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FLOOD ESTIMATION USING ARCGIS: A CASE STUDY OF KOLHAPUR DISTRICT, MAHARASHTRA, INDIA

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Abstract: Flood estimation is a crucial task for effective water resource management and disaster preparedness. This study focuses on flood estimation in the Kolhapur district using ArcGIS, a geographic information system software. The Kolhapur district, located in India, experiences regular flooding events, leading to significant socio-economic and environmental impacts. Accurate estimation of flood characteristics such as peak flow and flood extent is essential for developing reliable flood forecasting models and designing appropriate mitigation measures. ArcGIS provides powerful tools and functionalities for flood estimation by integrating various data sources such as digital elevation models, rainfall data, and river network information. This study uses these capabilities to analyze the spatial and transient flood patterns of floods in Kolhapur district. Key steps include preprocessing of input data, hydrological modeling, model calibration and validation, and visualization of flood results using ArcGIS. The finding of this study contributes to improved flood management strategies and decision-making processes in the Kolhapur district. The results can be used by water resource authorities, emergency management agencies, and urban planners to enhance flood preparedness, mitigate damages, and minimize the impact of future flooding events.

Keywords: **Flood Estimation, ArcGIS, Kolhapur district, Peak Flow, Flood Extent, Digital Elevation Models, Rainfall Data, Flood Management, Disaster Preparedness**

INTRODUCTION

Floods, as devastating hydro-meteorological phenomena, inflict significant devastation upon human life, settlements, industries, agriculture, and economies. With annual impacts affecting approximately 170 million people globally, these calamities are a pressing concern. Climate change, exacerbated by environmental degradation, population growth, urban expansion, and shifting land use patterns, has substantially increased the frequency and magnitude of floods. Remarkably, Alfieri et al. [12] have reported a staggering 40% surge in global flood occurrences over the last two decades, resulting in annual damages exceeding 75 billion USD. Accurate measurement of flood magnitude and timely documentation of inundation-induced destruction remain formidable challenges. Nevertheless, advancements in flood assessment and approximation techniques have offered significant progress.

Efforts to mitigate potential losses to natural and human environments underscore the vital importance of proactive flood prevention strategies. Identifying and mapping flood-prone area is essential for developing early warning systems, mitigation strategies, flood management, disaster risk reduction and emergency services. Flood forecasting has proven to be a useful tool for flood risk assessment, especially when using the Analysis Hierarchy Process (AHP) within the ARCGIS framework.

This approach is tailored to the unique landscape of Kolhapur district, with careful consideration of environmental, geological, topographic, meteorological, topographic and soil characteristics.

In this research, our primary focus is on employing the AHP method within the ARCGIS platform for Flood Estimation in the Kolhapur District. This region, situated in a geographically sensitive location, experiences recurrent flooding episodes, with the Panchganga River being a prominent feature. These floods have far-reaching consequences, affecting not only human lives and property but also the region’s agricultural and industrial sectors.

The significance of accurate flood estimation, particularly in this region, cannot be overstated. Effective flood management, preparedness, and mitigation strategies hinge on the precise delineation of flood-prone areas. The utilization of AHP within ARCGIS promises to provide a robust and tailored approach to flood estimation, one that factors in the unique geographical and environmental characteristics of Kolhapur District. These studies aim to provide useful information for flood risk assessment and disaster management in the region, ultimately reducing The significance of accurate flood estimation, particularly in this region, cannot be overstated. Effective flood management, preparedness, and mitigation strategies hinge on the precise delineation of flood-prone areas. The utilization of AHP within ARCGIS promises to provide a robust and tailored approach to flood estimation, one that factors in the unique geographical and environmental characteristics of Kolhapur District. These studies aim to provide useful information for flood risk assessment and disaster management in the region, ultimately reducing flood impacts and making communities more resilient.

STUDY AREA: KOLHAPUR DISTRICT, MAHARASHTRA

Kolhapur District, situated in the western part of Maharashtra, is a critical focus of this research on flood estimation using the AHP method within the ARCGIS framework.

1) Geographical Location: Kolhapur district is geographically located in the western part of Maharashtra and is part of the larger Krishna basin. It is famous for its proximity to the source of the Krishna River, which rises at an altitude of 1337 meters near Jhor village in Mahabaleshwar, Maharashtra.

