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GIS-Based Flood Risk Assessment Using DEM-Derived Hydrological Indices with Mitigation Measures

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Abstract

Flooding is a recurring natural hazard in the Krishna River basin of Maharashtra, leading to considerable damage to human settlements, agricultural land, and infrastructure. Therefore, identifying flood-prone areas effectively is essential for developing suitable mitigation strategies. The current study uses Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data processed in ArcGIS 10.8 to evaluate flood risk and propose flood mitigation strategies using a GIS-based terrain analysis approach. To extract topographic and hydrological parameters such as slope, flow direction, flow accumulation, topographic wetness index (TWI) and stream power index (SPI) were derived from digital elevation model. These parameters were used to understand patterns of water accumulation and flow velocity across the river basin. The results show that low-lying downstream areas and river floodplains are more vulnerable to flooding than areas with gentle slopes, high flow accumulation, elevated TWI, and high SPI values. The analysis highlights the importance of TWI in identifying zones at risk of extended saturation and waterlogging, even when SPI is successful in identifying active flood paths and locations of intense flow energy. The spatial analysis of these indices led to the proposal of both structural and non-structural flood mitigation strategies. The study demonstrates that DEM-based hydrological analysis using GIS provides a reliable and user-friendly framework for flood risk assessment and mitigation planning.

Keywords: DEM, Flood, GIS, Mitigation, SPI, STRM, TWI

1. Introduction

In many parts of India, flooding is a constant natural disaster that significantly affects infrastructure, agriculture, and settlements, particularly during the monsoon season. One such area is the Krishna River basin in Maharashtra, where floods are common because of heavy rainfall, complicated topography, and growing human activity along riverbanks and floodplains. The vulnerability of this basin and the need for improved knowledge of flood-prone areas and mitigation planning have been made clearly noticeable by recent severe floods [1]. Surface features including drainage patterns, slope, and the capacity of the land to store or transfer water play a important role in determining flood behavior in a river basin. The complete hydrological data required for complex flood modelling is frequently difficult to get, particularly for large river basins. Because of this limitation, GIS-based terrain analysis using digital elevation models has become a practical and reliable way to understand flood processes at the regional level [2].

Important hydrological data, such as flow accumulation and flow direction which describe how water moves across the landscape, can be extracted using digital elevation models. Zones of concentrated and strong flow are highlighted by the stream power index, while indices like the topographic wetness index assist in identifying locations where water tends to accumulate and stay for longer durations. When combined, these indices offer important information for assessing flood risk [3].

The present study uses processed SRTM DEM data to apply a GIS-based topography analysis to the Krishna River basin in Maharashtra. To determine flood-prone areas, important topographic and hydrological characteristics such as slope, flow direction, flow accumulation, TWI, and SPI were calculated. The study also recommends appropriate structural and non-structural flood mitigation strategies that can enable efficient flood risk management and planning based on this spatial understanding.

2. Study Area

The study area includes the whole Krishna river basin in Maharashtra, which is a river system that is prone to flooding in the area. A significant river, the Krishna River rises in the Western Ghats close to Mahabaleshwar and flows eastward across the Plateau before entering the state of Karnataka. Geographically, the basin is separated by around 73°30′ E to 75°30′ E longitude and 17°00′ N to 18°30′ N latitude. The change in elevation and slope has a major impact on flood inundation patterns, runoff generation, and flow buildup. The lower parts of the basin, particularly those around Sangli city and the surrounding floodplains, are particularly susceptible to flooding due to their shallow channel gradient, low elevation, and density to the main river course [4]. In the tropical monsoon climate of the Krishna River basin, the majority of the yearly rainfall occurs during the Southwest Monsoon season, which runs from June to September. Geographical factors in the Western Ghats result in heavy rainfall in upstream regions and moderate to low rainfall in downstream areas. Intense monsoon precipitation combined with both managed and uncontrolled releases from upstream reservoirs frequently causes flood occurrences, as demonstrated by major floods like those in 2005 and 2019 [5]. Figure 1 shows the study area location.

