

Spatial Zonation of Flood Hazards Using GIS Coupled with AHP

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HIGHLIGHTS

- Flood maps are prepared for and respond to flood risks.
- GIS and AHP improve accuracy in identifying flood-prone areas.
- Supports safe land-use planning by avoiding high-risk zones.

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ABSTRACT

Floods are among the most frequent and devastating natural hazards, occurring globally except in polar regions. They pose significant threats to human life, infrastructure, and ecosystems. The increasing frequency and intensity of floods are largely attributed to climate change and anthropogenic land-use changes, which alter river morphology and exacerbate channel stress. Effective flood risk management and policy interventions are essential to minimize these impacts. This study focuses on assessing flood hazards and mapping inundation-prone areas in the Balasore district and adjacent coastal regions of Odisha, which are highly susceptible to flooding. Key flood-contributing factors considered in the analysis include slope, elevation, drainage density, annual precipitation, Normalised Difference Vegetation Index (NDVI), land use/land cover (LULC), and the Topographic Wetness Index (TWI). These parameters were integrated using a Geographic Information System (GIS) and analyzed through the Analytical Hierarchy Process (AHP) to generate a comprehensive flood hazard zonation map. The results indicate that approximately 36.50 ha, 5,073.23 ha, 27,362.54 ha, 301,622.30 ha, and 32,937.77 ha fall under very low, low, moderate, high, and very high flood hazard zones, respectively. The AHP-based GIS model demonstrated high reliability and can be replicated in other flood-prone regions for effective planning and disaster risk reduction. This approach supports proactive flood prediction, early warning systems, and sustainable flood management practices that local and national authorities can institutionalize.

1. INTRODUCTION

Flooding is a natural phenomenon within the hydrological cycle, yet it ranks among the most destructive natural disasters. It inflicts severe damage on infrastructure, disrupts communication networks, and results in the loss of lives—both human and

livestock—as well as damage to crops and agricultural land. Floods can arise from various causes, including intense rainfall, river overflow, structural failures in flood defence systems, and rapid snowmelt in mountainous regions. While flash floods typically occur in hilly terrains with little warning, other types

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of floods tend to develop gradually over several hours or days. Riverine flooding, in particular, results from heavy precipitation or snowmelt that causes rivers to breach their banks and inundate surrounding low-lying areas.

In recent years, flood hazard mapping has been significantly enhanced through the integration of Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA). These techniques have become widely used for evaluating flood risks and identifying vulnerable zones. This study focuses on Balasore district in Odisha, a region frequently affected by flooding due to the Subarnarekha and Budhabalanga rivers, which are known to trigger flash floods. The worst-hit blocks include Baliapal, Bhograi, Basta, and Jaleswar. To mitigate flood impacts, flash flood modeling and hazard zonation are crucial for identifying high-risk areas. Accurate flood hazard maps are essential tools for informed land use planning in flood-prone regions. They provide accessible visual data that enable policymakers and disaster managers to assess risk levels, prioritize interventions, and implement effective flood mitigation strategies.

The development of flood hazard maps plays a vital role in raising awareness about flood risks. These maps are essential tools for informing residents in vulnerable areas, enabling them to take precautionary measures before the onset of flash floods. Flood hazard maps are specifically designed to educate the public, local authorities, and disaster response agencies about the likelihood and potential severity of flooding events. Their primary purpose is to minimize loss of life and property, facilitate timely evacuation, and enhance community preparedness by conveying critical information about flood-prone zones.

Geographic Information Systems (GIS) are widely employed in the creation of flood hazard maps, offering an efficient means of integrating various datasets, including topographic maps and digital elevation models. By analyzing elevation data in relation to projected flood levels, GIS enables accurate delineation of inundation zones. These maps are instrumental in guiding land-use planning and development decisions by highlighting high-risk areas and helping to avoid construction in such zones. For effective implementation, flood hazard mapping must be embedded into local and regional planning frameworks.

To support decision-making in flood risk assessment, the Analytical Hierarchy Process (AHP) is often utilized. AHP is a structured mathematical

technique used to assign numerical weights to multiple criteria based on their relative importance. It supports both qualitative and quantitative evaluations, making it particularly effective for complex environmental decision problems such as flood susceptibility analysis. Through the integration of GIS and AHP, flood hazard mapping becomes a powerful tool for disaster risk reduction and sustainable development planning.

