INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI, ASSAM 781039

Department of Civil Engineering

Geohazard Science and Engineering (CE594)

SESSION 2023-2024

A MINI PROJECT REPORT

ON

"Flood Susceptibility Mapping Using AHP Method: a case study of Farrukhabad district, Uttar Pradesh, India"

Submitted by

Km Divya Gupta	234104003
Lakshmi Priya PB	234104004
G.N. Revathi	234104007
Rojalin Panda	234104008
Viplav Prakash	234104011

Under guidance of
Dr. Rishikesh Bharti
Department of Civil Engineering

Flood Susceptibility Mapping Using AHP Method: a case study of Farrukhabad district, Uttar Pradesh, India

CONTENTS

LITERATURE REVIEW

Sr no.	Authors	Findings	Remarks
1.	Ratan Kumar Samanta, Gouri Sankar Bhunia, Pravat Kumar Shit, Hamid Reza Pourghasemi	Flood susceptibility mapping using geospatial frequency ratio technique: a case study of Subarnarekha River Basin, India	1. GIS based BSA has been adopted in FR model to measure the association between the flooding and classes of each conditioning factors. 2. FR model was implemented using independent variables that were reclassified and weighted based on the bivariate probability, to produce a more precise assessment of flood susceptibility map of lower and middle catchment of Subarnarekha River (India). 3. The flood inventory map was created using the 32 (70%) flood locations that were inundated in June 2008 and this data was employed for statistical analysis. 4. The remaining 30% (14 flood locations) flooded areas were considered to validate the probability model. 5. The results indicated that the very high susceptibility to flood zones was mostly located in the south-eastern part of study area. The ROC curve was used to assess the efficiency of the ensemble method and evaluate the

			results.
2.	Amit Kumar Saha, Sonam Agra-wal	Mapping and assessment of food risk in Prayagraj district, India: a GIS and remote sensing study	1. In the case of a food situation, it is important to find the food-prone areas for emergency management. 2. Flood affecting parameters are identified, which are drainage density, elevation, flow accumulation, LULC, roughness, slope and topographic wetness index 3. The food risk mapping is performed by integrating the GIS with multi-criteria decision-making method called analytical hierarchy process (AHP) and validated by the ROC curve method. 4. Flood risk map has revealed that in the study area 701.71 km2 (12.80%) region comes under the high risk, while 1273.0 km2 (23.22.8%) region comes under the moderate risk.

Abstract

Floods pose significant threats to human lives, infrastructure, and the environment, necessitating effective mitigation strategies to reduce their impact. Flood susceptibility mapping emerges as a vital tool for flood risk management, offering proactive insights into vulnerable areas and facilitating informed decision-making processes. In this study, Farrukhabad district of Uttar Pradesh is chosen due to its proximity to ganga and its tributaries, rendering it susceptible to recurrent flood events. The district's geographical location, hydrological characteristics, and socio-economic dynamics converge to create a complex landscape of flood vulnerability, necessitating comprehensive risk assessment and mitigation strategies. Flood conditioning factors such as elevation, slope, topographical wetness index, soil type, drainage, rainfall, and LULC were considered in this study. Finally, the flood susceptibility map was prepared and classified into very low, low, moderate, high, and very high susceptibility.

Keywords: Flood susceptibility, Remote sensing, GIS.

Introduction

A flood is a natural disaster characterized by the inundation or overflow of water onto land that is usually dry. Floods can occur due to various reasons, including heavy rainfall, snowmelt, storm surges, dam failures, or the overflow of rivers, lakes, or coastal areas. They are one of the most common and widespread natural hazards, affecting communities around the world. Floods can vary in severity and duration, ranging from localized flash floods that occur suddenly and recede quickly to large-scale riverine floods that persist for days or even weeks. The impacts of floods can be devastating, affecting human lives, infrastructure, agriculture, and the environment.

Flood susceptibility mapping is a crucial component of disaster risk management, particularly in flood-prone regions like Farrukhabad district, Uttar Pradesh, India. This study employs the Analytic Hierarchy Process (AHP) method to assess flood susceptibility in the Farrukhabad district. A multi-criteria decision-making approach is utilized to integrate various factors influencing flood vulnerability, including topography, land use/land cover, soil type, rainfall intensity, and proximity to water bodies. Data for each criterion are collected from diverse sources, including satellite imagery, GIS databases, and historical records. The AHP method allows stakeholders to systematically prioritize and weight these criteria based on their relative importance in contributing to flood susceptibility. Pairwise comparisons are conducted to establish the hierarchical structure and determine the weights of each criterion.