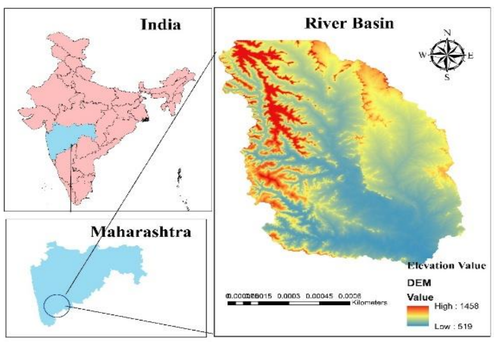

Figure 1. Study Area Location

3. Methodology

The present study employs a GIS-based terrain analysis approach to understand flood risk assessment. The analysis is carried out using Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data, which provides essential information on the surface characteristics of the basin. From the processed DEM, key topographic and hydrological parameters such as slope, flow direction, flow accumulation, Topographic Wetness Index (TWI) and Stream Power Index (SPI) were derived. These parameters collectively help in explaining how surface water moves, accumulates, and concentrates across the landscape, thereby influencing flood occurrence. The overall methodological workflow adopted in this study is presented in Figure 2.

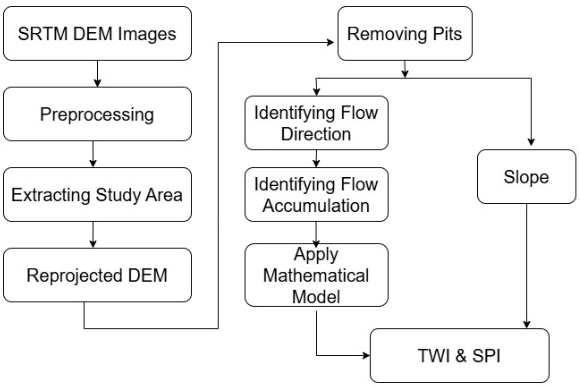

Figure 2. Adopted methodology

3.1 SRTM DEM Images and Preprocessing

SRTM DEM data having 30 m resolution were used as the primary source of elevation information for this study. The preprocessing involved removing pits and removing noise present in the elevation surface, followed by clipping the dataset to the river basin within Maharashtra. After processing, the DEM was reprojected into a projected coordinate system for WGS1984, UTM Zone 43N [6].

3.2 Removing Pits

Pit-filling was used to rectify incorrect depressions and sinks in the DEM in order to appropriately depict surface runoff. This ensured precise estimation of flow direction and flow accumulation as well as continuous flow paths. The revised DEM was then used for additional topographical and hydrological research [7].

3.3 Flow Direction and Flow Accumulation

In order to better understand how water travels across the surface, flow direction was derived from the revised DEM. Each grid cell is given a flow path in the direction of the downward slope by the analysis. Using this information, flow accumulation was calculated to identify the points where water from upstream meets downstream. Increased runoff areas and flowing drainage lines, which are essential for identifying flood pathways, are displayed as high flow accumulation cells [8].

3.4 Slope

Slope has a significant role in controlling how fast water flows over the surface and how much water infiltrates into the ground. Slope was derived from the revised DEM to understand the steepness of the terrain across the basin. Steep slopes tend to generate faster runoff, while gentle slopes allow water to accumulate and spread, increasing flood risk. The slope information was later combined with other hydrological indices to identify flood-prone areas [9].

3.5 Topographic Wetness Index

TWI is a terrain-based hydrological index that particularly useful for identifying flood prone locations and wet areas. It incorporates the influence of slope and upstream contributing area. To evaluate the spatial variance in surface saturation and possible water accumulation throughout the study area [10], the Topographic Wetness Index (TWI) was calculated.

Mathematical Formula:

1. t1 = (Slope * 1.570796)/90 (1)

2. t2 = Con (t1 >0, tan (t1),0.001) (2)

3. t3 = (Flow_Accumulation + 1) * cellSize) (3)

4. TWI = ln(t3/t2) (4)

3.6 Stream Power Index

Stream power index is a terrain-based hydrological indicator that incorporates the impact of slope and upstream contributing area. It is especially helpful for locating areas with concentrated flow and high runoff intensity, which are crucial for the creation and spread of floods. The study area's geographical distribution of flow energy and erosive potential was assessed using the Stream Power Index (SPI) [11]. The SRTM DEM was used to create flow direction and flow accumulation grids.