2. LITERATURE REVIEW

Sinha R et.al. (2005) Analyzed an objective to produce flood hazard map based on climate, geomorphology, hydrology for flood preparedness, and emergency response and propose an integrated flood management (IFM) that can be used to promote sustainable flood risk management measures. Geographic Information Systems (GIS) is frequently used to prepare flood hazard maps. It provides an effective way of assembling information from different maps and digital elevation models.

Drobne et.al. (2009) Examined that the synergistic role of multi-criteria decisions in geographical information systems and the use of geographical information systems in multi-attribute decision analysis. The results presented by them demonstrate the application of weighted linear combination (WLC) and ordered weighted averaging (OWA) within a GIS for the purpose of determining the most suitable locations for residential areas in the municipality. Integrated decision support tools in the GIS software system allow exploration of variety of rationales and perspectives in suitability evaluation and land allocation.

Fernández et.al. (2010) Analyzed a simple approach of urban flood hazard assessment in a region where primary data are scarce. The objectives they study are to develop a GIS-aided urban flood hazard zoning of the two cities applying multicriteria decision analysis and to evaluate it by means of uncertainty and sensitivity analysis. The research methodology focused on the analysis of those variables that control the water routing when high peak flows exceed the drainage-system capacity. The model was evaluated by the error propagation method and global sensitivity analysis to assess the uncertainty and the relative importance of model input factors.

Magesh NS et.al. (2012) examined the various groundwater potential zones for the assessment of groundwater availability in Theni district have been delineated using remote sensing and GIS techniques. Integration of remote sensing data and the

geographical information system (GIS) for the exploration of groundwater resources.

3. STUDY AREA

Balasore is a city in the state of Odisha, in Eastern India about 194 km north of the state capital of Bhubaneswar. It is the biggest city of North Odisha.

It is bounded by longitude 86°92'96" E and latitude 21°48'69" N, respectively. The city has the Bay of Bengal in the east and West Bengal in the north. Balasore has a field of 3076 km². Subarnarekha and Budhabalanga are two important rivers of Odisha that also pass through the Balasore district (Fig. 1). Broad irrigation is also present in the Balasore district.

