A DISSERTATION PHASE I

ON

"GIS BASED INTEGRATED FLOOD AND EROSION RISK MAPPING IN BARPETA DISTRICT USING AHP APPROACH"

Submitted in Partial Fulfillment for the Requirements for the award of Degree of

MASTERS OF TECHNOLOGY (CIVIL ENGINEERING)

UNDER

ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY

HRISHIK SARMA

MTECH 3RD SEMESTER

Roll no-230620061009

Under the guidance of:

Dr. BHARATI MEDHI DAS

PROFESSOR

DEPARTMENT OF CIVIL ENGINEERING

ASSAM ENGINEERING COLLEGE

JALUKBARI, GUWAHATI-781013

SESSION: 2023-2025

SELF DECLARATION

The work contained in the report **"GIS Based Integrated Flood and Erosion Risk Mapping in Barpeta District Using AHP Approach"** has been carried out by me under the supervision of **Dr. BHARATI MEDHI DAS**, Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari. The project is submitted in partial fulfillment of requirements for the award of the degree of "Master of Technology in Civil Engineering" under specialization on Water Resources Engineering to the Department of Civil Engineering, Assam Engineering College, Jalukbari , Guwahati-781013, Assam.

The matter embodied in this dissertation has not been submitted to any other institute for the award of any other degree. I have followed the guidelines provided by the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-781013, Assam. Whenever materials from other sources are used, due acknowledgement is given to them by citing them in the text of this project and giving their details in the references.

This is to certify that the above statement made is correct to the best of my knowledge.

Date:
Place: Assam Engineering College
Jalukabri, Guwahti, Assam

NAME - HRISHIK SARMA
MTech 3rd Semester
Department of Civil Engineering
Assam Engineering College

CERTIFICATE FOR APPROVAL

This is to certify that the dissertation report **entitled "GIS Based Integrated Flood and Erosion Risk Mapping in Barpeta District Using AHP Approach"** is submitted by **HRISHIK SARMA, Roll No 230620061009,** a student of 3rd semester in the Department of Civil Engineering, Assam Engineering College, Guwahati in partial fulfilment for the award of degree of **MASTERS OF TECHNOLOGY** in Civil Engineering with specialisation in **Water Resources Engineering** under **ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY** has been carried out under my guidance.

The content of this report has not been submitted to any other university for the award of any degree.

Date –

Place – Jalukbari, Guwahati

Dr. Bharati Medhi Das
Professor
Department of Civil Engineering
Assam Engineering College
Jalukbari, Guwahati, 781013

CERTIFICATE FROM THE HEAD OF THE DEPARTMENT

It is to certify that the project report entitled **"GIS Based Integrated Flood and Erosion Risk Mapping in Barpeta District Using AHP Approach"** is hereby accorded our approval as a study carried out and presented in a manner in their 3rd semester courses for acceptance in partial fulfilment for the award of Master of Technology in Civil Engineering under specialisation on Water Resources Engineering degree for approval does not necessarily endorse or accept every statement made, opinion expressed or conclusion drawn as recorded in the report. It only signifies the acceptance of the project report for the purpose for which it is submitted.

Date:
Place: Jalukbari, Guwahati

Dr. Jayanta Pathak

Professor & Head
Department of Civil Engineering
Assam Engineering College
Jalukbari, 781013

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude to all the people whose kind help and guidance has been instrumental towards the completion of this report. I would like to thank my guide **Dr. Bharati Medhi Das**, Professor, Department of Civil Engineering, Assam Engineering College for her immense help, kind support and constant encouragement throughout the course of my work.

I am indebted to **Dr. Jayanta Pathak**, Head, Department of Civil Engineering and all the faculties of Department of Civil Engineering, Assam Engineering College, for the deep insights and discernment given through the various courses they had taught.