2) River Network: The district is closely connected to the Krishna and its tributaries such as the Koyna, Warna, Panchganga, Dudganga and Ghataprabha rivers, all of which contribute to the complex Contributes to hydrology.

3) Triangular Shape: The topography of Kolhapur district can be described as almost triangular and is mainly covered by Deccan lava flows, creating unique topographical and geological features.

4) Alluvial Areas: Although Deccan lava flow predominates, sedimentary rocks are mostly found along the banks of the Krishna River and its main tributaries, and their thickness varies from 2 to 20 metres.

5) Rainfall Patterns: The study area experiences variable annual rainfall, with an average annual rainfall (AAR) of 1347 millimeters. However, rainfall patterns exhibit substantial variation, ranging from as low as 600 millimeters to as high as 6208 millimeters, contributing to flood susceptibility.

6) Population: According to the 2011 census, the total population of Kolhapur district, which is a part of the Upper Krishna Basin (UKB), is estimated to be 8,170,973. This population density is an essential consideration in flood risk assessment and disaster management efforts.

7) Monsoon Flooding: Like many parts of the UKB, Kolhapur district is also subject to repeated floods during the monsoon season. The Krishna River and its tributaries frequently rise during heavy rains, posing a major flood risk for the region.

8) Historical Flood Events: The area has witnessed a series of devastating floods in recent years, including notable events in 2005, 2006, 2009, 2011, and a particularly catastrophic flood in August 2019. These events underscore the urgency and importance of flood estimation and risk reduction measures within Kolhapur District.

Sr. no	**Flood Conditioning Factors**	**Description**	**Source**
1)	DEM	CartoDEM Version-2 R1 from Cartosat-1 (30m)	https://bhuvan-app3.nrsc.gov.in/data/download /index.php#
3)	Slope	CartoDEM Version-2 R1 from Cartosat-1 (30m)	https://bhuvan-app3.nrsc.gov.in/data/download /index.php#
4)	Rainfall	PERSIANN-Cloud Classification System (PERSIANN-CCS-2021)	http://chrsdata.eng.uci.edu/
5)	LULC	Sentinel-2 LULC time series 2022 (10m)	https://esri.maps.arcgis.com/apps/instant/media/index.html?appid=fe92d38533d440078f17678ebc20e8e2
6)	Distance from road	Export and convert scan data from regional road network	https://www.diva-gis.org/
7)	Distance from river	Export from flow mesh using ARCGIS	https://bhuvan-app3.nrsc.gov.in/data/download /index.php#
8)	Study area	Kolhapur District Shape file	https://www.diva-gis.org/
9)	Population density		https://bhuvan-app3.nrsc.gov.in/data/download /index.php#

RAINFALL MAP:

Rainfall is a critical component in understanding flood susceptibility within Kolhapur District, Maharashtra. The project leverages precipitation data sourced from the PERSIANN-Cloud Classification System (PERSIANN-CCS-2021). This system provides detailed insights into cloud cover and precipitation patterns, crucial for assessing the role of rainfall in flood risk estimation. PERSIANN-CCS-2021 is an invaluable resource, known for its accuracy and timeliness in providing precipitation information. The data obtained from this system is instrumental in evaluating the impact of rainfall events on flood occurrence. It allows us to analyze the frequency, intensity, and distribution of rainfall in the region, contributing to a comprehensive flood susceptibility assessment. The steps involved in acquiring this data include accessing the PERSIANN-CCS-2021 platform, which is hosted at the University of California, Irvine. This platform offers easy access to global precipitation information. For our study area, Kolhapur District, the precipitation data is particularly significant, considering the notable variations in annual rainfall patterns, ranging from as low as 600 millimeters to as high as 6208 millimeters. These variations underscore the importance of precise rainfall data in understanding and mitigating flood risks in the region.By incorporating PERSIANN-CCS-2021 rainfall data into our flood susceptibility mapping, we gain critical insights into the meteorological factors contributing to floods in Kolhapur District. This information plays an important role in the overall analysis of flood management and leads to the development of the flood risk assessment model within the framework of ARCGIS.