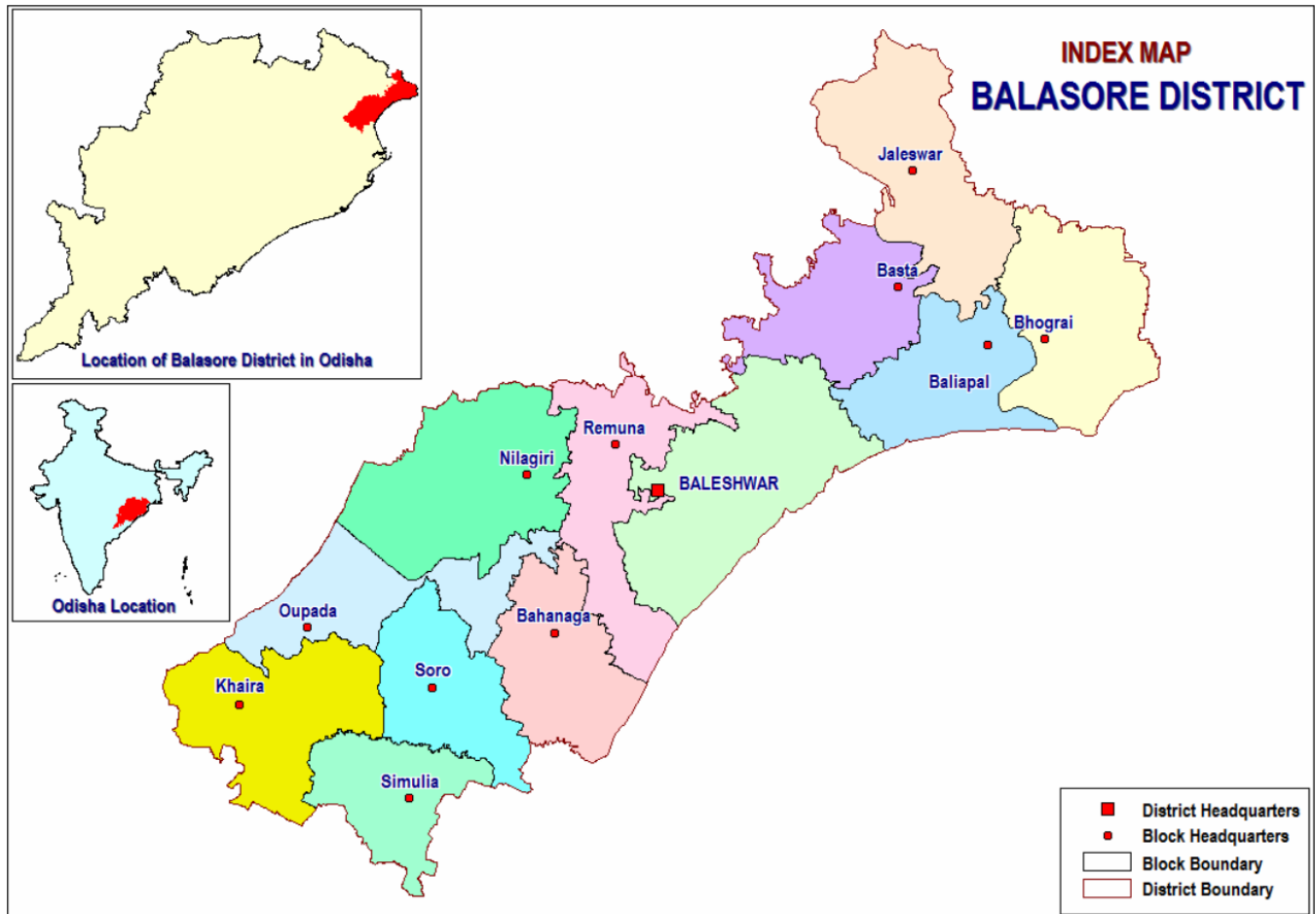


Figure 1. Study area

4. METHODOLOGY

A Geographic Information System (GIS) is a computer grounded system for checking, landing, storing, and displaying data related to positions on earth's face. GIS can show different kinds of data on one chart, similar as thoroughfares, structure and vegetation. This enables people to more fluently see, dissect, and understand patterns and connection. Information is now a valuable asset a commodity which can be bought and vended for a high price. Information and its communication is one of the key development processes and characteristics of contemporary societies. The relationship between GIS and computer-backed design, computer cartography, database management and remote seeing information

systems is important in establishing a description of GIS.

4.1 Analytical Hierarchy Process (AHP) Model

After preparation of all the thematic layers, the analytical hierarchy. Process model has been applied to give different weights/result to the parameter considered in this study. The flood potential of an area are controlled by elevation, slope, rainfall, land use land cover, drainage density, TWI & NDVI. The analytical hierarchy process (AHP) is a well-structured and very stretchy method that has ability to decode complex decision problems where multi-factors are involved. The AHP model has been applied to determine weights or results and ranks of different parameters for the flood hazard index model.

The Analytic Hierarchy Process (AHP), developed by Saaty [13], is a methodology crafted to tackle intricate issues that encompass numerous criteria. It utilizes mathematical techniques to assess decisions by taking into account the preferences of individuals or groups within a specific context, guided by chosen variables. AHP bridges the gap between the necessity for practical solutions and the rigor of scientific decision-making, offering a way to merge qualitative and quantitative assessments. This

fusion facilitates an efficient and effective strategy for navigating complex dilemmas. Implementing the AHP method unfolds through a five-step process, which includes: defining the issue and pinpointing the relevant factors; assigning values to these factors using the AHP scale; constructing the pairwise comparison matrix (Table 1); determining the relative importance of each factor; and assessing the consistency ratio (CR) to ensure the reliability of the analysis.

Table 1. Pair-wise comparison of factors influencing flood.

