

Hydrological Modelling of Urban Flood Prone Area and Geospatial Analysis

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Abstract— The city of Pune is facing a problem with urban flooding. This is happening because there are more surfaces that water cannot pass through the drainage systems are not good enough and the city is growing without a plan. The current research is focusing on the Mutha river basin area in Pune. It is using technologies like Geospatial and hydraulic modeling software to understand what happens during floods. The main goal of this study is to look at the land simulate what happens when it rains and see which areas are most vulnerable to flooding. To do this advanced techniques like QGIS and HEC-RAS are being used. A special map called DEM is helping to find information like the slope of the land how high it is and which way water flows. This information is crucial to understanding how water naturally flows in the area. Data on rainfall over the 20 years from the India Meteorological Department in Pune is being used to simulate what happens when it rains. The hydraulic modeling is being done using HEC-RAS to see which areas are most likely to flood. Things like the water level how fast it is. How deep it is are all being calculated for the flood prone zones, in the study area. The Mutha river basin and the city of Pune are being studied closely to understand flooding and find ways to deal with it. The findings show that water levels go up when it rains the most and this causes bad floods in flat areas. We also see differences in how the water moves, which affects how much dirt gets washed away and how much water gets stuck in one place. When we use computer programs that look at maps and water flow together we can get a really good idea of where floods are likely to happen and which areas are, in the most danger. This study shows that we really need to use these computer programs and our knowledge of water to manage flood risk. We need to use both of these tools to deal with flood risk. That is what this research is saying about flood risk management and water levels and floods.

Keywords— Hydrological Modelling, Flood Risk Assessment, QGIS, HEC-RAS, Digital Elevation Model (DEM), Water Surface Elevation (WSE), Flow Velocity, Flood Depth Analysis, Catchment Delineation, Rainfall-Runoff Simulation, Geospatial Analysis, Urban Flooding, Mutha River Basin, Pune City, Watershed Management, Hydraulic Modelling.

I. INTRODUCTION

Flooding is a problem that happens a lot and it is very bad for people in all countries whether they are rich or poor. It causes a lot of people to die it damages roads and buildings. It stops people from doing their normal activities. In the few years flooding in cities has become worse and it happens more often. This is because many people are moving to cities the weather is. The systems that are supposed to drain water are not planned well. Cities like Pune are, in trouble when it comes to flooding. This is because the city is getting bigger there are roads and buildings and people are building on the paths that water is supposed to follow. When we do all these things it changes the way water normally moves in the city. It makes a lot of water run over the surface. It stops the water from going into the ground. This makes it more likely that the city will flood [1].

Hydrological modelling is really important, for understanding floods and how they behave. It does this by simulating how water moves and gets spread out in a watershed. We get to learn a lot from it about how rainfall affects runoff and how floods move around in environments. Now that we have computers and mapping tools we can make really good models to study floods. Putting together Geographic Information Systems with software that models water flow has become an useful way to look at areas that are likely to flood. This helps people make decisions about water when they are working on engineering projects. Hydrological modelling helps us with this because it gives us an idea of what happens during floods [2].

In this case we use QGIS and its geospatial methods to analyze the land surface. We get information about the lands features, such as slope, elevation and flow direction. The digital elevation model helps us get this data. It shows where water flows naturally and areas that might flood because they are lower than parts. We also use tools like SAGA GIS and GRASS GIS with QGIS for detailed analysis of water flow. These tools help us understand the lands surface better. QGIS is useful for this kind of analysis and QGIS helps us get results. The digital elevation model is key, to understanding the land and the digital elevation

model provides insights. We rely on QGIS to get the data we need [3].

In addition we use HEC-RAS for modeling. It is an used tool for modeling water flow in rivers and channels. This tool helps analyze water flow under unsteady conditions. It also gives us information like Water Surface Elevation flow velocity and flood depth. These values help us understand how much flooding will happen and where it might be dangerous. For our project we use HEC-RAS to model flood impacts in the Mutha river basin. We use rainfall data and elevation data from our GIS analysis for this. The HEC-RAS tool is really helpful in this process. It allows us to see how floods affect the Mutha river basin. We get to know the Water Surface Elevation and other details. This helps us prepare for flooding, in the Mutha river basin [4].

The Mutha River that goes through Pune city is a reason for floods in the city especially when it rains really hard. The area around the Mutha River has types of land with some parts being very low so water collects there easily. As the city around the Mutha River is growing fast more water runs off the surface. The natural way water used to drain is not working as well which makes floods worse. So it is very important to learn about how water moves, in the Mutha River area and find the places that're most likely to flood so we can do something to stop the floods from happening.

Among the factors affecting floods rainfall plays a role. In this study we used rainfall data collected over 20 years from 2004 to 2024 from the India Meteorological Department. This data, on rainfall intensity, frequency and distribution helps in models. Looking at rainfall data shows how extreme rainfall events lead to floods. We also included rainfall data in our model.

Geospatial analysis helps us see where flooding happens and hydraulic modelling gives us numbers to work with. This way of doing things helps engineers and city planners find the places that need help away and come up with plans to control floods. It also helps design drainage systems make better plans for using land and get ready for disasters. Flood risk assessment is important and geospatial analysis and hydraulic modelling play a big role in this. The study is not about technical things it also talks about how cities should grow in a way that is good for the environment and how water should be managed. Cities like Pune are having a time dealing with stormwater and preventing floods because so many people are moving there and buildings are going up. Using computer tools helps us come up with solutions that are based on data and these solutions can reduce the bad effects of floods and help cities withstand them for a long time. Geospatial analysis and hydraulic modelling are tools, in flood risk assessment and they can really make a difference.

This project shows how modern geospatial and hydraulic modelling techniques can be used to deal with real-world problems, in engineering. It combines QGIS and HEC-RAS to create a way to look at areas that are likely to flood and understand how floods work. The results of this study can help planners, engineers and policymakers make good plans to stop

floods from happening and make cities safer and more sustainable. The project uses QGIS and HEC-RAS to look at flood- areas and understand flood dynamics. The people who plan cities and the engineers who design them can use the results of this study to make cities safer. The goal is to make flood mitigation strategies that really work and improve the safety of cities.

II. OBJECTIVES

The study is about finding flood- areas in Pune city. It uses a mix of mapping techniques and water flow modelling. The goal is to understand how the land behaves during floods how rainfall affects it and how floods move around. This will help create a plan to assess and reduce flood risks. The project aims to provide a basis for flood risk assessment and mitigation planning in Pune city using geospatial techniques and hydraulic modelling. It will help to understand terrain behaviour, rainfall impact and flood dynamics, in Pune city.