Mathematical Formula:

SPI = ln ("Flow_Accumulation" + 0.001) * (("Slopein%"/100) + 0.001) (5)

4. Result and Discussion

A Geographic Information System has been used to extract slope, topographic wetness index, and stream power index from SRTM DEM Data.

4.1 Slope Characteristics

The Krishna River basin in Maharashtra has notable spatial variation, according to the slope analysis obtained from the SRTM DEM. In contrast to the central and eastern parts of the basin, which have broad low-relief topography and mild slopes, steep slopes are primarily found in the western upstream regions close to the Western Ghats. These gently sloping regions increase surface water retention and decrease runoff velocity, making them more vulnerable to flooding, especially during the height of the monsoon [12]. The study region and other downstream floodplains are known for their low-gradient topography, which encourages extensive flooding.

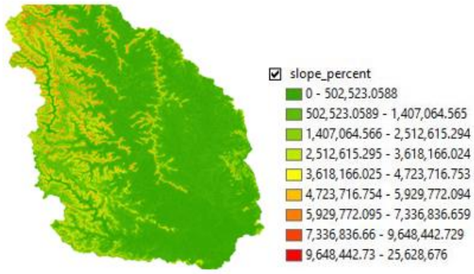

Figure 3. Slope

The map is divided into slope categories, each of which is represented by a color gradient from green to red. Higher slope values are shown by yellow to red, signifying moderately steep to extremely steep terrain, while lower slope values are exhibited in shades of green, indicating gently sloping to almost level terrain. Low to moderate slope classes (green shades) make up a significant percentage of the basin, especially in the central and downstream areas. Because of the soft terrain in these locations, surface runoff is slowed down and water accumulation occurs.

4.2 Topographic Wetness Index

The Topographic Wetness Index (TWI) map demonstrates the spatial variations in the surface saturation of the study area. Higher TWI values are primarily located along drainage lines, river channels and low-lying areas of the basin. During rainfall, these areas' mild slopes and high flow accumulation promote surface saturation and prolonged water retention. Low TWI values are typically seen in uplands and steep slopes where rapid drainage prevents long-term water storage. [13]. The distribution of TWI values makes it evident that areas with high TWI are more vulnerable to waterlogging and flooding, especially when low slope and high flow accumulation are present.

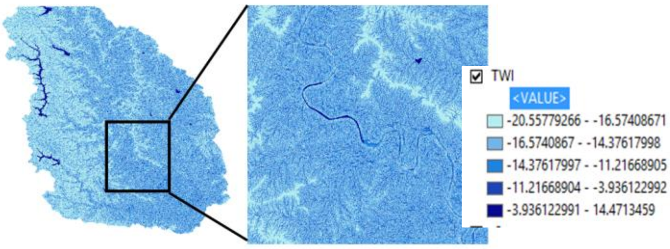

Figure 3. Topographic Wetness Index

Table 1. Computed Topographic Wetness Index

Sr. No.	Variable	Computed Value (Low)	Computed Value (High)
1	t1	0	1.57079
2	t2	0.001	235415
3	t3	0.000277778	3673.25

4.3 Stream Power Index

The SPI values in the study area range from low (−1.77) to high (1.85), with increasing SPI indicating greater flow concentration and erosive potential. When interpreted together with slope and TWI, areas exhibiting high SPI act as runoff-contributing and flow-accelerating zones, while downstream regions with lower slopes and higher TWI experience water accumulation and flood inundation [14]. This integrated interpretation provides a comprehensive understanding of flood dynamics and supports targeted flood mitigation measures.