Factor	Slope	Elevation	Drainage Density	NDVI	Rainfall	TWI	LULC
Slope	1.00	2.00	3.00	3.00	5.00	7.00	9.00
Elevation	1/2	1.00	2.00	3.00	5.00	7.00	9.00
Drainage density	1/3	1/2	1.00	2.00	3.00	5.00	7.00
NDVI	1/3	1/3	1/2	1.00	3.00	5.00	7.00
Rainfall	1/5	1/5	1/3	1/3	1.00	3.00	5.00
TWI	1/7	1/7	1/5	1/5	1/3	1.00	3.00
LULC	1/9	1/9	1/7	1/7	1/5	1/3	1.00
Sum	2.62	4.29	7.18	9.68	17.34	28.20	41.00

Pairwise Comparison Matrix: This matrix uses numerical values based on the AHP scale to show the relative importance of the elements (see Table 1). Equation 1 is utilized in order to create a pairwise comparison matrix.

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \tag{Eq 1}$$

Two factors are compared in the equation. A value between 1 and 9 should be assigned if a factor value in the row has a higher weight than another factor in the column. Conversely, if a factor in the column has a lower weight than another, its value should be assigned between 1/2 and 1/9, and the cross parameters should naturally equal 1.

AHP values for every parameter Following the pairwise matrix's generation, the matrix must be normalized using Equations 2 and 3.

Evaluation of Consistency: To ensure that the comparisons are consistent, the consistency ratio (CR) is computed. The matrix is deemed consistent if the CI value is zero. Additionally, a pairwise comparison matrix exhibiting a CR of less than 0.1 indicates a decent degree of consistency, while a CR of more than 0.1 suggests inconsistent evaluations.

Equations 5 and 6 indicate that the CR value is the product of the CR value over the RI value.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{Eq 2}$$

$$CR = \frac{CI}{Random\ Index(RI)} \tag{Eq 3}$$

where, λ_{max} denotes the largest Eigenvalue acquired from the pairwise matrix, while "n" signifies the count of parameters. Furthermore, "RI" stands for the random index, which varies according to the matrix's dimensions (refer to Table 2). We opted for a value of 1.12 for RI based on our parameter count.

Table 2. Random Index (RI)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

5. RESULTS AND DISCUSSION

5.1 Slope

Lower slope values represented flatter topography that was especially valuable to flooding, where higher slope value represented steeper topography that was less vulnerable to flooding. Here slope is categorized into five classes based on its impact on flood risk i, e. very low (0-2.12), low (2.13-8.82), moderate (8.83-20.80), high (20.9051.10), very high (51.20-90) (Fig. 2).

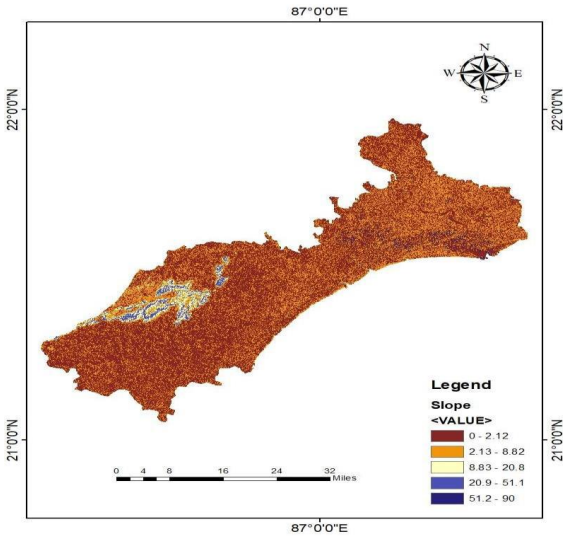


Figure 2. Slope map

5.2 Elevation

The lower below the base flood elevation a building/property sits, the advanced the flood risk. The DEM of resolution 10x10 is obtained from USGS site to determine elevation. Here elevation is categorized into five classes based on its impact on flood risk i.e. very low (0-91), low (91.10-237), moderate (238-421), high (422-696), very high (697-65,500) (Fig. 3).