The weighted criteria are integrated spatially using Geographic Information Systems (GIS) software to generate a composite flood susceptibility map for the Farrukhabad district. The resulting map provides valuable insights into areas at higher risk of flooding, enabling authorities to implement targeted mitigation and preparedness measures. Validation of the flood susceptibility map is performed using historical flood data and field observations to assess its accuracy and reliability. The study highlights the importance of incorporating stakeholder inputs and expertise in the decision-making process to enhance the effectiveness of flood risk management strategies.

Overall, this research contributes to the development of proactive approaches for flood risk assessment and management in Farrukhabad district, Uttar Pradesh, facilitating informed decision-making and enhancing community resilience to future flood events.

Study Area

The present study area, Farrukhabad district, is situated in the northern part of Uttar Pradesh, approximately 180 kilometres west of the state capital, Lucknow. It lies in the Ganga-Yamuna Doab region, between the Ganges and Yamuna rivers. The district's topography is characterized by flat plains with fertile alluvial soil.

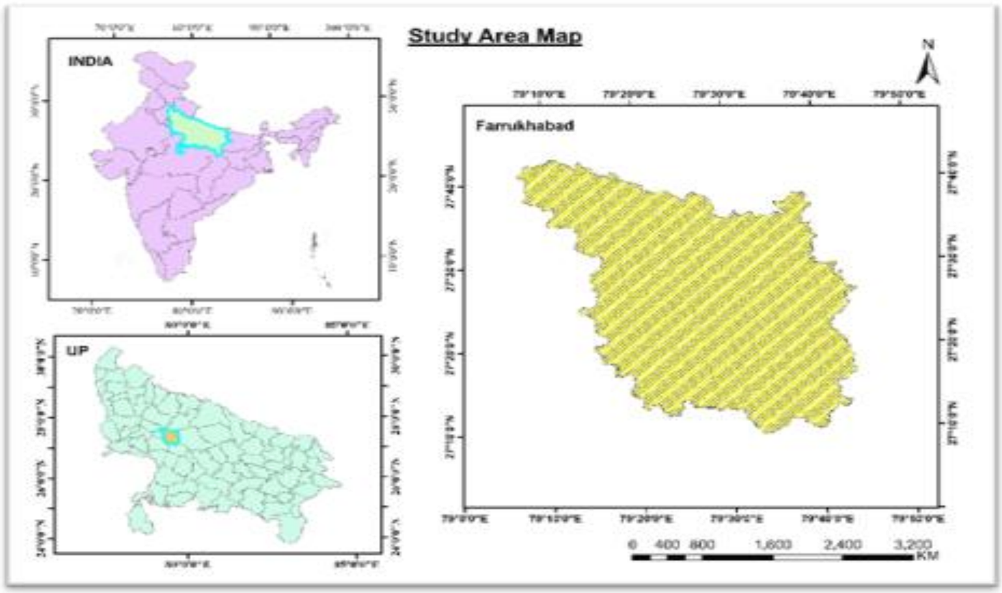


Fig 1: Study area Map (Farrukhabad, Uttar Pradesh)

It is part of the Gangetic Plain, which is one of the most agriculturally productive regions in India. The elevation in Farrukhabad district ranges from approximately 132 meters to 155 meters above sea level. Farrukhabad town is the administrative headquarters of the district and serves as a major urban centre.

Data and Methodology

Preparation of thematic layers

The methodology adopted for this study has been shown in Fig. 2 through a schematic diagram. The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM)of 90m of resolution have been downloaded from the USGS official website. The DEM has been processed in ArcGIS 10.8 software to delineate the Farrukhabad district, preparation of elevation map, slope map, and drainage map, rainfall distribution map. The drainage network and flow accumulation have been developed by using hydrology tools in ArcGIS. Landsat 7 and Landsat 8 images of Farrukhabad district have been obtained from United States Geological Survey (USGS) official website and processed in ArcGIS to make the thematic maps of different parameters.

Topographic Wetness Index is prepared in ArcGIS using DEM. Daily rainfall data have been collected from IMD. The mean rainfall distribution map has been prepared in ArcGIS. After Preparation of the thematic layers, all the layers have been converted to raster format with 90m resolution. Thereafter, the raster files have been reclassified using AHP ranks.