A. To Delineate the Study Area Using GIS Techniques

One of the important tasks in this research is determining the study site accurately using geographical methods. In this study, the Mutha River basin at Pune will be studied, where the urban floods have been experienced quite often in recent years. Using the latest geospatial software like QGIS, the boundary of the catchment area is determined depending on the topography of the area. Determining the catchment area boundary is an important task for the drainage system to understand how much the watershed covers and the areas that contribute to the generation of surface run-off. This includes the analysis of DEM data for the delineation of the watersheds and drainage lines [5].

B. To Analyse Terrain Characteristics Using DEM

In addition another major goal is to assess the terrain characteristics of the study area using DEM data. The terrain characteristics include elevation, slope, aspect and hill shade which can be obtained through DEM analysis. Slope analysis helps us identify areas with flat terrain. Steep slopes have water runoff while flat areas lead to water accumulation. To understand the drainage system we need to create flow direction and flow accumulation maps. These maps are crucial, in identifying flood- zones in the study area [6].

C. To Determine Flow Direction and Drainage Patterns

The goal is to figure out where water flows when making models of how water moves. To do this we need to find out where water flows from points to low points. We can make maps that show where water flows and how much water collects in one place using computer tools. These maps help us see how water drains in an area and find streams and rivers. We use these maps to predict how floods will behave and where water might collect. This helps us find places that need drainage systems. The goal of understanding water flow direction is useful for identifying sites. It helps to improve drainage systems in those areas. We can use this information to make plans for managing water. Understanding drainage patterns is key to predicting floods and finding areas that need help. Water flow direction and accumulation maps are tools, for this [7].

D. To Simulate Rainfall-Runoff Conditions Using Hydraulic Modelling

Figure 3.1 illustrates the geographical location of the study area. The left map shows the position of Pune within India, while the right map represents the detailed boundary of the study area extracted using GIS techniques. This spatial representation helps in understanding the regional context and extent of the Mutha River basin considered for analysis.

A. Geographic Location and Extent

Pune city is situated in the western part of Maharashtra state and lies within the Deccan plateau region. The geographical coordinates of Pune are approximately 18.52° N latitude and 73.85° E longitude. The city is bounded by hills and undulating terrain, which significantly influence the natural drainage pattern. The Mutha River flows through the central part of the city and acts as a major drainage channel for stormwater runoff. The study area includes urban as well as peri-urban regions that are directly influenced by the river and its tributaries. The spatial extent of the study area has been delineated using GIS tools based on watershed boundaries derived from DEM data [9].

B. Topography and Terrain Characteristics

The city of Pune has a lot of types of land. You will find hills and gentle slopes and also flat areas that are low to the ground. The west side of Pune is full of hills. The middle and east sides are pretty flat. When it rains the water moves around Pune in ways because of the hills and flat areas. To understand this better people use something called Digital Elevation Model data with a program called QGIS. They make maps that show how high and steep the land is. The steepness of the land determines how fast the water on the surface moves. If the land is steep the water moves fast and does not soak into the ground. On the hand if the land is flat the water collects and does not move. This makes flat areas of Pune very likely to flood. People also use something called hillshade analysis to get a picture of the land. This helps them see how the water will move around Pune and where the water will collect. Pune city has a lot of types of land and this affects how the water moves around during rainfall events, in Pune city [10].

C. Hydrology of the Mutha River Basin

The Mutha River is really important for the area we are studying. It starts in the Western Ghats. Flows to the east through Pune city. The Mutha River is a part of the Bhima River and it helps a lot to remove stormwater from the city. The Mutha River has small areas that drain water into it and many channels that help the water flow. When it rains a lot the Mutha River gets a lot water and this causes flooding in the areas around it. The way the Mutha River basin works is affected by how it rains, what the land is, like the type of soil and how the land is used. We used computer tools to study the Mutha River and see where the water flows how much water flows and where the water flows to. This helps us understand where the water goes in the Mutha River basin and which areas will have a lot of water when it rains a lot [11].

D. Climate and Rainfall Characteristics

Due to heavy rainfall, there is a risk of floods in the low-lying regions. The data related to rainfall has been obtained from the India Meteorological Department (IMD), Pune for a period of 20 years, i.e., from 2004 to 2024. Rainfall records have been taken into account on a daily basis. Data regarding rainfall helps in analysing the rainfall patterns and identifying extreme events of rainfall. High-intensity rainfall is responsible for increasing surface flow and reducing infiltration. Thus, it contributes towards the formation of floods. Analysis of the rainfall data helps in comprehending the variability of rainfall and its influence on flood occurrence. Further, rainfall data is used as an input for hydraulic modelling by HEC-RAS. [12].

E. Land Use and Urbanization Impact

There are changes in the setting and water flow in the area because Pune City is becoming more urbanized. The conversion of spaces to homes, shops and factories has increased the amount of hard surfaces like roads, buildings and pavements. These hard surfaces make rainwater flow over the surface of soaking into the ground. Another reason for rainwater flowing over the surface and causing urban flooding is that natural waterways and flood areas are being built over. In some areas the drainage system for rainwater is not well developed. Can't handle the increased flow of rainwater. A GIS-based analysis of how land's used can help find areas where development has disrupted the natural drainage system leading to urban flooding and related issues. The urbanization of Pune City and the increase in surfaces are major contributors to urban flooding. The city's natural drainage system is getting disturbed due to development. This results, in surface runoff and urban flooding.

F. Flood-Prone Areas and Vulnerability

Pune is changing a lot because of urbanization. This means natural areas are becoming cities. When this happens we get roads, buildings and pavements. These things do not let water soak into the ground. So when it rains the water does not get. This causes flooding in cities. The natural way water used to flow is now disturbed because cities are getting bigger. This is a problem in Pune. Many areas in Pune have trouble with stormwater drainage. This is because urbanization is changing the way water flows. We can use something called GIS analysis to see how land is being used. This can help us find out which areas have become cities and how this is affecting the flow of water. GIS analysis can show us which places are having problems with drainage because of urbanization. Urbanization is really affecting Pune. We need to think about how it is changing the natural drainage, in the city of Pune.

G. Importance of Study Area Selection

I think Pune city is a place to study because it is getting more and more likely to have big floods. The city has the Mutha River. It is growing really fast plus the weather is changing a lot. This makes it a perfect place to do studies on water and flooding. What we learn from this study can also help cities that have the same problems. This way we can find ways to deal with floods

and make cities safer. Pune city is an example of what happens in the real world so we can use special computer programs to understand and solve big problems that affect the city and its people.