NAME: Hrishik Sarma

M.tech 3rd semester

ASTU ROLL: 230620061009

ABSTRACT

The GIS based remote sensing has been accepted widely as an as an effective tool to study complex problems associated with water resource management. The vulnerability of Barpeta District to flooding and water erosion necessitates an in-depth analysis to facilitate effective disaster management and land-use planning. This thesis aims to develop comprehensive flood risk and water erosion maps using Geographic Information Systems (GIS) coupled with the Analytic Hierarchy Process (AHP).

The study begins by identifying key criteria influencing flood risk and erosion, such as topography, soil type, land use/land cover, rainfall intensity, drainage density, proximity to water bodies etc. These criteria are then weighted through AHP, a multi-criteria decision-making method, to reflect their relative importance in determining flood and erosion susceptibility. GIS technology is utilized to overlay these weighted criteria, thereby creating detailed spatial maps that depict areas of high to low risk for both phenomena. The resulting maps provide a visual representation of the areas most at risk, which is crucial for informing local authorities and policymakers about where to focus mitigation efforts, such as flood defenses, land use zoning, and erosion control measures.

This research not only contributes to the scientific understanding of environmental hazards in Barpeta District but also offers practical applications for enhancing resilience against natural disasters, ensuring sustainable development in flood and erosion-prone regions. The findings underscore the utility of combining GIS with AHP for environmental risk assessment, offering a model that can be adapted to other similar geographical contexts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1GENERAL

Floods and water erosion are known to offer significant environmental challenges in states like Assam, known for its vulnerability to monsoon induced flooding and flood degradation. This study through integration of Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) aims to conduct a comprehensive assessment for flood risk and water erosion in the Barpeta District of Assam. The primary objective is to produce detailed and accurate flood risk maps and erosion maps using ArcGIS and ArcGIS Pro, focusing on Barpeta District in Assam which is physically and climatically sensitive to natural disasters.

GIS technology helps in making it easier to spatially analyze crucial environmental elements such as topography, soil types, land use, drainage patterns, and rainfall data (Smith et al. 2020). Overlaying these layers allows us to see the spatial distribution of flood and erosion hazards throughout the area. AHP, as defined by Saaty (1980) et al., is used to manage the complexity of decision-making in environmental risk assessments. It entails assessing the relative importance of several criteria via pair wise comparisons, and then giving weights that represent their impact on the overall risk profile. This strategy quantifies expert opinions and deals with many criteria in a systematic manner, even when they dispute.

The approach consists of data collecting from several sources (satellite imagery, meteorological data, and local records), data pretreatment for interoperability with GIS tools, the use of AHP for weighting criteria, and spatial analysis to generate risk maps. These maps will depict areas of 'high', 'moderate', and 'low' risk, which are critical for strategic disaster management planning such as evacuation, infrastructure development, and sustainable farming practices. This study intends not only to map existing flood and erosion threats, but also to develop a reproducible methodology for similar environmental scenarios. This project aims to improve decision-making for environmental protection, land use planning, and sustainable development in Barpeta District by integrating GIS and AHP, with the ultimate goal of mitigating disaster impacts on both the environment and the community.

1.1 OBJECTIVES OF THE STUDY

The main objectives of the study are listed below:-

- To identify and assess key environmental criteria influencing flood and erosion risks, including topography, soil type, land use, rainfall, and drainage patterns.
- To apply the Analytic Hierarchy Process (AHP) for weighting these criteria based on their relative importance to hazard assessment.
- To apply precise and accurate hazard risk values to criterias affecting flood.
- To determine flow accumulation and flow direction value of study area for analyzing criteria.
- To accurately classify each criterion as per requirement of the study
- To enhance community resilience by pinpointing high-risk areas for targeted interventions and public awareness campaigns.
- To demonstrate the effectiveness of combining GIS with AHP in environmental risk assessment, offering a model that can be adapted for similar contexts elsewhere.