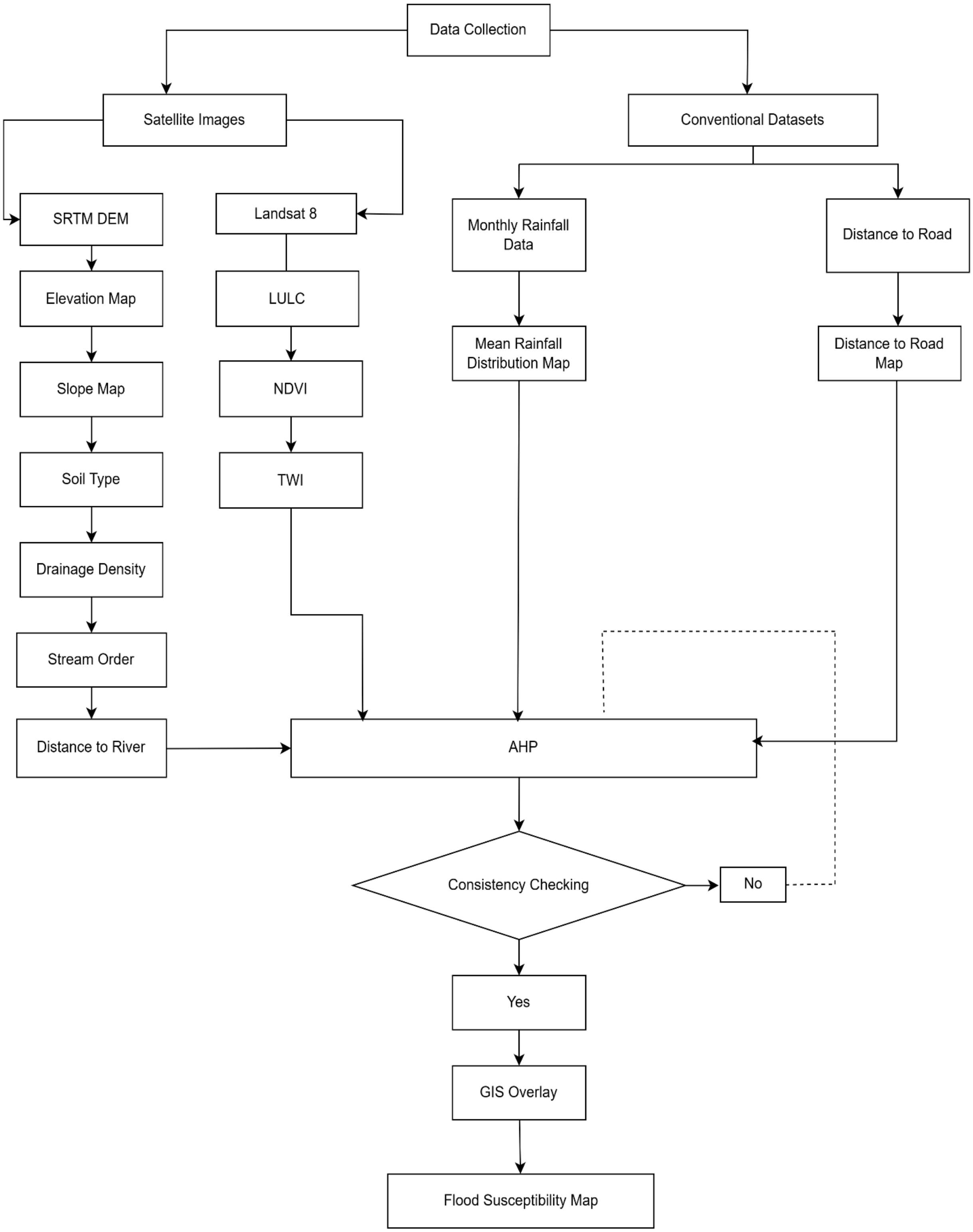


Fig 2: The methodology used for the study

Analytical hierarchy process (AHP) model

After preparation of all the thematic layers, the analytical hierarchy process model has been applied to give different weights to the parameter considered in this study. The factors controlling the flood potential of an area are TWI, Elevation, Slope, Precipitation, LULC, NDVI, Distance from river, Distance from road, Drainage density and Soil type.

The analytical the analytical hierarchy process is a very stretchy and well-structured method that has ability to decipher complex decision problems where multi-factors are involved. The AHP model has been applied to determine weights and ranks of different parameters for the flood hazard index model. The flood index model can be stated as following:

$$\mathrm{FH} = \sum_{i=1}^{n} Wi * Ri$$

where FH is the flood hazard index, Wi is the weight of each parameter, and Ri is the rank of rating of the classified values under a parameter.

The probability of flood incidence has been assessed in this study by using FH model where the final map has been categorized into five classes are very low, low, moderate, high, and very high.

The analytical hierarchy process in this paper consists of two major parts. The first section is the main classification scheme of all the parameters where according to the importance of each parameter values are given and weights are calculated (Table 1). The second section is constructed by categorizing all the parameters into subcategory (Table 2).