Summary of Study Area

The city of Pune the area around the Mutha River has a lot of different land features and weather patterns that affect how floods happen. When we use computer mapping and water flow models together we get a good idea of this area and can find out which places are most likely to get flooded. The Mutha River basin, in Pune city has types of land and different amounts of rain and people use the land in different ways so we need to use science to really understand where floods are likely to happen and how to deal with them. The study area of Pune city is an example of this and the Mutha River basin is a key part of it.

IV. DATA COLLECTION

Collecting information for models about water and floods is a part of the process. The model is only as good as the information you put into it. For this project we got lots of information from places to look at areas in Pune city that are likely to flood. We got information, about the shape of the land how much rain falls and how water moves. We used computer programs to look at this information and understand how water and floods work.

A. Collection of Digital Elevation Model (DEM) Data

The Digital Elevation Model data is really important for looking at the terrain in this study. Digital Elevation Model data shows how high the earth's surface is. We need Digital Elevation Model data to understand the shape of the land how steep it's where the water flows. For this project we got the Digital Elevation Model data from the Shuttle Radar Topography Mission datasets. Shuttle Radar Topography Mission datasets give us information about the height of the entire earth, which is good enough for studying water flow. We downloaded the Digital Elevation Model data using tools in QGIS like the SRTM Downloader. Then we cleaned up this data to remove errors and ensure everything matches. The Digital Elevation Model data helps us understand things. We can see how steep the land is. We also know which direction it faces. We find out where the water flows. We even determine how much water accumulates [13].

B. Rainfall Data Collection and Analysis

Rainfall is the most significant factor influencing flood generation. In this project, long-term rainfall data has been collected from the India Meteorological Department (IMD), Pune. The dataset includes daily rainfall records for a period of 20 years (2004–2024), providing comprehensive information about precipitation patterns in the study area. The collected rainfall data was analysed to determine monthly and yearly trends, as well as extreme rainfall events. This analysis helps in understanding the variability and intensity of rainfall, which are critical inputs for hydrological modelling. High-intensity rainfall events are particularly important as they lead to sudden increases in surface runoff and contribute to flooding. The rainfall data

was further processed and formatted for use in hydraulic modelling using HEC-RAS. By incorporating real rainfall data into the model, more realistic flood simulations were achieved, enhancing the reliability of the results [14].

C. Hydrological and Hydraulic Data

In addition to rainfall and terrain data, hydrological and hydraulic parameters are required for accurate flood modelling. These include information related to river geometry, flow characteristics, and boundary conditions. For the study area, the focus is on the Mutha River, which plays a major role in urban flooding. Hydraulic parameters such as channel dimensions, flow velocity, and discharge conditions were considered while developing the model. These parameters were either obtained from secondary sources or estimated based on standard engineering practices. The hydraulic modelling process involves defining cross-sections of the river, assigning boundary conditions, and simulating flow conditions under different rainfall scenarios. The accuracy of these inputs is essential for generating reliable outputs such as Water Surface Elevation (WSE), flow velocity, and flood depth [15].

D. Land Use and Land Cover (LULC) Data

Land use and land cover (LULC) data is another important component of data collection in this project. Urbanization has a significant impact on hydrological processes, as it alters natural drainage patterns and increases surface runoff. LULC data was obtained through satellite imagery and GIS datasets, which were analysed using QGIS. The data was classified into different categories such as residential areas, commercial zones, vegetation, water bodies, and barren land. This classification helps in understanding how different land use types influence runoff generation and infiltration. For example, built-up areas with impervious surfaces generate higher runoff compared to vegetated areas. Incorporating LULC data into the analysis improves the accuracy of flood modelling and helps in identifying areas where urban development has increased flood risk [16].

E. Satellite and Remote Sensing Data

Remote sensing data plays a vital role in providing spatial information about the study area. Satellite imagery was used to analyse land use patterns, river morphology, and surface features. These images help in identifying changes in land use over time and detecting areas affected by urbanization. Remote sensing data also supports the validation of GIS analysis by providing visual confirmation of terrain features and drainage patterns. High-resolution satellite images enable accurate mapping of the study area and improve the overall quality of spatial analysis. The integration of remote sensing data with GIS tools enhances the capability of flood modelling by providing detailed and up-to-date information about the study area.

F. Data Processing and Integration

After collecting data from various sources, it was necessary to process and integrate the datasets to make them suitable for

analysis. Data preprocessing involved steps such as data cleaning, formatting, and conversion into compatible formats. DEM data was processed to remove errors and generate hydrological parameters. Rainfall data was analysed and formatted for input into hydraulic models. LULC data was classified and converted into raster format for GIS analysis. All datasets were then integrated within the GIS environment to create a comprehensive database for the study area. This integrated dataset was used as input for hydraulic modelling in HEC-RAS. The proper integration of data ensures consistency and accuracy in the modelling process, leading to reliable results.

G. Importance of Accurate Data Collection

Accurate data collection is essential for the success of any hydrological modelling study. Errors or inconsistencies in input data can lead to incorrect results and misinterpretation of flood behaviour. Therefore, careful attention was given to data selection, validation, and preprocessing in this project. The use of reliable data sources such as IMD for rainfall and SRTM for DEM ensures the credibility of the study. Additionally, the integration of multiple data types provides a comprehensive understanding of the factors influencing flooding. This objective highlights the importance of adopting a systematic approach to data collection and management in civil engineering projects, particularly those related to flood risk assessment and water resource management.

Summary of Data Collection

In summary, the data collection process involved gathering and analysing various datasets, including DEM, rainfall data, hydrological parameters, and land use information. These datasets were processed and integrated using GIS and hydraulic modelling tools to support flood analysis in Pune city. The accuracy and reliability of the collected data play a crucial role in ensuring the effectiveness of the modelling process and the validity of the results.

V. METHODOLOGY

The methodology adopted in this study involves a systematic and integrated approach combining geospatial analysis and hydraulic modelling to assess flood-prone areas in Pune. The entire process includes data preparation, terrain analysis, hydrological modelling, and flood simulation using advanced tools such as QGIS and HEC-RAS. The methodology is designed to ensure accurate representation of terrain, realistic simulation of rainfall-runoff processes, and reliable identification of flood-prone zones.

A. Preparation of Spatial Data

The first step in the methodology involves the preparation of spatial data required for analysis. Digital Elevation Model (DEM) data is imported into the GIS environment and processed to remove inconsistencies such as voids and noise. The DEM is then projected into a suitable coordinate system for accurate spatial analysis. Other datasets such as land use/land cover (LULC) and satellite imagery are also imported and

preprocessed. These datasets are converted into compatible formats (raster or vector) for further analysis. Proper data preparation is essential to ensure that all datasets align correctly and provide accurate results during modelling [17].