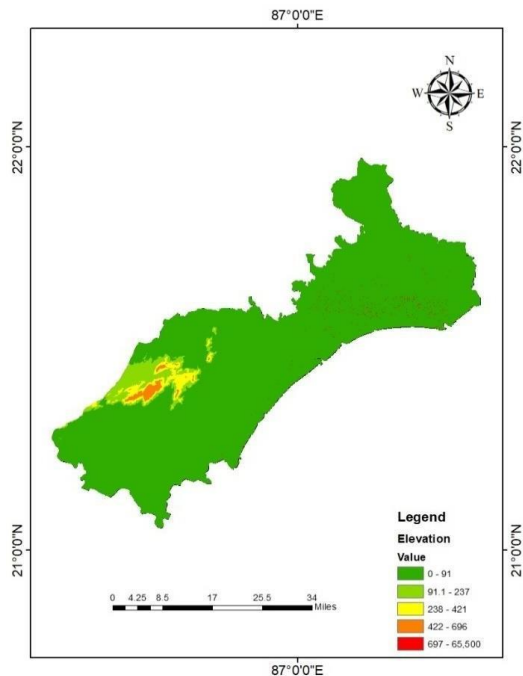


Figure 3. Elevation map

5.3 Drainage Density

The viscosity of drainage is a major factor impacting flood hazard. The drainage system that develops in an area is entirely dependent on the pitch, the type of bedrock and the regional and original

fracture pattern. Here slope is categorized into five classes based on its impact on flood risk i.e. very high (151-212), high (127-150), moderate (102-127), low (68.10-101), very low (3.40-68) (Fig. 4).

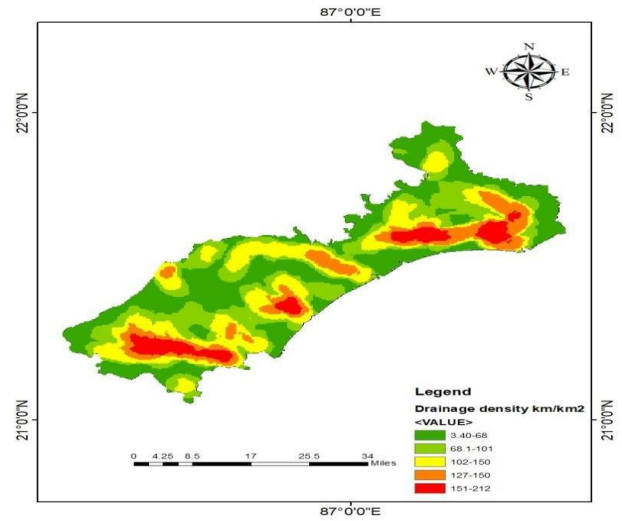


Figure 4. Drainage density map

5.4 Rainfall

The precipitation data is collected from IMD. Here rainfall is categorized into five classes based on its impact on flood risk i.e. very high (1890- 1940), high (1860-1890), moderate (1820-1860), low (1780-1820), very low (1730-1780) (Fig. 5).

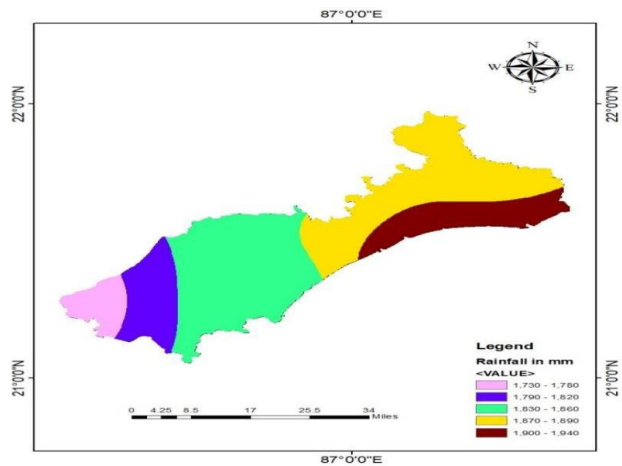


Figure 5. Rainfall map

5.5 Land Use Land Cover (LULC)

Reforestation can foster localized cooling while in civil areas continued warming is anticipated to complicate urban heat island goods. The landsat8 data of 10x10 resolution is obtained from the USGS site to check the land use land cover of Balasore. Here LULC is categorized into five classes i.e. water body, vegetation, open land, built-up area, shrub land (Fig. 6).