A pairwise comparison matrix has been built in which the diagonal elements are equal to 1 (Eq. 2). The relative importance of all these parameters is given based on different criteria and values (1. Equally important; 3. Moderately more important; 5. Strongly more important; 7. Very strong more important; 2, 4, and 6 are intermediate values). Each row of these values describes the relative importance between two parameters. For instance, the first row represents the significance of elevation with compared to other eight parameters positioned in the column. In the pairwise comparison matrix, the rows follow the inverse value of each factor and its significance with other (e.g., the elevation is little more important than the slope and distance from river; hence, the value of elevation is 1 and other two factors are 2, thus in the next row slope in having a value of ½ and so on).

After that, weighted arithmetic mean methodology has been employed to calculate the weights in the pairwise comparison matrix. The values in the pairwise comparison is normalized to acquire the normalized values in the standard pairwise comparison matrix (Eq. 2) (Table 2). Later, the weight of all the parameters is determined by mean row method in the standard pairwise comparison matrix. The maximum characteristics root can be expressed as follows:

$$Aw = \lambda maxw$$

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}}$$

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

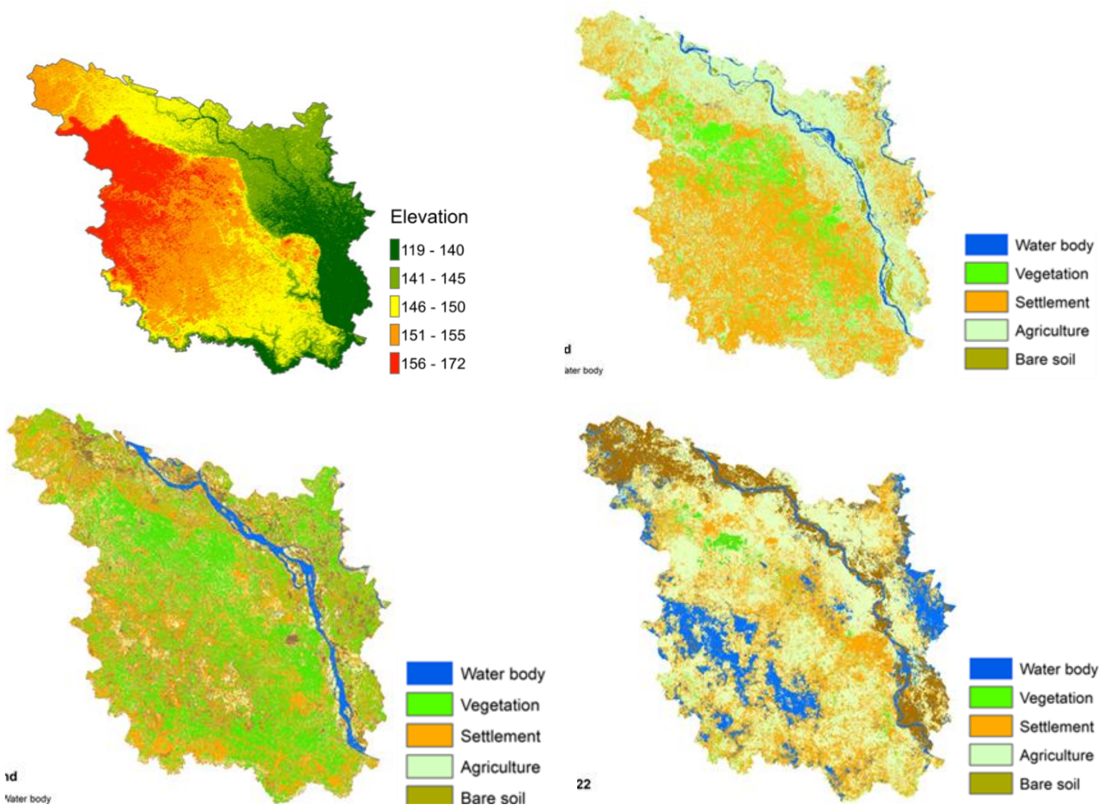
where CR represents the consistency ratio, CI stands for the consistency index, RI indicates the random index, λmax represents the principal eigenvalue of matrix, and n is the number of components or factors in the matrix.