B. Terrain Analysis Using DEM

Terrain analysis is carried out using DEM data to extract important topographical features of the study area. The following analyses are performed using GIS tools:

1. Slope Analysis: Determines the steepness of the terrain, which influences runoff velocity.
2. Elevation Analysis: Identifies high and low-lying areas.
3. Aspect Analysis: Determines the direction of slope, affecting sunlight exposure and evaporation.
4. Hillshade Analysis: Provides a three-dimensional visualization of terrain.

These analyses help in understanding how water flows across the surface and identifies regions where water is likely to accumulate. Low-lying areas with gentle slopes are identified as potential flood-prone zones.

C. AHP-Based Weight Determination

The Analytic Hierarchy Process is a way to figure out how important different things are when it comes to flooding. Things like how steep the land's how high it is, how much rain falls what the land is used for and how the water drains away are all looked at. We make a table to compare each of these things to each other to see which ones matter most when it comes to flooding. This table is then made simpler so we can get a score for each thing. We check to make sure our comparisons make sense by using something called the Consistency Index and Consistency Ratio. If the Consistency Ratio is than 0.1 that means our comparisons are good. The scores we get from the Analytic Hierarchy Process are then used to make a map of where flooding's most likely to happen. This helps us make an accurate map because each thing is given the right amount of importance. The Analytic Hierarchy Process helps us be more objective when we are making the map so we can see which areas are really, at risk of flooding.

1. Pairwise Comparison Matrix

Factors	Slope	Depth	Velocity	WSE
Slope	1	1/5	1/3	1/5
Depth	5	1	3	1
Velocity	3	1/3	1	1/3
WSE	5	1	3	1

Table 1: Pairwise Comparison Matrix

2. Normalized Matrix & Criteria Weights

Factors	Slope	Depth	Velocity	WSE	Weight	Weight (%)
Slope	0.071	0.10	0.047	0.10	0.0796	7.96%
Depth	0.357	0.50	0.42	0.50	0.4443	44.43%
Velocity	0.214	0.166	0.14	0.166	0.1716	17.16%
WSE	0.357	0.50	0.42	0.50	0.4443	44.43%

Table 2: Normalized Matrix and Derived Criteria Weights

3. Consistency Check Table

Factors	Weighted Sum	Weight	WSV/CW
Slope	0.312	0.0796	3.91
Depth	1.788	0.4443	4.02
Velocity	0.700	0.1716	4.07
WSE	2.668	0.4443	6.00

Table 3: Consistency

Consistency Formula

You can include this line in text (no need image):

- $\lambda_{max} = 4.507$
- $n = 4$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.507 - 4}{3} = 0.169$$

$$CR = \frac{CI}{RI} = \frac{0.169}{0.89} = 0.1965$$

The weights we got from the AHP analysis are used to make a flood map. We do this to see how much each thing affects flooding. We look at things like slope and depth and velocity and water surface elevation. Each of these things gets a weight based on how important it's. We use these weights to combine all the information in a Geographic Information System. Each piece of information is multiplied by its weight. Then we add them all together to get a flood score. This score shows us where flooding is more likely to happen. Places with scores are more likely to flood because of many factors. Places with scores are safer. We use this score to make a flood map, with areas that're high risk and areas that are low risk. This way we can be sure that we are considering all the things that affect flooding. This makes our flood map more accurate than if we just gave everything the weight or if we just guessed.

D. Watershed Delineation and Catchment Analysis

Watershed delineation is performed to define the boundary of the catchment area contributing to runoff. Using hydrological tools in QGIS, flow direction and flow accumulation maps are generated from the DEM.

- Flow Direction: Determines the direction in which water flows from each cell.
- Flow Accumulation: Identifies areas where water accumulates.
- Catchment Boundary: Defines the drainage area of the basin. The delineated watershed provides a clear understanding of drainage patterns and helps in identifying major channels and sub-catchments within the study area. This step is crucial for accurate hydrological modelling.

E. Extraction of River Geometry and Channel Characteristics

The geometry of the river channel is an important input for hydraulic modelling. In this study, the focus is on the Mutha River, which is the primary drainage channel in the study area. River cross-sections are defined based on terrain data and available information. Channel characteristics such as width, depth, and slope are considered while preparing the model.

These parameters influence the flow of water and are essential for simulating realistic flood conditions.

F. Rainfall-Runoff Modelling

Rainfall-runoff modelling is carried out using historical rainfall data collected from the India Meteorological Department (IMD). The rainfall data is analysed to identify peak rainfall events and their duration. The rainfall input is used to simulate runoff generation within the catchment area. The relationship between rainfall intensity and runoff is established based on hydrological principles. This step helps in estimating the volume of water entering the river system during rainfall events. The generated runoff data is then used as input for hydraulic modelling to simulate flood conditions.

G. Hydraulic Modelling Using HEC-RAS

Hydraulic modelling is performed using HEC-RAS to simulate water flow in the river and surrounding areas. The model is developed by integrating terrain data, river geometry, and runoff inputs.

The following steps are involved in hydraulic modelling:

- Importing terrain data into HEC-RAS
- Defining river geometry and cross-sections
- Assigning boundary conditions
- Inputting flow data derived from rainfall-runoff modelling
- Running simulations for different flow conditions

HEC-RAS is capable of simulating both steady and unsteady flow conditions. In this study, unsteady flow simulation is used to represent real flood scenarios where flow varies with time [18].

H. Analysis of Hydraulic Parameters

After running the HEC-RAS model, several important hydraulic parameters are obtained, including:

- Water Surface Elevation (WSE): Indicates the height of water along the river.
- Flow Velocity: Represents the speed of water movement.
- Flood Depth: Shows the extent of inundation in different areas.

These parameters are analysed to understand flood behaviour and identify areas at risk. High WSE indicates potential overflow, high velocity indicates erosion risk, and high depth indicates severe flooding.

I. Flood Inundation Mapping

The results obtained from HEC-RAS are integrated with GIS to generate flood inundation maps. These maps visually represent areas affected by flooding based on depth and extent of water spread. Flood inundation mapping helps in identifying critical zones that require immediate attention. It also supports decision-making for flood management and urban planning. The maps provide a clear representation of flood-prone areas, making it easier to communicate results to stakeholders [19].