Table 2. Computed Topographic Wetness Index

Sr. No.	Variable	Computed Value (Low)	Computed Value (High)
1	SPI	-1.7703	1.8450

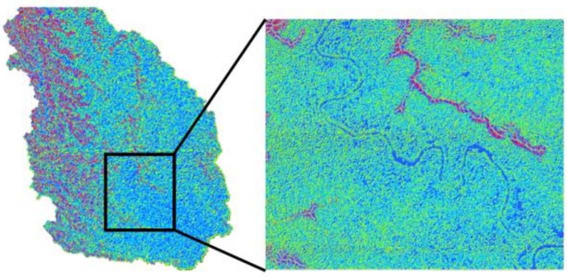

Figure 4. Stream Power Index

4.4 Integrated Identification of Flood-Prone Areas

Through the combined interpretation of slope, flow accumulation, TWI and SPI layers, flood-prone locations within the river basin were identified. Areas with high flow accumulation, higher TWI, high SPI and moderate slopes were categorized as very vulnerable to flooding. The Krishna River floodplain and downstream areas of the basin, especially in and around Sangli district, are where these conditions are most frequently seen.

5. GIS-Based Flood Mitigation Strategies

Based on the geographic features of the identified flood-prone areas, suitable flood mitigation strategies were proposed using a GIS-based decision-support system. In order to address both physical flood processes and planning-level interventions, the mitigation techniques were divided into structural and non-structural strategies [15].

5.1 Structural Flood Mitigation Measures

Structural flood mitigation techniques were proposed based on the spatial characteristics of flood-prone areas identified by slope, flow accumulation, TWI, and SPI analysis. To reduce the risk of river overtopping and protect nearby communities and agricultural regions, measures like embankments and levees are recommended in river segments with high flow concentration and enhanced stream power. In low-lying areas with high wetness and gentle slopes, storage and drainage basins can help temporarily store extra floodwater and reduce downstream flood peaks. Channel improvement and elimination are advised in urban and rural settings where reduced drainage capacity increases the intensity of floods. Furthermore, minor storage facilities and check dams in tributary areas upstream can assist regulate runoff, reduce flow energy and reduce the flooding in floodplains downstream [16].

5.2 Non-Structural Flood Mitigation Measures

Non-structural flood mitigation techniques are essential for long-term flood risk reduction and sustainable river basin management. Land-use restrictions and floodplain zoning are particularly important in areas with low elevation and high TWI values. Authorities can control unwanted growth in these areas with the aid of GIS-based flood vulnerability maps.

While satellite-based observations and rainfall criteria enable prompt flood alerts, rainfall monitoring when combined with SPI-dominant stream networks may improve early warning systems by detecting potential flood starting zones. To reduce waterlogging and shorten the length of floods, high TWI zones should be given priority in drainage planning in urban areas [17]. Furthermore, GIS-based identification of safe shelters, evacuation routes and high-risk settlements can greatly improve community readiness particularly in downstream flood-prone areas.

6. Conclusion

This study shows how areas in the Krishna river basin in Maharashtra that are susceptible to flooding can be identified using GIS-based terrain analysis. Hydrological measures like slope, flow direction, flow accumulation, topographic Wetness Index (TWI), and Stream Power Index (SPI) were computed using SRTM DEM data to understand runoff behavior and predict flood risk. It was discovered that locations with significant flow accumulation, elevated TWI, high SPI, and gentle slopes were more susceptible to flooding, especially along river floodplains and low-lying downstream areas. The results show the value of DEM-based indices as an effective approach to flood assessment and help in the planning of both structural and non-structural flood mitigation strategies.