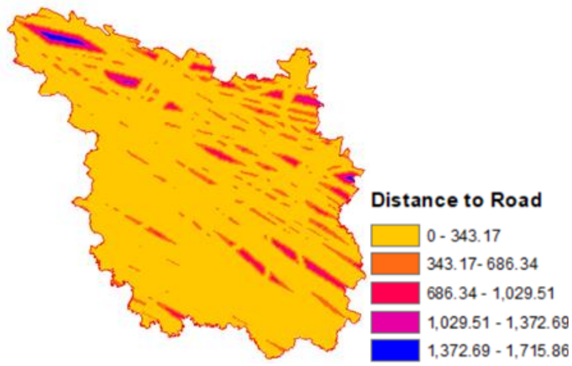
Table 1: Comparison matrix and relative score of each parameter

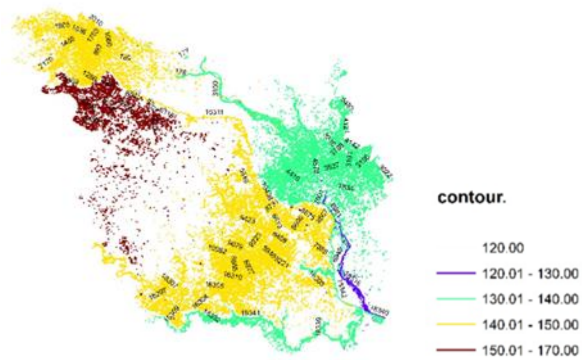
Parameter	TWI	Elevation	Slope	Precipitation	LULC	NDVI	Distance from River	Distance from Road	Drainage density	Soil type
TWI	**1**	1	1	1	3	5	1	3	1	1
Elevation	1	**1**	1	1	2	3	1	3	1	1
Slope	1	1	**1**	1	3	1	1/2	1	1	1
Precepitation	1	1	1	**1**	3	2	2	3	1	1
LULC	1/3	1/2	1/3	1/3	**1**	1	1/3	3	1	1
NDVI	1/5	1/3	1	1/2	1	**1**	1/5	1	1	1
Distance from River	1	1	2	1/2	3	5	**1**	3	1	1
Distance from Road	1/3	1/3	1	1/3	1/3	1	1/3	**1**	1	1
Drainage density	1	1	1	1	1	1	1	1	**1**	1
Soil Type	1	1	1	1	1	1	1	1	1	**1**

Results and Discussion:

Occurrence of flood depends on several topographic and climatic factors of an area. Combine assessment of those factors using modern techniques can provide a detailed picture of flood hazard vulnerable locations with different magnitudes. In this paper, a total nine topographic and climatic factors are considered to map the flood hazard map of Farrukhabad District with the help of analytical hierarchy process (AHP) model. All these factors and the results are discussed below.







Elevation

In the field of flood mapping, according to the experts' opinion, elevation of an area is the most important factor which controls the flood vulnerability Regions located in higher elevation generally have lower potentiality to be flooded, whereas low elevated regions are having higher vulnerability. Water is tending to flow towards lower region from a higher place; and therefore, lower regions with flat surface are having higher probability of flood occurrences. The variation of relief in Farrukhabad District is 119 to 172 m.

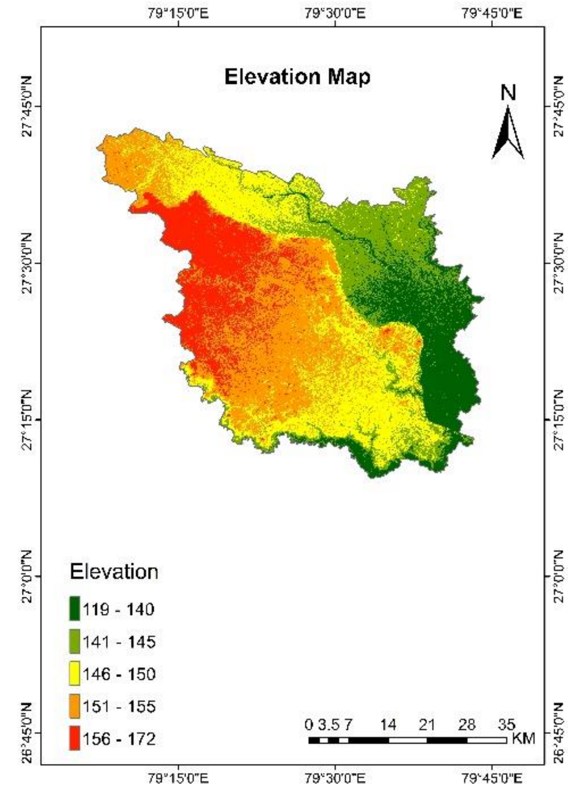


Fig. 3a: Elevation map

Slope

In hydrological study, slope plays a crucial role to regulate the flow of surface water, and it is a very important topographic factor for such studies. Slope of a channel in a region is having a direct relationship with the flow velocity. As the gradient becomes higher, the flow velocity also becomes higher. Infiltration process is also partially controlled by gradient. An increase of the gradient reduces the infiltration process but increases the surface runoff; as a result, in the regions having sudden decrease in the gradient, an enormous volume of water becomes stagnant and causes flood situation. Variation of the slope in Farrukhabad District ranges from 0° to 22° (Fig. 3b).