J. Validation and Interpretation of Results

The final step in the methodology involves validating and interpreting the results obtained from the model. The results are analysed in relation to terrain characteristics, rainfall patterns, and land use. Where possible, the model results are compared with observed flood events to assess accuracy. Interpretation of results helps in understanding the causes of flooding and identifying areas where improvements are needed. This step ensures that the model provides reliable and meaningful insights for flood risk assessment.

Summary of Methodology

In summary, the methodology involves a comprehensive approach combining GIS-based terrain analysis and hydraulic modelling to simulate flood conditions. The use of QGIS for spatial analysis and HEC-RAS for hydraulic simulation ensures accurate representation of flood behaviour. The integration of various datasets and modelling techniques provides a reliable framework for identifying flood-prone areas and supporting effective flood management strategies.

VI. RESULT AND ANALYSIS

The results obtained from this study are based on the integration of geospatial analysis using QGIS and hydraulic modelling using HEC-RAS. The analysis focuses on understanding flood behaviour in the Mutha River basin located in Pune. The results include terrain-based analysis, hydrological parameters, and hydraulic simulation outputs such as Water Surface Elevation (WSE), flow velocity, and flood depth. These outputs provide a comprehensive understanding of flood dynamics and help in identifying high-risk areas.

A. Terrain Analysis Results

The terrain analysis carried out using DEM data provides valuable insights into the topographical characteristics of the study area. The elevation map indicates that the western part of Pune is characterized by higher elevations, while the central and eastern parts consist of relatively low-lying areas. The slope analysis reveals that steep slopes are present in the hilly regions, which contribute to faster surface runoff. In contrast, flatter regions exhibit lower slopes, leading to slower movement of water and higher chances of water accumulation. Flow direction and flow accumulation maps indicate the natural drainage pattern of the area. Water flows from higher elevations towards the Mutha River, which acts as the main drainage channel [20].

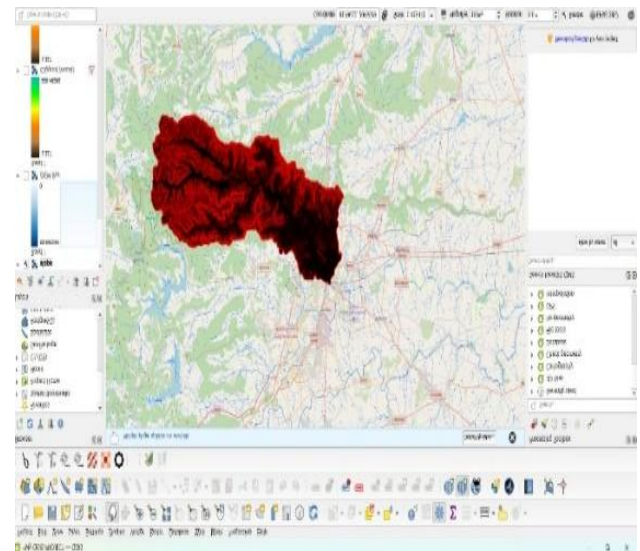


Fig. 6.1 DEM and Slope Map of Study Area using QGIS

B. Watershed and Drainage Analysis

The delineation of the watershed using GIS tools provides a clear understanding of the catchment area contributing to runoff. The watershed boundary defines the area from which water drains into the Mutha River. The drainage network extracted from the DEM shows the presence of several natural channels and tributaries that contribute to the main river flow. These channels play a crucial role in transporting runoff during rainfall events. However, in urban areas, many of these natural drainage paths have been altered or obstructed due to construction activities. This leads to inefficient drainage and increased risk of flooding. The watershed analysis helps in identifying such areas and highlights the need for proper drainage planning.

C. Rainfall Analysis Results

The analysis of 20 years of rainfall data (2004–2024) indicates significant variability in precipitation patterns. The monsoon season contributes the majority of annual rainfall, with several instances of high-intensity rainfall events. These extreme rainfall events are identified as the primary cause of flooding in Pune city. The data shows that short-duration, high-intensity rainfall leads to rapid generation of surface runoff, overwhelming the drainage system. The rainfall analysis also helps in identifying trends and patterns that can be used for predicting future flood events. The integration of rainfall data into hydraulic modelling ensures that the simulation represents realistic conditions.

D. Water Surface Elevation (WSE) Analysis

The Water Surface Elevation (WSE) results obtained from HEC-RAS indicate a gradual increase in water level along the river during flood conditions. The WSE profile shows that water levels rise significantly during peak rainfall events, leading to overflow in certain sections of the river. Areas where the WSE exceeds the bank level are identified as flood-prone zones. These areas are particularly vulnerable as even a small increase in rainfall can result in flooding. The WSE analysis provides a clear understanding of how water levels change along the river and

helps in identifying critical sections that require flood control measures. It also aids in designing structures such as embankments and levees to prevent overflow [21].

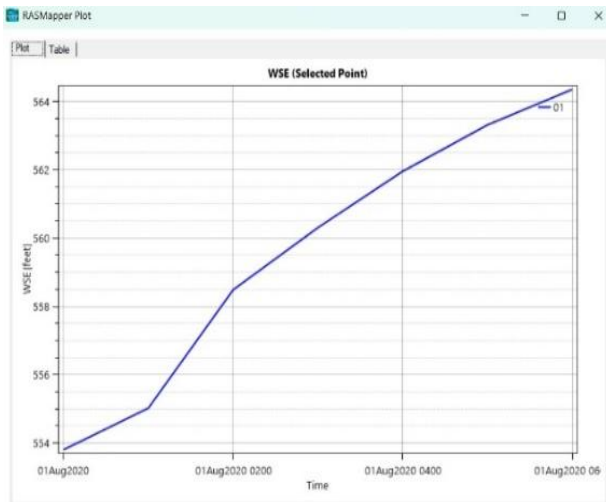


Fig. 6.2 Water Surface Elevation (WSE) vs Time at Selected Point

E. Flow Velocity Analysis

The flow velocity results indicate the speed at which water moves through the river channel during flood conditions. The analysis shows that velocity increases rapidly during the initial stages of rainfall due to sudden runoff generation. Peak velocity values are observed in sections with steep slopes and narrow channels, where water flows more rapidly. High velocity can lead to erosion of riverbanks and damage to infrastructure such as bridges and culverts. In contrast, areas with low velocity are characterized by water stagnation, which leads to prolonged inundation and waterlogging. These areas are particularly problematic in urban environments, as stagnant water can cause health and sanitation issues. The velocity analysis helps in identifying zones of erosion and deposition, providing valuable information for river management and flood mitigation.