CHAPTER 2

LITERATURE REVIEW

Smith et al. (2020) introduced the use of GIS for flood risk mapping, emphasizing the integration of various data sources like rainfall, topography, and land use to create detailed risk maps. Their work highlighted the effectiveness of GIS in visualizing spatial data for better decision-making. The integration of multi-source data in GIS provided a more detailed and accurate depiction of flood risk than simpler models. They could visualize not just where flooding might occur but also understand the implications in terms of population, infrastructure, and economic assets affected. The resultant maps were instrumental for emergency planning, urban development, insurance assessments, and public policy formulation.

Rahman et al. (2016) applied AHP in conjunction with GIS to assess flood risk in urban areas, demonstrating that AHP's ability to weight different criteria could significantly improve the accuracy and reliability of flood maps. The study was carried out in Riyadh, Saudi Arabia, and focused on the vulnerability to flash floods, which are a major issue due to the city's fast growth and meteorological circumstances that occasionally result in severe, short-duration rainfalls. Experts compared the criteria pair wise using Saaty's 1-9 scale to evaluate their relative relevance in contributing to flood danger. The study produced a vulnerability map indicating regions in Riyadh that are at high, medium, and low risk of flash floods. Areas with a high percentage of impermeable surfaces, poor drainage, and closeness to river were recognized as more vulnerable. The findings underscored the need for better urban planning, particularly in managing drainage systems and controlling development in high-risk areas.

Gupta et al. (2021) proposed an integrated approach combining both flood and erosion risks using GIS and AHP, similar to the methodology of this project. Their work in another Indian context supports the feasibility and benefits of such an integrated approach. AHP, when combined with GIS, provides a powerful tool for decision-makers in urban planning and disaster management. The methodology offers a scalable approach that can be adapted to other urban areas, helping in the prioritization of mitigation measures. Their study supports the need for integrating scientific methods in urban planning to reduce disaster risks, potentially influencing policy decisions regarding land use and infrastructure development

Mattivi et al. (2019) published a paper called "Topographic Wetness Index calculation guidelines based on measured soil moisture and plant species composition." Their study focused on the Topographic Wetness Index (TWI), a tool used to quantify soil moisture and water accumulation based on topographical factors. Here's an overview of their findings: This work improves our understanding of how TWI can be customized to specific environmental circumstances for greater accuracy, resulting in a methodological development in the application of topographic indices in environmental science. It also emphasizes the significance of empirically validating such indices using field data to assure their applicability in real-world circumstances.

Zhao et al. (2020) authored a study titled "Topographic Wetness Index calculation guidelines based on measured soil moisture and plant species composition.". The study emphasized that the method of flow dispersion in TWI calculations significantly affects its accuracy in predicting soil moisture. The TWI calculated with the FD8 (Freeman's algorithm) showed the best correlation with soil moisture and plant species assemblages, particularly when the flow dispersion parameter was close to 1.0.

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

3.1 INFORMATION OF THE STUDY AREA

Barpeta District, nestled in the state of Assam, India, presents a unique blend of geography, climate, and hydrology that significantly shapes its environmental and socio-economic landscape. The district spans across approximately 2,243.96 square kilometers, with its topography ranging from flat plains to gentle slopes and small hillocks in the southwest, known as Baghbar, Fulora, and Chatala. These hills overlook the mighty Brahmaputra River, which flows east to west along the southern boundary, influencing the district's landscape and life profoundly. Barpeta is bordered by various districts, including Baksa to the north, Bajali to the east, Kamrup and Goalpara to the south, and Bongaigaon and Chirang to the west, creating a diverse geographical interface.

The climate here is humid subtropical with a dry winter, characterized by three distinct seasons: a hot, humid summer from March to May with temperatures often exceeding 35°C; a monsoon season from June to September, where Barpeta receives an average annual rainfall of about 2,110 millimeters, occasionally leading to floods; and a cooler, more pleasant winter from October to February. This climatic pattern not only affects agriculture, the primary occupation, but also poses challenges with flood and water management.