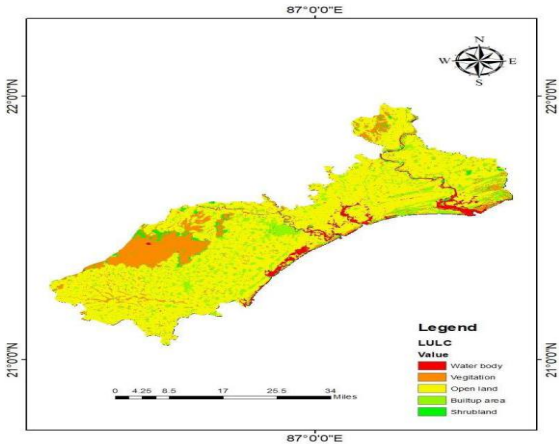


Figure 6. LULC map

5.6 Normalize Difference Vegetation Index (NDVI)

NDVI has negative relationship with flooding advanced NDVI values indicate lower probability flood and lower NDVI values indicate advanced flood probability. Every time flood claims hundreds of mortal lives and cause damage to the worldwide economy and environment. Accordingly, the identification of flood vulnerable areas is important for comprehensive flood risk management. To calculate NDVI of the study area the data is collected from USGS site of DEM 10x10 resolution attained from SRTM. Here the minimum value of NDVI is -0.28 and the maximum value 0.25 (Fig. 7).

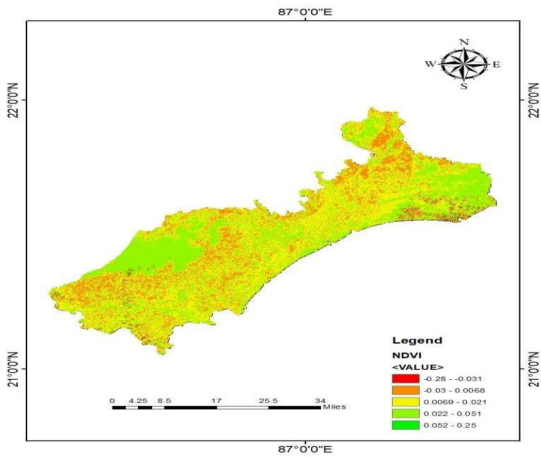


Figure 7. NDVI map

5.7 Topographic Wetness Index

The Topographic Wetness Index (TWI) can be determined as an indispensable to the traditional approach of delineating flood-prone areas using silhouettes alone. The TWI provides a further cost-effective approach to flood determination than conventional hydrodynamic models. This data is collected from USGS site of DEM 10x10 resolution attained from SRTM. The minimum value of TWI is -

15.30 to -8.90 and maximum value 2.41 to 12.70 (Fig. 8).

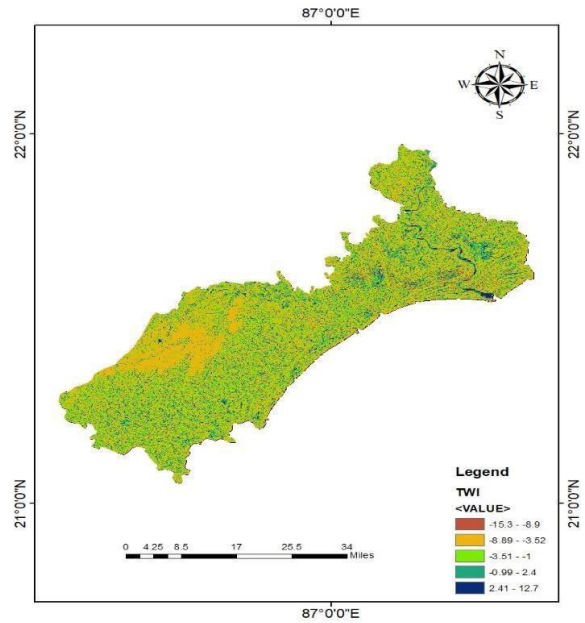


Figure 8. TWI map

5.8 Validation of the Flood Hazard Map

Model validation is the process of systematically comparing model outputs to independent real-world observations in order to assess quantitative and qualitative concordance with reality. Many models are used by researchers to assess flood hazard in various parts of the world, but it is critical to test the model's outputs to ensure that the model adequately represents the actual ground conditions or recorded observations. By comparing model output to observable data, model calibration and validation can be accomplished (Fig. 10). To validate Balasore flood hazard map results, the locations of historical flood occurrences and flood spots were superimposed on Google Earth Engine (Fig. 9).