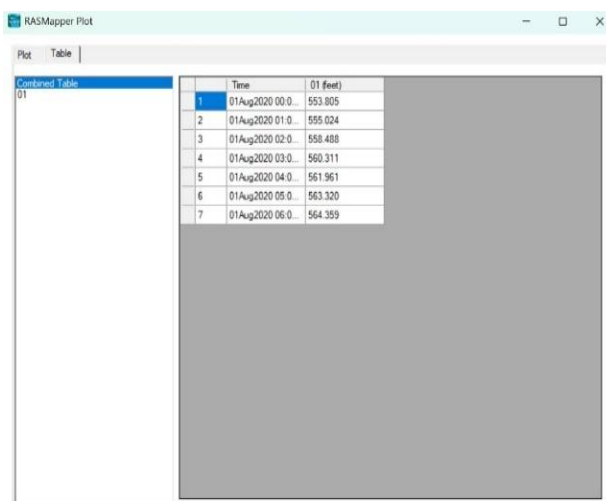


Fig. 6.3 Velocity Data Table at Selected Point

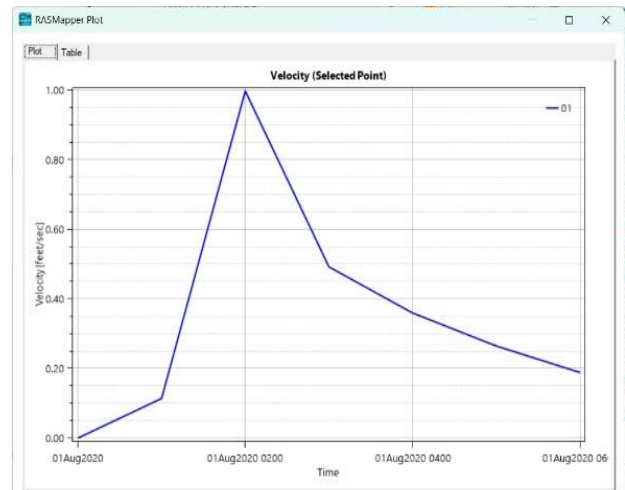


Fig. 6.4 Velocity vs Time Graph

F. Flood Depth Analysis

Flood depth is one of the most important parameters in assessing the severity of flooding. The depth results obtained from the model indicate that water depth increases significantly in low-lying areas during flood events. Regions with higher flood depth are identified as high-risk zones, as they experience severe inundation and longer water retention periods. These areas are often located near the riverbanks and in regions with poor drainage. The depth analysis helps in estimating the extent of damage that may occur during flooding. It also supports the development of evacuation plans and emergency response strategies.

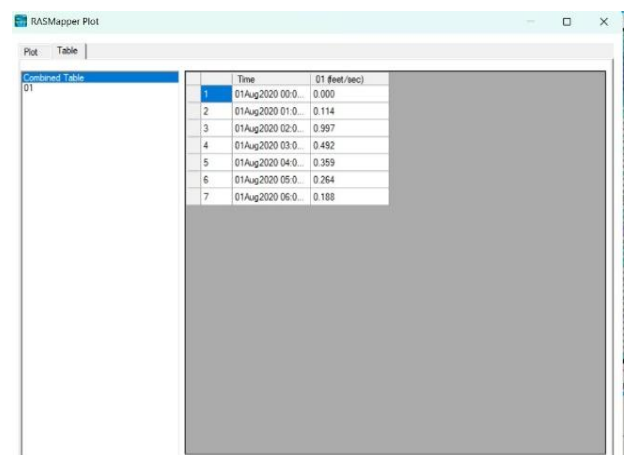


Fig. 6.5 Flood Depth Table at Selected Point

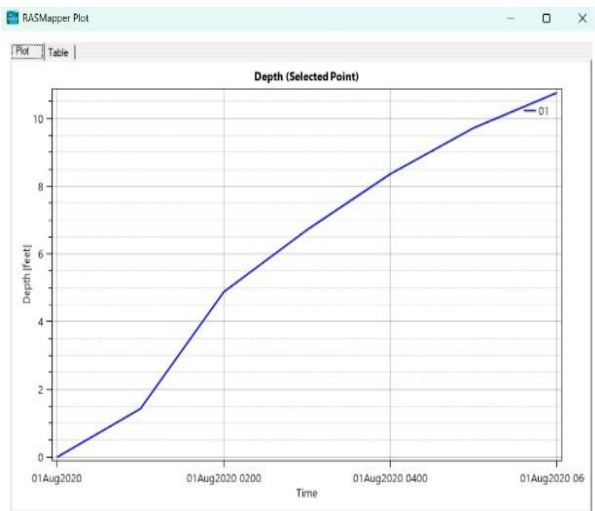


Fig. 6.6 Flood Depth vs Time Graph

G. Flood Inundation Mapping

Flood inundation maps generated using GIS provide a visual representation of areas affected by flooding. These maps show the spatial distribution of flood depth and extent, making it easier to identify vulnerable zones. The integration of hydraulic model outputs with GIS enables the creation of detailed flood maps that can be used for planning and decision-making. These maps highlight areas that require immediate attention and help in prioritizing mitigation measures. Flood inundation mapping is a powerful tool for communicating results to stakeholders and raising awareness about flood risks [22].

H. Impact of Urbanization on Flooding

The results clearly indicate that urbanization has a significant impact on flood behaviour in Pune city. The increase in impervious surfaces has led to higher surface runoff and reduced infiltration. Encroachment on natural drainage channels has further aggravated the problem by obstructing water flow. As a result, even moderate rainfall events can lead to flooding in certain areas. The analysis highlights the need for proper urban planning and the implementation of sustainable drainage systems to reduce flood risk.

I. Identification of Flood-Prone Zones

Based on the combined analysis of terrain, rainfall, and hydraulic parameters, several flood-prone zones have been identified within the study area. These zones are characterized by:

- Low elevation
- High flow accumulation
- High flood depth
- Poor drainage conditions

The identification of these zones is essential for effective flood management. It helps authorities in implementing targeted measures to reduce flood risk and protect vulnerable areas.

Summary of Results and Analysis

In summary, the results of this study provide a comprehensive understanding of flood behaviour in Pune city. The integration

of GIS and hydraulic modelling has enabled the identification of flood-prone zones and the analysis of key parameters such as WSE, velocity, and depth. The findings highlight the significant impact of terrain, rainfall, and urbanization on flood occurrence. The study demonstrates the effectiveness of combining geospatial and hydraulic modelling techniques for flood risk assessment and provides valuable insights for planning and mitigation strategies.