Water bodies in Barpeta are numerous, with the Brahmaputra being the most significant. It is joined by several tributaries like the Beki, Manah, Pohumara, Kaldia, Palla, Nakhanda, Marachaulkhowa, and Bhelengi, which crisscross the district, contributing to its rich aquatic life and agricultural potential but also making it prone to flooding and erosion. The confluence of rivers like Pohumara and Kaldia near Barpeta town, forming the Nakhanda River, underscores the complex hydrological network here.

Culturally, Barpeta is regarded as the "Satra Nagari," as it is home to multiple Vaishnavite Satras that play an important role in preserving and promoting Assamese religion and culture. The district's proximity to Manas National Park, which is currently in a distinct administrative division, has traditionally had an impact on local biodiversity and environment. Barpeta's unusual combination of geographical features, climatic circumstances, and an extensive river system makes it a focal point for disaster management research and initiatives, notably those involving flood risk and erosion control. The constraints offered by its natural environment are balanced by its cultural diversity, making it an appealing location for combined environmental and cultural research.

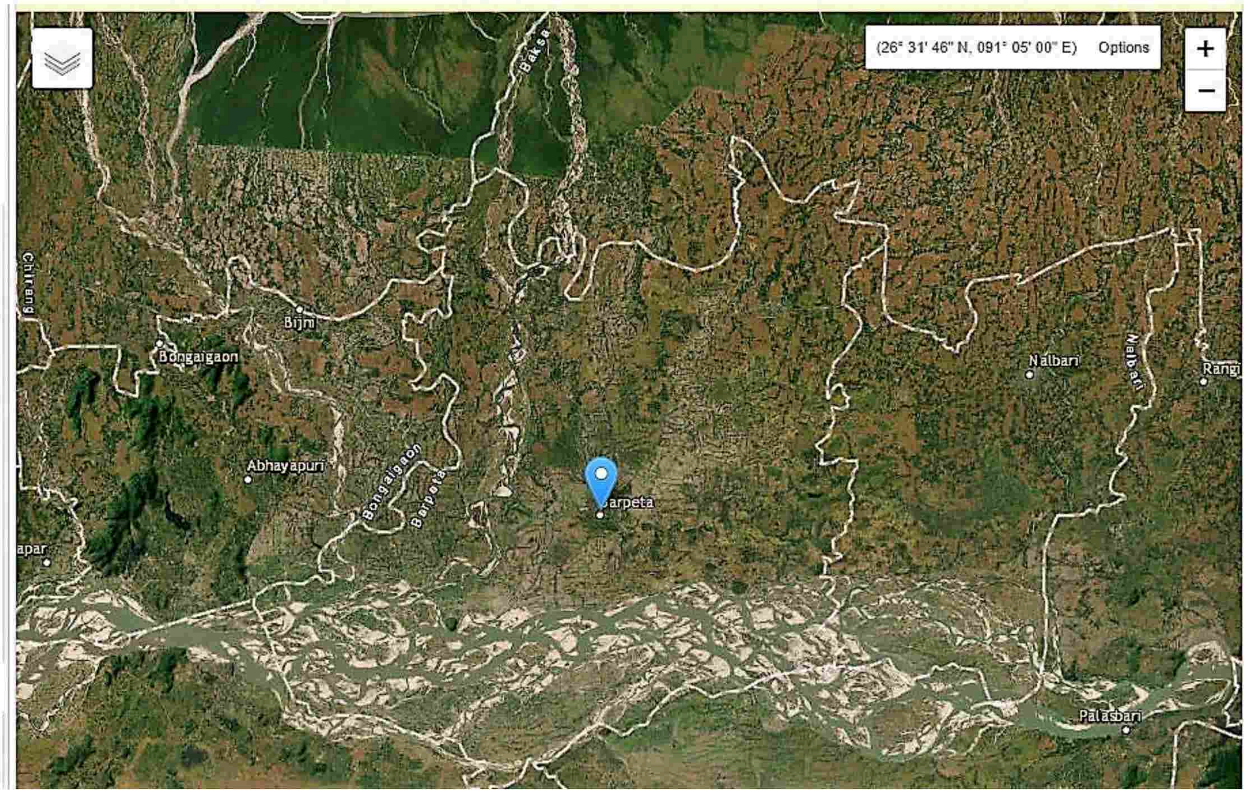


Fig 3.1 USGS earth explorer image showing the study area of Barpeta district

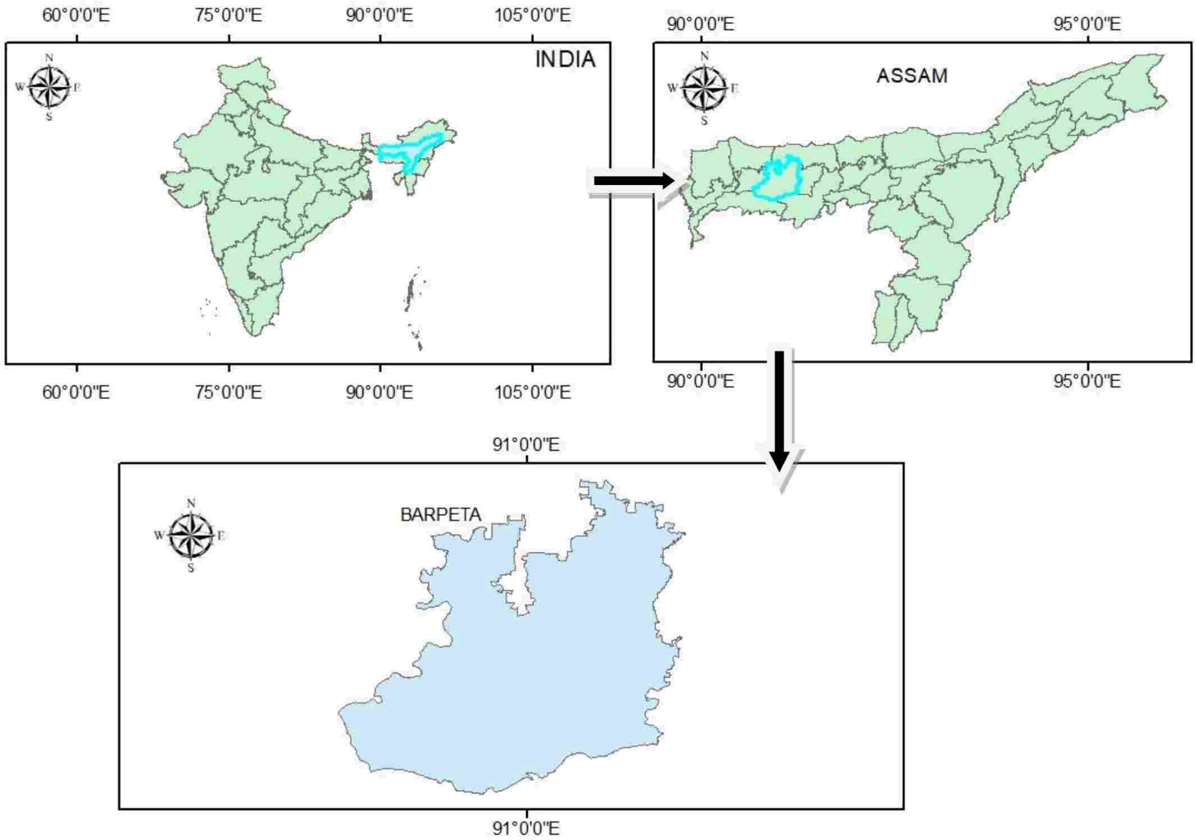


FIGURE 3.2 Study area in ArcGIS layout a) INDIA b) ASSAM c) BARPETA

In recent years, Barpeta District in Assam, India, has seen a disturbing trend of flooding and its consequences, caused by both natural and man-made factors. The primary natural cause is heavy monsoon rains, which have become more severe and variable as a result of climate change. This rains leads the Brahmaputra River and its other tributaries, including the Beki, Manah, and Pohumara, to overflow their banks. The rivers transport not just water but also considerable sediment loads, resulting in siltation and changes in river courses, exacerbating flooding in formerly unaffected areas. Human activities have also contributed significantly to the severity of the flood crisis. Deforestation in upper catchments and within the district diminishes natural water retention and speeds up runoff into rivers.