SLOPE MAP:

The slope map, a fundamental component of our flood susceptibility mapping project in Kolhapur District, is derived from the Cartosat-1 DEM (Digital Elevation Model) data, which offers a spatial resolution of 30 meters. The source of this valuable dataset is the Bhuvan platform, specifically the Carto DEM Version-2 R1. The slope map provides critical insights into the terrain characteristics of the study area, enabling us to understand the gradients and inclines across the landscape. The process begins with accessing the Carto DEM Version-2 R1 data from Bhuvan, a resource-rich platform for geospatial data. Once acquired, this high-resolution DEM is used to calculate the slope values for Kolhapur District. The slope map allows us to identify areas with gentle gradients and steeper slopes, which are pivotal for understanding how water flows and accumulates during rainfall events. Steeper slopes can influence the speed and volume of water runoff, potentially contributing to flood susceptibility, whereas flatter terrain may be less prone to rapid water accumulation. By incorporating the slope map into our project, we gain valuable insights into the topographical aspects that play a crucial role in flood estimation. This geospatial data layer, combined with other factors like rainfall patterns, land use, and proximity to rivers, contributes to a comprehensive flood susceptibility assessment, enhancing our understanding of flood risk in Kolhapur District. It serves as a key piece of the puzzle as we work towards more informed flood management and risk reduction strategies in this region. The topographic slope, characterized by both its length and steepness, plays a pivotal role in our project's assessment of flood susceptibility in Kolhapur District. This key factor significantly influences the flow and inundation dynamics of the area, thereby impacting flood risk. Areas with low and flat topography exhibit reduced runoff, promoting higher infiltration rates and potentially leading to waterlogging conditions. Conversely, low-lying areas with minimal slope angles tend to become inundated early in the event of flooding. In contrast, regions with steeper slopes contribute to higher peak discharges, leading to a faster drainage of water and potential depletion of storage in upstream areas. For the age of the incline map, we saddled information from the SRTM (Transport Radar Geography Mission) DEM, using the ArcGIS device known as "Slant" inside the Information The executives Examination augmentation. For this purpose, the SRTM 90m DEM variant, available from the USGS Earth Asset Perception and Science (EROS) community for 2020, was used.. The SRTM DEM, in GeoTIFF design with a Geographic projection, is re-projected to the Widespread Cross over (UTM) WGS84, Zone45, guaranteeing similarity with our examination structure. This internationally obtained dataset, given by associations like NASA, NGA, DLR, and ASI, offers a goal of 90 meters (roughly 3 bend seconds) and keeps a revealed vertical precision of under 16 meters. Our work included broad pre-handling of the SRTM information, tending to difficulties like voids or missing information, which can altogether affect information quality. Voids regularly result from factors like shadows and delay, frequently saw in precipitous locales with unfortunate sign returns or in smoother regions like water bodies and sandy landscapes, which reflect restricted radar energy. To alleviate these issues, we utilized ArcGIS devices to make up for in the shortfalls and improve information fulfillment. The last handled map was then utilized to create slant values in degrees, a significant part of our flood defenselessness examination for Kolhapur Region.

DISTANCE FROM RIVER MAP:

Distance from River holds significant importance in flood estimation and risk assessment within Kolhapur District, Maharashtra. The proximity of human settlements, infrastructure, and land use to rivers greatly influences the vulnerability and potential impact of flooding. Analyzing this spatial characteristic is crucial in understanding flood dynamics and implementing effective flood management strategies.

The distance from rivers acts as a critical indicator in flood estimation. It influences the exposure of various elements, including residential areas, agricultural lands, and infrastructure, to flood risks. Proximity to rivers often correlates with higher vulnerability to flooding, making it a pivotal factor in risk assessment.

Distance from the river directly affects the flood exposure area. Closer proximity increases the likelihood of inundation during flood events. Analyzing this parameter aids in identifying areas at higher risk and helps prioritize intervention strategies, such as land use planning and the development of early warning systems. Leveraging Geographic Information System (GIS) tools such as ArcGIS, data related to river networks, and the spatial distribution of human settlements and infrastructure have been employed to measure the distance from the river. This analysis aids in creating maps depicting areas based on their proximity to rivers and subsequently assessing their vulnerability to floods. Understanding the proximity of areas to rivers is crucial for effective flood risk management. This analysis allows for the identification of regions most susceptible to flooding due to their proximity to water bodies, aiding in the development of targeted mitigation strategies, land use regulations, and evacuation planning.