VII. DISCUSSION

The discussion section provides a detailed interpretation of the results obtained from the integration of geospatial analysis using QGIS and hydraulic modelling using HEC-RAS. The findings of this study are critically analysed to understand the influence of terrain, rainfall, and urbanization on flood behaviour in the Mutha River basin located in Pune. The discussion also highlights the practical implications of the results for civil engineering applications and flood management strategies.

A. Influence of Topography on Flood Behaviour

The results clearly indicate that topography plays a fundamental role in controlling flood dynamics within the study area. The elevation and slope derived from DEM analysis show that water naturally flows from higher elevations in the western region towards the lower-lying central and eastern parts of Pune. Low-lying areas act as natural collection points for runoff, leading to water accumulation and prolonged flooding. The presence of gentle slopes in urban regions further reduces the rate of water movement, increasing the chances of waterlogging. This observation confirms that terrain characteristics must be carefully considered in flood modelling and urban planning [23].

B. Role of Rainfall Intensity and Duration

Rainfall analysis reveals that high-intensity rainfall events are the primary drivers of flooding in Pune city. The study shows that short-duration, intense rainfall leads to rapid runoff generation, overwhelming the drainage capacity of the region. The incorporation of 20 years of rainfall data into the model provides a realistic representation of hydrological conditions. The results demonstrate that extreme rainfall events significantly increase Water Surface Elevation (WSE) and flood depth, resulting in overflow of the river channel. This highlights the importance of considering rainfall variability and extreme events in flood modelling. It also emphasizes the need for developing early warning systems and rainfall monitoring mechanisms to reduce the impact of floods [24].

C. Impact of Urbanization on Hydrological Response

Urbanization has a significant impact on the hydrological behaviour of the study area. The conversion of natural land surfaces into impervious surfaces such as roads, buildings, and pavements reduces infiltration and increases surface runoff. The study indicates that areas with high urban density experience more severe flooding compared to less developed regions. Encroachment on natural drainage channels and floodplains further obstructs water flow, leading to localized flooding.

D. Interpretation of Hydraulic Parameters

The hydraulic modelling results provide valuable insights into flood behaviour through parameters such as Water Surface Elevation (WSE), flow velocity, and flood depth.

- a) Water Surface Elevation (WSE): The gradual increase in WSE indicates rising water levels during rainfall events, which can lead to overflow in certain sections of the river.
- b) Flow Velocity: The variation in velocity across different sections of the river highlights areas of erosion and deposition. High velocity zones are associated with potential structural damage, while low velocity zones indicate water stagnation.
- c) Flood Depth: The increase in flood depth in low-lying areas indicates severe inundation and higher flood risk.

These parameters collectively provide a comprehensive understanding of flood dynamics and help in identifying critical areas that require intervention.

E. Effectiveness of Integrated Modelling Approach

The integration of GIS and hydraulic modelling has proven to be highly effective in analysing flood-prone areas. GIS provides spatial information about terrain and drainage patterns, while HEC-RAS simulates water flow and flood conditions. This combined approach allows for accurate identification of flood-prone zones and provides both qualitative and quantitative insights into flood behaviour. The use of geospatial techniques enhances the visualization of results, making it easier to interpret and communicate findings. The study demonstrates that integrated modelling is a powerful tool for flood risk assessment and can be applied to other urban areas facing similar challenges.

F. Identification of Critical Flood Zones

Based on the analysis, several critical flood-prone zones have been identified within the study area. These zones are characterized by:

- a) Low elevation
- b) High flow accumulation
- c) High flood depth
- d) Poor drainage infrastructure

These areas are more vulnerable to flooding and require immediate attention. The identification of such zones is essential for implementing targeted flood mitigation measures and reducing the impact of future flood events.

G. Limitations of the Study

While the study provides valuable insights into flood behaviour, certain limitations must be acknowledged.

- a) The accuracy of the model depends on the quality of input data such as DEM and rainfall data.
- b) Simplifications in hydraulic modelling may not fully capture complex flow behaviour.
- c) Limited availability of field data may affect the validation of results.

Despite these limitations, the study provides a reliable framework for flood analysis and highlights areas for future improvement.

H. Implications for Civil Engineering Practice

The findings of this study have significant implications for civil engineering practice, particularly in the field of water resources

and urban planning. Engineers can use the results to design efficient drainage systems and flood control structures. The identification of flood-prone zones helps in planning infrastructure development and avoiding construction in high-risk areas. The study also supports the development of sustainable solutions such as green infrastructure, which can reduce surface runoff and improve water management.

I. Recommendations for Flood Mitigation

Based on the discussion, several recommendations can be made to reduce flood risk in Pune city:

- a) Improvement of stormwater drainage systems
- b) Preservation of natural drainage channels
- c) Implementation of rainwater harvesting systems
- d) Development of flood forecasting and warning systems
- e) Adoption of sustainable urban planning practices

These measures can help in minimizing the impact of floods and enhancing the resilience of urban areas [25].

Summary of Discussion

In summary, the discussion highlights the key factors influencing flood behaviour in Pune city, including terrain characteristics, rainfall intensity, and urbanization. The integration of GIS and hydraulic modelling provides a comprehensive understanding of flood dynamics and supports effective flood risk assessment.

The study emphasizes the need for sustainable urban planning and improved water management practices to reduce flood risk and ensure long-term resilience.

VIII. CONCLUSION

The present study successfully demonstrates the application of hydrological modelling integrated with geospatial techniques for the analysis of flood-prone areas in Pune, particularly focusing on the Mutha River basin. The project effectively combines the capabilities of QGIS for spatial analysis and HEC-RAS for hydraulic simulation, providing a comprehensive framework for understanding flood behaviour in an urban environment.

The use of Digital Elevation Model (DEM) data enabled detailed terrain analysis, including slope, elevation, flow direction, and watershed delineation. These analyses helped in identifying the natural drainage patterns and low-lying regions that are more susceptible to flooding. The study clearly establishes that topography plays a significant role in controlling the movement and accumulation of water during rainfall events. Areas with gentle slopes and low elevation were found to be highly vulnerable due to reduced runoff velocity and increased water retention.

The incorporation of long-term rainfall data (2004–2024) from the India Meteorological Department (IMD), Pune, provided a realistic basis for hydrological modelling. The analysis of rainfall patterns revealed that high-intensity and short-duration rainfall events are the primary causes of flooding in the study area. These events lead to rapid generation of surface runoff, which exceeds the capacity of existing drainage systems and results in urban flooding.