Urbanization without adequate planning has led to the blocking of natural drainage systems, causing waterlogging even during moderate rains. Furthermore, the construction of embankments, while aimed at flood control, sometimes fails or breaches, causing severe flooding in areas behind these structures.

The effects of these floods on Barpeta District are multifaceted and profound:

Agricultural Damage: Vast areas of cropland are inundated, leading to the destruction of crops, particularly during critical growth stages. This not only affects the current year's yield but also long-term soil fertility due to sediment deposition.

Economic Loss: The agricultural sector's downturn directly impacts the local economy, with farmers losing income and facing increased costs for replanting. The damage to infrastructure like roads, bridges, and homes adds to economic strain, with recovery often slow due to limited resources.

Health Risks: Floodwaters bring increased risks of waterborne diseases, compounded by damaged sanitation systems. The displacement of populations into relief camps can lead to outbreaks of diseases like cholera, dengue, and malaria.

Displacement and Livelihood: Many residents are forced to leave their homes temporarily or permanently, leading to a loss of livelihood, especially in riverine or char areas where land tenure is insecure. This displacement disrupts education, as schools often double as relief shelters.

CHAPTER 4

THEORITICAL BACKGROUND

4.1 GENERAL

Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) are powerful tools when combined for the mapping of flood risk and soil erosion, offering a methodical approach to understanding and mitigating these environmental hazards.

GIS for Mapping:

GIS technology excels in managing, analyzing, and visualizing spatial data. For flood risk and erosion mapping, GIS can integrate various data layers such as:

Topography: Using Digital Elevation Models (DEMs) to understand terrain and predict water flow paths.

Land Use/Land Cover: To assess how different land uses (urban, agricultural, forest) affect water accumulation and runoff.

Hydrology: Mapping rivers, streams, and drainage systems to evaluate flood paths and water accumulation zones.

Rainfall Data: Overlaying historical and real-time precipitation data to predict areas prone to flooding.

Soil Characteristics: Including soil type, permeability, and erosion potential.

GIS allows for the overlay of these layers to create detailed maps showing areas at risk of flooding or erosion. It can perform spatial analysis like flow accumulation, watershed delineation, and slope analysis, all critical for understanding water movement and soil loss.

AHP for Decision Making:

The Analytic Hierarchy Process (AHP) complements GIS by providing a structured technique for multi-criteria decision analysis. Here's how AHP can be applied:

Criteria Selection: Experts or stakeholders identify key factors influencing flood risk or erosion, like rainfall intensity, slope, proximity to rivers, land use, etc.

Hierarchy Construction: AHP organizes these factors into a hierarchical structure where the goal (e.g., flood risk assessment) sits at the top, followed by criteria and sub-criteria.

Pairwise Comparisons: Each criterion is compared with others in terms of importance or influence on the goal. AHP uses a scale from 1 to 9 for these judgments.

Weight Determination: Through matrix calculations, weights are assigned to each criterion, reflecting their relative importance. This process involves normalizing the matrix and computing an eigenvector to derive these weights.

Consistency Check: AHP ensures the consistency of judgments with a consistency ratio, refining the decision-making process.

4.2 Flood risk mapping

Flood risk mapping is an important tool in disaster management and urban planning since it visualizes and analyzes flood-prone areas. This procedure consists of multiple processes and uses a variety of data sources to determine where, how frequently, and to what degree flooding may occur, assisting in the planning and mitigation of flood-related damages. Flood risk mapping is fundamentally about creating predictive models by combining hydrological, meteorological, and geographical data. Hydrological data comprises information on rivers, streams, drainage networks, and past flood events, which aids in understanding water flow patterns and potential inundation zones. Meteorological data, particularly rainfall patterns, helps anticipate how much water will enter these systems during a storm. Geographic information includes topography, land usage, and soil types, all of which influence how water moves across and into the landscape.