ELEVATION MAP (DEM):

In flood estimation project for Kolhapur District, the utilization of Digital Elevation Model (DEM) data is of paramount significance. We sourced our DEM data from CartoDEM Version-2 R1, derived from Cartosat-1 satellite imagery with a spatial resolution of 30 meters. This high-resolution elevation data serves as the foundational layer for understanding the region's topography, vital for our flood susceptibility mapping.

Our journey began by accessing this DEM data through the Bhuvan portal, a valuable resource for geospatial data in India. This resource facilitated the download of the CartoDEM Version-2 R1, a crucial initial step in our project. With this data in hand, we were able to create detailed topographic representations, allowing us to assess how elevation variations contribute to flood susceptibility.

By analyzing the DEM data, we gain insights into the terrain, identifying low-lying areas that might be prone to inundation during heavy rainfall. The DEM also enables the calculation of slope, which, when combined with rainfall data and land use information, enhances our ability to predict flood risk. The integration of this geospatial data helps us develop more accurate flood estimation models and, ultimately, contributes to better disaster management strategies for Kolhapur District.The DEM data, alongside other conditioning factors and geographical information, forms the backbone of our flood estimation project, empowering us to create a comprehensive flood susceptibility map for this region.

LANDUSE & LANDCOVER MAP:

The World Meteorological Organization (2020) advocates the integration of river basins, aiming to maximize the benefits derived from flood plains utilization while minimizing potential life loss due to flooding. Land use and land cover significantly affect catchment characteristics in river basins. Areas with low forest cover and increased population density are more vulnerable to flood damage. In such areas, runoff accelerates, volumes increase, and concentration time decreases, increasing their susceptibility to flooding. A 2020 Landsat-7 image, in the post avulsion period, was verified using Maximum Likelihood Classification (MLC) land use and Landcover and floor This classification distinguished six main categories: agriculture, forests, wet sandy areas, drysandy areas, settlements and settlements. However, the precise definition of class in supervised classification is critical, especially for coarse-resolution images due to the presence of cloudy or mixed areas and wet sandy areas in the settlement. The error matrix calculated using 250 random sampling points showed an overall accuracy of 85.59%. The KHAT statistics showed good classification across the main classes, but showed confusion between settlement and wet sand areas. As a result, distinct settlements were extract from the LISS-4 postavulsion image and overlaid with land cover (Landsat-7) to obtain the final LULC. LULC statistics describe agriculture as the dominant land cover, covering 33% (1,109 square kilometers) of the total area. Moist sand areas constitute 48% (1613 sq.km), followed by dry sand areas at 9% (294 sq.km), a result of the widespread sand sheets post the 18/8 avulsion. Forest cover is minimal, estimated at around 2% of the total area, while settlements account for 5%, significantly affected by recurrent flooding, necessitating strategic rehabilitation efforts.

POPULATION DENSITY Map:

Estimating the size of the population at risk is crucial in assessing the damage caused by floods. Determine population density per block to quantify economic assets at potential risk maps were derived using the 2021 census data for Maharashtra, India, obtained from "Land Scan Global East View." This secondary data has been pre-processed and integrated, providing a spatial resolution of 1km x 1km for 2020.

The data, in ESRI grid format with the WGS 84 projection, utilizes The Land Scan algorithm combines spatial data, imaging technology and the latest census data within management boundaries. The extracted population data aids in estimating the population at risk, considering demographic characteristics for comprehensive flood risk estimation.

The population within the study area was extracted using the Land Scan tool, an add-in compatible with ArcGIS-10 versions. Utilizing the feature extraction tool, the population of each block was determined by analyzing the population grid data of Nepal and India. The feature extraction tool allows cumulative population calculations, essential for generating block-wise population density.

DISTANCE FROM ROAD MAP:

The distance from road parameter provides vital information in flood risk assessment within the Kolhapur District. It is derived from the region's road network data and carefully converted to raster data, allowing a comprehensive assessment of the impact on flooding. The distance from roadways serves as an essential component for understanding the potential risk posed by road networks in flood-prone areas.