The hydraulic modelling carried out using HEC-RAS provided detailed insights into flood parameters such as Water Surface Elevation (WSE), flow velocity, and flood depth. The results indicated a significant rise in water levels during peak rainfall conditions, leading to overflow in certain sections of the river. Velocity analysis highlighted areas prone to erosion and structural damage, while depth analysis identified zones of severe inundation. These parameters collectively contributed to a better understanding of flood dynamics and their impact on the study area.

The integration of GIS and hydraulic modelling proved to be highly effective in identifying flood-prone zones. The flood inundation maps generated through this approach provided a clear visualization of affected areas, enabling easy interpretation and communication of results. The study successfully identified critical zones characterized by low elevation, high flow accumulation, and poor drainage conditions, which are highly vulnerable to flooding.

Another important outcome of this study is the identification of the impact of urbanization on flood behaviour. The increase in impervious surfaces, encroachment on natural drainage channels, and inadequate stormwater management systems have significantly contributed to the severity of flooding in Pune city. The findings highlight the need for sustainable urban planning practices that consider natural hydrological processes and ensure efficient water management.

The study also emphasizes the importance of adopting modern tools and technologies in civil engineering practice. The use of QGIS and HEC-RAS enables engineers to perform detailed analysis and develop data-driven solutions for complex problems such as urban flooding. The methodology developed in this project can be applied to other regions facing similar challenges, making it a valuable contribution to the field of hydrology and water resources engineering.

Furthermore, the results of this study can be utilized by urban planners, engineers, and policymakers for designing effective flood mitigation strategies. Measures such as improving drainage infrastructure, preserving natural waterways, implementing rainwater harvesting systems, and developing early warning systems can significantly reduce the impact of floods. The study provides a scientific basis for such interventions and supports informed decision-making. In conclusion, this project highlights the effectiveness of integrating geospatial analysis and hydraulic modelling for flood risk assessment. It provides a comprehensive understanding of the factors influencing flood behaviour and offers practical solutions for managing flood risks in urban areas. The findings contribute to enhancing the resilience of cities like Pune against flooding and promote the development of sustainable and safe urban environments.

IX. FUTURE SCOPE

The present study provides a comprehensive framework for analysing flood-prone areas using geospatial techniques and hydraulic modelling. However, there is significant scope for further improvement and expansion of the work to enhance

accuracy, applicability, and real-time usability in civil engineering and urban planning practices.

A. Implementation of Advanced 2D and 3D Hydraulic Modelling

In this study, flood analysis is primarily carried out using hydraulic modelling techniques. In future, the implementation of advanced 2D and 3D hydraulic models using HEC-RAS can significantly improve the accuracy of flood simulation. 2D modelling allows for better representation of lateral water spread and complex flow behaviour in urban areas, especially where multiple flow paths exist. It can simulate real-world conditions more effectively compared to traditional 1D models. The use of 3D modelling can further enhance visualization and provide detailed insights into velocity distribution and turbulence effects.

B. Integration of Real-Time Data and Flood Forecasting Systems

Future work can focus on integrating real-time rainfall and river flow data into the modelling framework. By linking the model with live data from weather stations and sensors, it is possible to develop a real-time flood forecasting system. Such systems can provide early warnings to authorities and the public, helping to reduce the impact of floods. The integration of Internet of Things (IoT) devices and automated monitoring systems can further enhance data collection and improve prediction accuracy.

C. Inclusion of Climate Change Impact Analysis

Climate change is expected to increase the frequency and intensity of extreme rainfall events. Future studies can incorporate climate change scenarios to analyse their impact on flood behaviour in Pune. By using climate models and projected rainfall data, it is possible to assess future flood risks and develop long-term mitigation strategies. This will help in designing resilient infrastructure capable of withstanding extreme weather conditions.

D. Detailed Urban Drainage and Stormwater Network Analysis

The current study focuses on natural drainage patterns and river flow. Future work can include a detailed analysis of urban drainage networks, including stormwater drains, culverts, and sewer systems. By integrating drainage network data into the model, a more accurate representation of water flow in urban areas can be achieved. This will help in identifying bottlenecks and designing efficient drainage systems to prevent waterlogging and flooding.

E. Use of High-Resolution Data and Remote Sensing Techniques

The accuracy of hydrological modelling can be further improved by using high-resolution DEM and satellite data. Advanced remote sensing techniques such as LiDAR can provide detailed elevation data, enabling precise terrain analysis. The use of high-resolution imagery can also improve land use classification and help in identifying small-scale features that influence flood behaviour. Integration with QGIS can enhance spatial analysis capabilities and provide more reliable results.

F. Development of Decision Support Systems (DSS)

Future research can focus on developing a Decision Support System (DSS) for flood management. Such a system can integrate GIS, hydraulic modelling, and real-time data to provide actionable insights for decision-makers. A DSS can help authorities in planning evacuation routes, allocating resources, and implementing mitigation measures during flood events. It can also be used for long-term urban planning and infrastructure development.

G. Application of Machine Learning and Artificial Intelligence

The integration of machine learning (ML) and artificial intelligence (AI) techniques can significantly enhance flood prediction and analysis. ML models can be trained using historical data to predict flood occurrence and severity. AI-based approaches can also be used to optimize model parameters and improve simulation accuracy. Combining traditional hydrological models with data-driven techniques can provide more robust and reliable results.

H. Expansion to Other River Basins and Urban Areas

The methodology developed in this study can be extended to other river basins and urban areas facing similar flooding issues. By applying the same approach to different regions, it is possible to develop a generalized framework for flood risk assessment. This will contribute to the development of standardized methods for flood analysis and support large-scale planning and management efforts.

I. Implementation of Sustainable Flood Management Practices

Future work can focus on the implementation of sustainable solutions such as:

- Green infrastructure (rain gardens, bioswales)
- Permeable pavements
- Rainwater harvesting systems
- Floodplain restoration

These practices can reduce surface runoff, improve water infiltration, and enhance the natural capacity of the environment to manage floodwaters.

J. Validation with Field Data and Case Studies

Further studies can include validation of model results using field data collected during actual flood events. This will help in improving model accuracy and reliability. Conducting detailed case studies and field surveys can provide practical insights into flood behaviour and support the development of more effective mitigation strategies.

Summary of Future Scope

In summary, the future scope of this project lies in enhancing modelling techniques, integrating real-time data, incorporating

climate change impacts, and developing advanced decision-making tools. The adoption of modern technologies such as remote sensing, AI, and IoT can significantly improve flood prediction and management. The continued development and application of such integrated approaches will play a vital role in reducing flood risk and ensuring sustainable urban development in cities like Pune.

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