Distance from the stream

The occurrence of the flood concentrates alongside of the river. Hence, distance from the river in an important geomorphic factor should be considered for accurate flood mapping. As the distance increases, the slope and elevation become higher. Also, a stream is generally the lowest point of that region. As a result of this, regions far from the channel are having lower vulnerability of flood occurrence. In this paper, the distance from the river is prepared in ArcGIS software by using buffer tool multiple times by giving an interval of 0.5 km, and later, a single vector has been created and converted to the raster image (Fig. 3c)

Rainfall

Rainfall is the only source of surface water except glacial regions. Rainfall has a significant relationship with the river discharge, and it directly controls the occurrence of flood. Unexpected rainfall in an area can trigger flash flood situation in semi-arid regions. Farrukhabad District experiences a typical subtropical climate, where enormous amount of rainfall occurs only in June to September, which is known as monsoon season (Fig. 4). In Farrukhabad district, more than 85% rainfall occurs in the monsoon months.

Soil types

The soils of the study area have been categorized into Sandy-clay-loam and Sandy-silt-loam as represented in fig depending upon the different composition of sand, silt and clay in loam soil. These soils are fertile, easy to work with. The clay and silt particles improve moisture retention while the sand minimizes compaction and improves drainage.

Drainage density

The drainage data is represented in fig. The entire study area has been divided into five categories—no waterlogged/moist/very poorly drained, poorly drained, moderately well drained, well drained, and very well drained. The moderately well drained area is observed in the eastern part and some small pockets of the western part. The poorly drained areas were observed in the southern part. Very well drained areas were marked in the riverine region. Well drained areas exist in regions bordering the rivers as well as small pockets in the southwestern part.

Land use / Land cover

Land use pattern of an area reveals the type of utilization of lands by living population and the natural processes Landscape planning in urban environment has numerous benefits in associations of environment. It is crucial to envisage the changes of the land-surface over time and the effects of natural influences as well as anthropological activities. These activities are considered as triggering factors for catastrophic natural hazards. The anthropological activities, such as deforestation and urbanization have severe impact on natural hazards such as flood. Surface water flow can significantly be controlled by different types of land use; runoff of the rainwater is generally higher in case of bare rocks, whereas agricultural land or grass covers slow the water to flow and make stagnant situation. At the same time, in highly built-up regions, due to the lack of proper drainage system, flood situation can occur very frequently.

The study area is classified on seven categories of land use practices (Fig. 3f). About 1.74% of the total area in Farrukhabad District is cover by several dams and small water reservoirs, 0.49% is river channels, 28.14% is agricultural land, 40.91% is covered by natural vegetation, 13.48% is rocky outcrop, and 15.23% is covered by built-up area (Fig. 5).

NDVI

The Normalized Difference Vegetation Index (NDVI) is a metric used to gauge vegetation health and density by analysing data from the visible and near-infrared spectrum. Negative NDVI values are associated with non-vegetated surfaces like water bodies, urban areas, and barren land, contributing to heightened flood risks, especially in scenarios of deforestation or urbanization that accelerate surface runoff. Conversely, positive NDVI values indicate vegetated areas capable of absorbing rainfall and slowing surface runoff, thus mitigating flood risks by acting as natural buffers against excessive water flow. NDVI Value ranges from –0.18 to 0.55.

Topographic wetness index (TWI)

Topographic wetness index (TWI) indicates the effect of topography on runoff generation and the amount of flow accumulation at any locations in a river catchment. The formula to calculate the TWI can be expressed as follows:

OBJOBJOBJ

whereas represents specific catchment area (m2 m−1), and β indicates the local slope gradient in degree. Higher TWI regions have a higher vulnerability of flood. Inversely, the lower TWI regions have lower vulnerability. Calculation of the TWI has been carried out directly through processing of SRTM DEM (Fig. 6b)

Assessment of flood potential

The resultant flood susceptibility map exhibits values of certain range, and are categorized into five distinctive classes, using the in ArcGIS 10.3 (Fig. 7). The classes are very low, low, moderate, high, and very high probability of flood. High flood potential locations are situated on the north-eastern portion of the basin where the rivers are having a sudden change of magnitude in slope in the foot of the mountains. By contrast, regions having a higher degree of slope are less susceptible to flood. Hence, the elevation and slope play a crucial role to control the flood potentiality of an area. Zaharia et al. (2017) postulated that regions with slopes exceeding 15° do not favour the accumulation of water and the process of stagnation, whereas regions having a large cover of dense vegetation and flat surface topography favour the retention of the excess surface water during a flood.