Transport Infrastructure Impact: The proximity of roads to water bodies can significantly influence flood vulnerability. Roads, particularly those situated in low-lying areas or close to rivers, might contribute to flood risk, as they can impede or redirect water flow during inundation events.

Drainage Implications: Understanding the distance of roads from water bodies aids in assessing potential drainage disruptions. Roads might obstruct natural drainage paths, affecting the flow of excess water during flooding. Human Settlement Concerns: Road networks, especially those closely associated with human settlements, can impact evacuation routes and accessibility during flood events.

Utilization in Flood Estimation: By incorporating distance from road data into flood risk modeling, this allows a more comprehensive understanding of the flood susceptibility in the Kolhapur District.

Integrating this parameter helps in mapping and identifying areas where road proximity might exacerbate flood vulnerability.GIS tools, such as ArcGIS, enable the conversion of road network data into raster format, facilitating its integration into flood risk analysis. The data for distance from road is derived from the Kolhapur district road network and converted to a simpler raster format incorporation into the flood estimation model.The specific source or creation method for this data is obtained from https://www.diva-gis.org/. Distance from road profiles and other control parameters such as DEM, slope, rainfall, vegetation/land cover, distance from rivers and population density help in assessing the flood risk for Kolhapur district. Its utilization alongside other parameters aids in identifying areas with higher vulnerability, contributing to more accurate flood estimation and risk mitigation strategies.

AHP ANALYSIS FOR FLOOD RISK ESTIMATION:

Flood risk estimation involves the evaluation of flood hazard and vulnerability. To conduct an Analytic Hierarchy Process analysis for both flood vulnerability and hazard, it's crucial to establish a hierarchical structure. Utilizing the insights gained from the diverse physical and socio-economic factors described earlier, I developed a comprehensive hierarchy. Subsequently, distinct hazard and vulnerability maps were generated. Ultimately, these individual maps were integrated to perform a holistic flood risk assessment.

Table 1: Hazard Factor

Attribute or Criteria	1	2	3	4
	Rainfall	Slope	Distance from River	Elevation

Table 2: Vulnerability Factor

Attribute or Criteria	1	2	3
	Population Density	LULC	Distance from Road

I. Consistency Ratio Calculations for Hazard Factors:

Table 3: Pair wise Comparison Matrix

	Rainfall	Slope	Distance from River	Elevation
Rainfall	1	9	5	3
Slope	1/9	1	4	6
Distance from River	1/5	1/4	1	7
Elevation	1/3	1/6	7	1

Table 4: Normalized Pair wise Comparison Matrix

	Rainfall	Slope	Distance from River	Elevation	Weighted Sum Value	Criteria Weights	Ratio
Rainfall	0.535	2.043	0.815	0.216	3.609	0.535	6.745
Slope	0.053	0.227	0.652	0.432	1.364	0.227	6.008
Distance from River	0.107	0.056	0.163	0.504	0.83	0.163	5.092
Elevation	0.160	0.036	0.022	0.072	0.2905	0.072	4.034

λmax = **5.425**, Consistency Index = **0.475**, Consistency Ratio = **0.054**

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

II. Consistency Ratio Calculations for Vulnerability Factors:

Table 5: Pair wise Comparison Matrix

	Population Density	LULC	Distance from Road
Population Density	1	9	4
LULC	1/9	1	7
Distance from Road	1/4	1/7	1

Table 6: Normalized Pair wise Comparison Matrix

	Population Density	LULC	Distance from Road	Weighted Sum Value	Criteria Weights	Ratio
Population Density	0.653	2.264	0.372	3.289	0.653	5.036
LULC	0.065	0.216	0.651	0.382	0.251	3.704
Distance from Road	0.163	0.035	0.093	0.291	0.093	3.131