References

1. M. L. Mulla, "Socio-Environmental Impacts of Flood Disaster on Agricultural and Common People Related Activities in Krishna River Basin," International Journal for Research in Applied Science and Engineering Technology, vol. 8, no. 8, pp. 1009–1013, 2020, doi: 10.22214/ijraset.2020.31083.
2. S. K. Patil, A. S. Sajane, and A. S. Ingale, "Technical Investigation By Using Gis for Flood Condition Arisen in Upper Krishna Basin, Maharashtra, India," no. November, 2023.
3. S. B. Kore, "Flood Risk Analysis of Upper Krishna Sub-Basin using GIS," International Journal for Research in Applied Science and Engineering Technology, vol. 10, no. 7, pp. 3319–3320, 2022, doi: 10.22214/ijraset.2022.45701.
4. C. N. Kale, "Causes of floods in upper Krishna Basin of Maharashtra," Nature Environment and Pollution Technology, vol. 8, no. 2, pp. 287–295, 2009.
5. B. D. P. A. A. Lole and S. B. P. S. B. Kore, "Flood Analysis of Krishna River at Sangli (MS) Sanjay Ghodawat Group of Institutions , Atigire-416118 , Maharashtra , India," vol. 6, no. 02, pp. 1917–1918, 2018.
6. E. Feloni, I. Mousadis, and E. Baltas, "Flood vulnerability assessment using a GIS-based multi-criteria approach—The case of Attica region," *Journal of Flood Risk Management*, vol. 13, no. S1, pp. 1–15, 2020, doi: 10.1111/jfr3.12563.
7. S. S. Alarifi, M. Abdelkareem, F. Abdalla, and M. Alotaibi, "Flash Flood Hazard Mapping Using Remote Sensing and GIS Techniques in Southwestern Saudi Arabia," *Sustainability (Switzerland)*, vol. 14, no. 21, 2022, doi: 10.3390/su142114145.
8. S. S. Deepika, C. Dandu, R. Kavala, and D. B. Kumar, "Hydrological Inferences from Watershed Analysis using Remote Sensing & GIS," *International Journal of Creative Research Thoughts*, vol. 6, no. 2, pp. 2320–2882, 2018, [Online]. Available: www.ijcrt.orgwww.ijcrt.org.
9. P. K. Arya and A. Kumar, "Application of hydrological indices in developing erosional hazard vulnerability map in parts of the Gandak River Basin , Bihar," vol. 11, no. 3, pp. 135–148, 2024.
10. M. Rizalihadi, E. Meilianda, A. Yulianur, and Y. Away, "Identification of spatial potential flood-prone area using topographic wetness index under the digital elevation model of Kr. Keureuto watershed, North Aceh.," Journal of Physics: Conference Series, vol. 2916, no. 1, 2024, doi: 10.1088/1742-6596/2916/1/012009.

11. A. Krishnan et al., “Flood susceptibility mapping in Kali River Basin, Southern India: A GIS-based analytical hierarchy process modelling,” Results in Earth Sciences, vol. 3, no. February, p. 100079, 2025, doi: 10.1016/j.rines.2025.100079.
12. S. K. Sharma, Y. J. Kwak, R. Kumar, and B. Sarma, “Analysis of hydrological sensitivity for flood risk assessment,” ISPRS International Journal of Geo-Information, vol. 7, no. 2, 2018, doi: 10.3390/ijgi7020051.
13. K. A. Ali, “Geospatial Hydrological Analysis in GIS Environment for Selecting Potential Water Harvest Sites: The Case of Badrah –Wasit,” Journal of University of Babylon for Engineering Sciences, vol. 26, no. 2, pp. 328–337, 2018, doi: 10.29196/jub.v26i2.574.
14. C. S. Dwivedi, Dishant, B. R. Parida, A. C. Pandey, R. Kumar, and N. Kumar, “Geoinformatics-Based Mapping of Environmental Sensitive Areas for Desertification over Satara and Sangli Districts of Maharashtra, India,” GeoHazards, vol. 5, no. 2, pp. 415–440, 2024, doi: 10.3390/geohazards5020022.
15. S. Katla, P. R. Saxena, and N. Kota, “Hydrological and surface analysis using remote sensing & GIS techniques in parts of Nalgonda district , Telangana , India,” vol. 3, pp. 1272–1276, 2017.
16. K., Patil Suraj, S. S. Amitkumar, and S. I. Appasaheb, “Water Resources Development and Causes of Flood Blossoming in Upper Krishna River Basin,” International Journal of Application or Innovation in Engineering & Management (IJAIEM, vol. 10, no. 7, 2021.
17. N. I. Saikh and P. Mondal, “GIS-based machine learning algorithm for flood susceptibility analysis in the Pagla river basin, Eastern India,” *Natural Hazards Research*, vol. 3, no. 3, pp. 420–436, 2023, doi: 10.1016/j.nhres.2023.05.004.