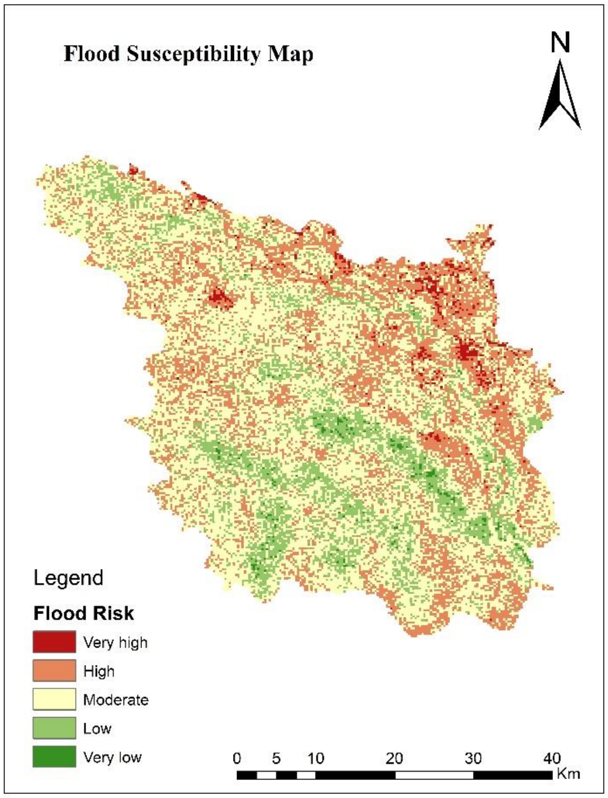


Fig 1. Flood Susceptibility map of the

About 22% area in Farrukhabad district show moderate susceptibility of flood. These locations are mostly interfluvial areas, concentrated throughout the basin, having moderate elevation and the dissected structural hilly regions in the central and western section of Farrukhabad District.

The southern section of the Farrukhabad District shows low to very low potentiality of the flood as the elevation is very high in these regions and slope is more than 40° and region is far away from the river. The Western Ghat escarpment propels the streams to have very high velocity, which cannot retain the water in such regions. Consequently, these regions show a very low probability of flood.

Moreover, the susceptibility through geospatial mapping can be improved by the selection of high-resolution spatial datasets, accurate conventional data, and an advance method to rank the factors. Field validation also improves the accuracy by comparing the results, and it will help the decision-makers and administrative bodies in achieving proper planning and management. In the resultant map, the regions having very high has been highlighted; however, the rest of the areas indicating high flood susceptibility cannot be ignored. Field work has been carried out in this study (particularly in the high flood zones) and validation is done based on communication with the nearby villagers. In addition to frequent flooding, damages to the agricultural activities are also disrupting the production of crops. The regions identified as high flood zone (HFZ) require some serious attention of the administrative bodies to prevent flood conditions in future.