λmax = **3.957**, Consistency Index = **0.478**, Consistency Ratio = **0.092**

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

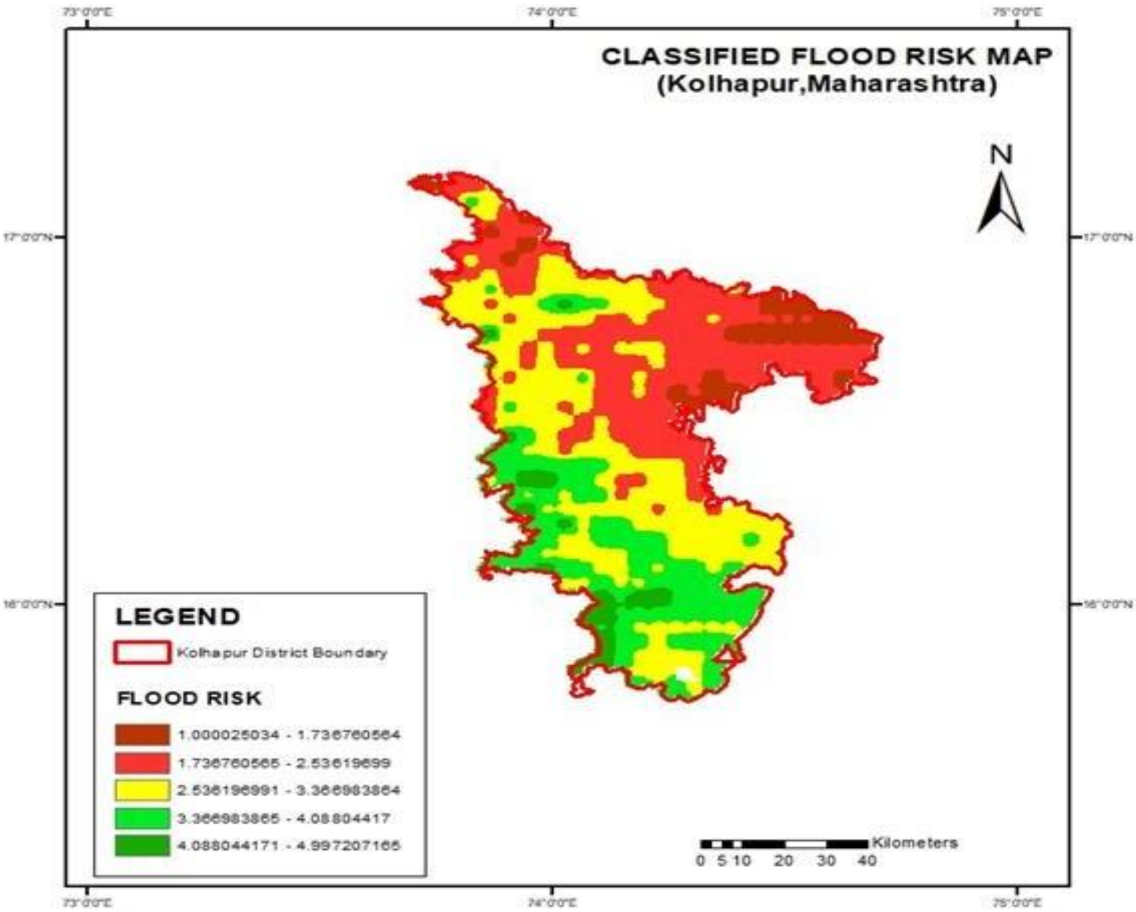

Fig 1: Classified Flood Risk map

GENERATION OF FLOOD RISK MAP:

The flood safety map and risk map were combined through equations in the design model to create the final flood risk map for the study area. The assessment was conducted on a block-wise basis. The resulting Flood Risk Index (FRI) range in the final map spans from 4.088 to 1.000, as depicted in the provided figure. Histograms are used to analyze the flood risk index for different risk levels (low, very low, medium, high, very high). This classification method helped in delineating the risk map into five important categories according to the attached table.

Table 7: Flood Risk Index

Range	**FRI**
4.088–4.997	Very Low Risk
3.366–4.088	Low Risk
2.536–3.366	Moderate Risk
1.736–2.536	High Risk
1.000–1.736	Very High Risk

The final flood risk map categorizes the study area into various blocks based on the illustration displayed in Figure. There is no complete dominance of a particular risk index in any of the blocks within the study area. As a result, a range of risk values has been assigned to each block, as detailed in the table below.

The high-risk index in certain areas can be attributed to different factors. These include high population density, significant rainfall in the region, areas affected by avulsion and the region and remarkably flat topography. One particular area included in the high-risk zone is Kolhapur.