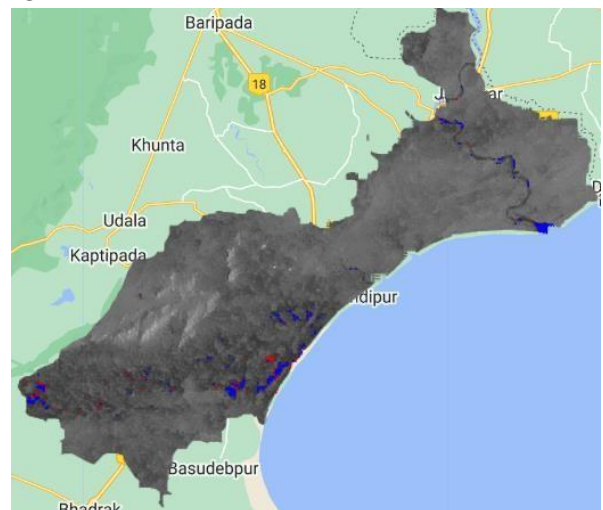


Figure 9. Validation map in Google Earth Engine

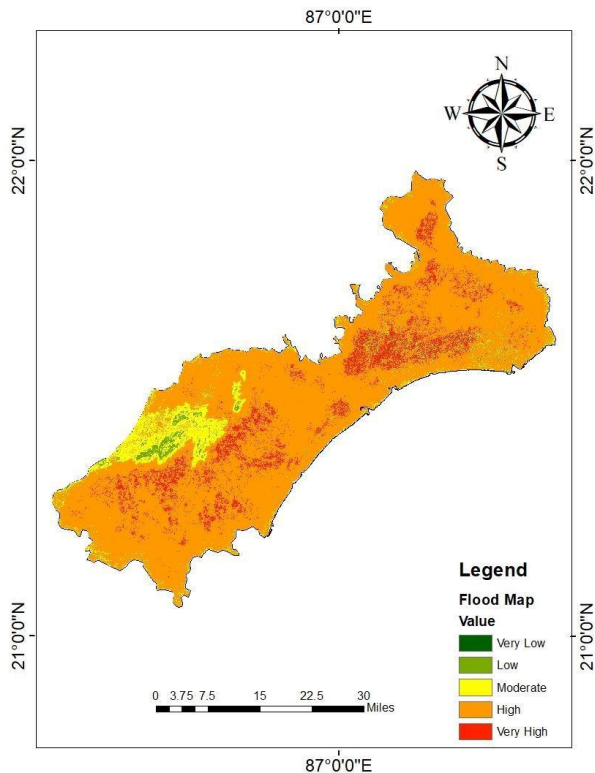


Figure 10. Final flood hazard map

6. CONCLUSION

Floods significantly impact human life, infrastructure, and environmental resources. While floods cannot be entirely prevented, flood simulation and risk assessment are essential tools for minimizing their damage and guiding effective planning. Identifying flood-prone areas is a key component of any flood management strategy. In this study, a multi-criteria evaluation approach was applied to assess flood susceptibility in Balasore district. Seven key input parameters were used to generate thematic layers: slope, elevation, drainage density, annual precipitation, NDVI, land use/land cover (LULC), and the Topographic Wetness Index (TWI). These datasets were analyzed using the Analytical Hierarchy Process (AHP) and processed within a Geographic Information System (GIS) framework to produce a flood hazard map. The results were validated using historical flood data with the help of Google Earth Engine. The flood hazard model categorized the district's land area into five risk zones: very low (13.57%), low (20.71%), moderate (19.02%), high (30.39%), and very high (26.36%) flood risk. The GIS-based approach proved effective in delineating vulnerable zones, offering a valuable foundation for flood preparedness and mitigation. The study also demonstrates that multi-criteria analysis techniques can assist local authorities and planning agencies in accurately identifying flood-prone regions and implementing targeted flood control measures to reduce future impact.

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