(6)**, 4977-4991 **(2022)**

19. Lakshmi L., Reddy M.P., Santhaiah C. and Reddy U.J., Smart phishing detection in web pages using supervised deep learning classification and optimization technique ADAM, *Wireless Personal Communications*, **118(4)**, 3549-3564 **(2021)**

20. Malliga S., Prasad N.L.V., Janakiramaiah B., Mohan Babu A. and Sathishkumar V.E., Hyperparameter Optimization for Transfer Learning of VGG16 for Disease Identification in Corn Leaves Using Bayesian Optimization, *Big Data*, **10(3)**, 215-229 **(2022)**

21. Mandapudi S., Chaganti S.S., Gorle S., Prasad S.U., Govardhan D. and Praveen B., CFD simulation of flow past wing body junction: a 3-D approach, *International Journal of Mechanical and Production Engineering Research and Development*, **7(4)**, 341-350 **(2017)**

22. Padmaja B., Prasad V.R. and Sunitha K.V.N., A machine learning approach for stress detection using a wireless physical activity tracker, *International Journal of Machine Learning and Computing*, **8(1)**, 33-38 **(2018)**

23. Penki R., Basina S.S. and Tanniru S.R., Application of geographical information system-based analytical hierarchy process modeling for flood susceptibility mapping of Krishna District in Andhra Pradesh, *Environmental Science and Pollution Research*, **30(44)**, 99062-99075 **(2023)**

24. Radhakrishna V., Kumar P.V., Janaki V. and Rajasekhar N., Estimating prevalence bounds of temporal association patterns to discover temporally similar patterns, *Advances in Intelligent Systems and Computing*, **576(2)**, 209-220 **(2017)**

25. Ramu G., A secure cloud framework to share EHRs using modified CP-ABE and the attribute bloom filter, *Education and Information Technologies*, **23(5)**, 2213-2233 **(2018)**

26. Reddy M.M., Rani S.P., Naresh N., Sai kumar R. and Janaki V., Assessing flood susceptibility in the Godavari River Basin, Bhadrachalam Region, Sothern India: A GIS-AHP Multi-Criteria Approach, *Disaster Advances*, **17(5)**, 61-71 **(2024)**

27. Rizwana M.S. and Sarah P., Impedance and electromechancial studies on Ca0. 1Sr0. 9LaxBi2-xTa2O9 ceramics, *Ferroelectrics*, **524(1)**, 95-101 **(2018)**

28. Saaty T.L., The Analytical Hierarchy Process: Planning Priority Setting Resource Allocatio, McGrawrHill International Book Co., London, England **(1980)**

29. Sahana M. and Patel P.P., A comparison of frequency ratio and fuzzy logic models for flood susceptibility assessment of the lower Kosi River Basin in India, *Environmental Earth Sciences*, **78(1)**, 1-27 **(2019)**

30. Saini S.S. and Kaushik S.P., Risk and vulnerability assessment of flood hazard in part of Ghaggar Basin: A case study of Guhla block, Kaithal, Haryana, India, *International Journal of Geomatics and Geosciences*, **3(1)**, 42-54 **(2012)**

31. Sarkar D., Saha S. and Mondal P., GIS-based frequency ratio and Shannon's entropy techniques for flood vulnerability assessment in Patna district, Central Bihar, India, *International Journal of Environmental Science and Technology*, **19(9)**, 8911-8932 **(2022)**

32. Sastry Y.S., Budarapu P.R., Krishna Y. and Devaraj S., Studies on ballistic impact of the composite panels, *Theoretical and Applied Fracture Mechanics*, **72(1)**, 2-12 **(2014)**

33. Shejkar S.K., Agrawal B., Agrawal A., Gupta G. and Pati P.R., Influence of filler content and surface modification on physical and mechanical properties of epoxy/walnut shell particulate composites, *Journal of Adhesion Science and Technology*, **37(7)**, 1215-1232 **(2023)**

34. Spandana K. and Rao V.S., Internet of Things (Iot) Based smart water quality monitoring system, *International Journal of Engineering and Technology (UAE)*, **7(3)**, 259-262 **(2018)**

35. Telagam N., Kandasamy N. and Nanjundan M., Smart sensor network based high quality air pollution monitoring system using labview, *International Journal of Online Engineering*, **13(08)**, 79-87 **(2017)**

36. Vaddiraju S.C. and Talari R., Urban flood susceptibility analysis of Saroor Nagar Watershed of India using Geomatics-based multi-criteria analysis framework, *Environmental Science and Pollution Research*, **30(49)**, 107021-107040 **(2023)**

37. Vallabhuni R.R., Lakshmanachari S., Avanthi G. and Vijay V., Smart cart shopping system with an RFID interface for human assistance, In 2020 3rd International Conference on Intelligent Sustainable Systems (ICISS), IEEE, 165-169 **(2020)**

38. Vilasan R.T. and Kapse V.S., Evaluation of the prediction capability of AHP and F-AHP methods in flood susceptibility mapping of Ernakulam district (India), *Natural Hazards*, **112(2)**, 1767-1793 **(2022)**

39. Vojtek M. and Vojteková J., Flood susceptibility mapping on a national scale in Slovakia using the analytical hierarchy process, *Water*, **11(2)**, 364 **(2019)**.

(Received 16th June 2024, accepted 19th July 2024)