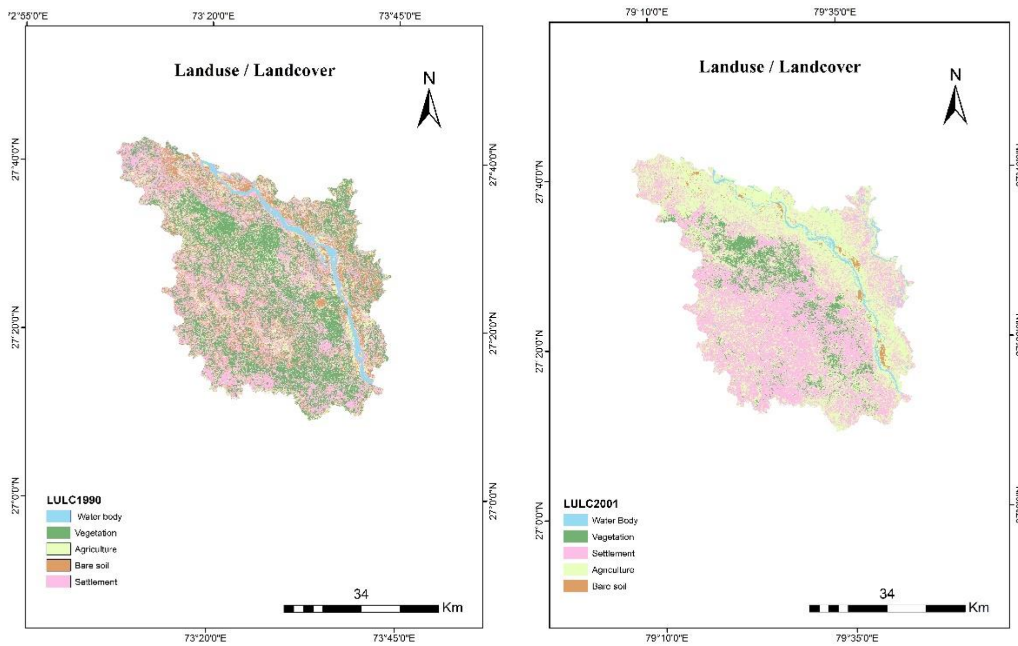
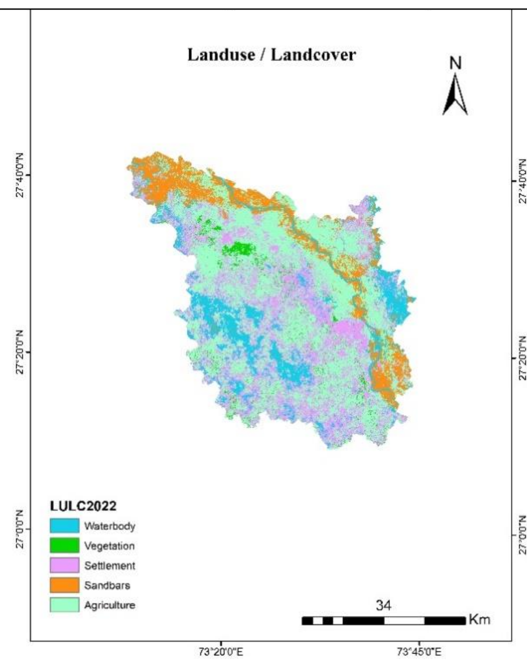


Fig 2. LULC maps of three consecutive decades



Over the years it has been observed from LULC maps that the agriculture near to the river region if increased. Vegetation has also drastically reduced. Earlier, several studies are carried out in the different places around the world to build an accurate flood susceptibility map using several decision-making tried to identify probable high flood susceptible regions by analytical hierarchy process using geospatial techniques. Similar methods are adapted by many researchers to assess hazard zonation using geospatial modelling carried out flood prediction analysis by assessment of TWI and maximum likelihood modelling. Prediction of flood using all these methods offered quite an accurate result. AHP is a simple decision-making approach based on relative importance of different factors. In the present study, it is seen that elevation and slope are the most important parameter for the assessment of flood.

In recent times, workers from different places around the world emphasized the importance of decision-making approaches through GIS techniques in flood susceptible zonation, which is very cost- and time-effective. The accuracy of the AHP technique depends on assigned weights. However, a noteworthy point is that in different studies it is observed a disparity in the weightage and ranking given for a certain parameter by different researchers. The endeavour to prepare precise flood susceptible map depends on the data availability of different parameters, their accuracy, and regional conditions.

Conclusion

Demarcation of flood susceptible regions in Farrukhabad District, Uttar Pradesh has been conducted by utilizing analytical hierarchy process (AHP) and geospatial techniques that provided a cost-effective and less time-consuming methodology. Numerous factors such as elevation, slope, distance from the river, rainfall, Drainage, land use, TWI are integrated in the ArcGIS platform. As a result, a flood susceptibility map has been produced, which shows that about 25% of the total study area is having very high probability of flood. These regions are mostly located near the south-central part of the Farrukhabad District, where a sudden change in the slope gradient is found and many small tributaries join the main river. The methodology employed in this study is having capability to serve as a recommendation for the flood management in the study area. In addition, the methodology carried out in this study can be applied to similar studies in the different part of the world.

Reference

1. Tiwari, A. K., Mishra, M., Singh, R., & Singh, G. S. (2023). Assessment of river channel dynamics and its impact on land use/land cover in the middle Ganga plain, India. [Journal Name, Volume (Issue), Page numbers].

2. Agnihotri, A. K., Ohri, A., & Mishra, S. (2019). Channel planform dynamics of lower Ramganga River, Ganga basin: GIS and remote sensing analyses. [Journal Name, Volume (Issue), Page numbers].

3. Rudra, K. (Year not provided). Dynamics of the Ganga in West Bengal, India (1764–2007): Implications for science–policy interaction. [Journal Name, Volume (Issue), Page numbers].