CONCLUSION:

In conclusion, the use of ArcGIS for flood estimation in the Kolhapur District has provided valuable insights and tools for flood management and mitigation strategies. Integration of various data such as digital elevation models, precipitation data, land use data enables comprehensive assessment of ocean and landscape features. There is a risk of flooding of the basin. By employing hydrological modelling techniques, ArcGIS has facilitated the estimation of flood extents, depths, and velocities, enabling the identification of vulnerable regions and the prioritization of response measures. Additionally, the visualization capabilities of ArcGIS have enhanced communication and decision-making processes by effectively conveying complex spatial information to stakeholders. Overall, ArcGIS has proven to be a powerful tool for flood forecasting in the Kolhapur region, helping to develop flood management strategies and improve preparedness for future floods.

The fusion of physical and socio-economic aspects in the assessment of flood risk within Kolhapur District, Maharashtra, is a fundamental aspect critical to understanding the multifaceted dynamics of potential inundation. Leveraging the robust Analytic Hierarchy Process (AHP) methodology, a well-structured hierarchy was formulated, highlighting the integral role of amalgamating a diverse array of factors in the assessment framework. In meticulously exploring flood hazard and vulnerability, a thorough investigation was conducted, drawing insights from an extensive range of satellite-based remote sensing datasets. These datasets, encompassing essential elements like Digital Elevation Models (DEM), slope analytics, precipitation patterns, land use/land cover classifications, in conjunction with proximity to roads and rivers, served as pivotal indicators in determining the landscape's vulnerability to flooding. The detailed examination of physical attributes, including terrain configuration, land cover variations, and proximity to water bodies, elucidated their collective impact on shaping the potential flood risks within the region. Simultaneously, the integration of socio-economic considerations such as population density, infrastructure distribution, and societal resilience, provided crucial insights into community exposure and vulnerability to flood hazards. The merging of these multifaceted factors laid the foundation for creating separate hazard and vulnerability maps. This process culminated in the synthesis of comprehensive flood risk assessment maps, offering a holistic view of the interplay between physical predispositions and societal vulnerabilities. This integrated approach yielded nuanced insights, uncovering critical findings with far-reaching implications. These findings are poised to inform and shape pragmatic disaster management strategies, urban planning initiatives, and effective mitigation measures for the Kolhapur District, catering to both the immediate and long-term needs of the region

The implementation of flood control measures on the Kolhapur District has been critical in mitigating the impact of floods in the region. The construction of dams, levees, and other infrastructure projects have provided a significant level of protection to the people, property, and agricultural lands in the basin. Using modern technology to predict and monitor weather and water flows allows for early warning, increasing response time to flood events. However, it is important to remember that flood prevention success depends on many methods such as land use management, water management and community participation. The long-term sustainability of flood control measures will depend on the effective coordination between government agencies, local communities, and stakeholders in the region.

The risk assessment conducted in this thesis uses an effective method to identify flood risk area, flood risk area and combined risk area in the Kolhapur region. The analysis is based on morphological, topographic and demographic data that can be used to assess risk factors such as population, slope, precipitation and land use. It focuses on understanding the factors affecting flood risk hazard and vulnerability in the study area. The application of this method is not limited to Kolhapur region but can be extended to other river regions.

Geomorphic mapping was carried out using satellite/remote sensing images during different time periods, before and after avulsion to track landform evolution in flood propagation and predict paleochannel connections. A variety of geomorphic units have been identified, including active channel zones, active and passive floodplains, small active channel deposits, channel strip deposits, and fan surfaces. In the post- avulsion image, a unique avulsion channel and avulsion deposit were mapped, covering most of the fan surface.

Determinants taken into account in this study include rainfall amount, population density, distance from water networks, land use/land cover, slope and characteristics of the area. Thematic maps are created using different levels of image processing and GIS operations. Each thematic layer was normalized to the same scale for analysis.

AHP has been used as a multivariate decision-making process to evaluate and integrate various variables. A good way is to come to terms with good and diverse information with different degrees of dependency and independence. Vulnerable areas are delimited by assigning weights based on each area's flood risk and vulnerability. The thematic framework was then used to create flood and flood safety plans in ArcGIS Model Builder, and together they created the final flood safety map. During overlay analysis, it is important that thematic processes have different outcomes (as in the event map) to facilitate AHP analysis.

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