Once the data is assembled, flood risk mapping typically involves:

- Hazard Assessment: Determining the likelihood of flooding by modeling water depth, velocity, and duration based on historical data and predictive modeling. This can include scenarios for different rainfall intensities or river discharges.
- Vulnerability Assessment: Evaluating how exposed populations, infrastructure, and ecosystems are to flood hazards. This considers factors like population density, building types, and the economic value of assets.
- Risk Calculation: Combining hazard and vulnerability assessments to produce maps that categorize areas by risk level—often depicted as zones ranging from low to high risk. This step can involve integrating socioeconomic data to understand the impact on communities.

- Mapping and Visualization: Producing maps that are not only informative for experts but also accessible to the public, policymakers, and emergency services. These maps can show potential flood extents, evacuation routes, and areas for intervention.

Flood risk maps are crucial for proactive measures like land-use planning, where zoning laws can be adjusted to restrict development in high-risk areas, or for engineering solutions like flood defenses. They also play a key role in emergency preparedness, helping to design evacuation plans, allocate resources, and inform insurance assessments. Moreover, by communicating risks to communities, these maps foster increased public awareness and resilience, encouraging local adaptations like improving drainage or elevating structures.

4.3 Water erosion mapping

Water erosion mapping focuses on identifying and visualizing areas where soil loss occurs due to the action of water, encompassing processes like sheet, rill, gully, and stream bank erosion. This mapping is essential for land management, environmental protection, and agricultural sustainability, as it helps pinpoint where preventive measures should be implemented. The process of mapping water erosion involves several steps and utilizes a range of data:

Topographic Analysis: Digital Elevation Models (DEMs) are crucial for understanding the slope and relief of the land. Steeper slopes are generally more susceptible to water erosion due to increased runoff speed.

Soil Properties: Soil texture, structure, organic content, and permeability are analyzed to determine soil erodibility. Soils with lower organic matter or those that are more compacted are more likely to erode.

Vegetation and Land Cover: The presence, type, and density of vegetation help in assessing erosion risk. Vegetation slows down water flow, reduces splash erosion, and its roots bind soil particles together.

Climatic Factors: Rainfall intensity, duration, and frequency are key. Areas with high-intensity rainfall events experience more significant erosion due to the increased energy of water impacting the soil.

Land Use Practices: Agriculture, urbanization, deforestation, and other human activities can either mitigate or exacerbate erosion. Practices like contour farming or terracing can reduce erosion, while clear-cutting forests can dramatically increase it.

Hydrological Features: Mapping rivers, streams, and drainage patterns helps understand how water is channeled across the landscape, potentially leading to specific forms of erosion like gully formation in poorly managed areas.

Using GIS, these factors are integrated into a spatial framework where:

- Erosion Models like the Universal Soil Loss Equation (USLE) or its revisions (RUSLE) are applied. These models estimate soil loss based on rainfall erosivity, soil erodibility, slope length and steepness, cover-management factor, and supporting practices.
- Simulation: Models simulate water flow and soil detachment, providing predictions on where erosion is likely to be most severe.
- Risk Assessment: Areas are then classified based on erosion risk, often visualized through color-coded maps where darker or brighter colors signify higher erosion rates.
- Mapping Outputs: The final maps not only show areas prone to water erosion but can also highlight where sediment deposition might occur, affecting water bodies and infrastructure downstream.

4.4 Application of GIS based AHP in flood-erosion mapping:

The application of Geographic Information Systems (GIS) combined with the Analytic Hierarchy Process (AHP) for mapping flood risk and water erosion provides a robust framework for environmental management and disaster preparedness. This integrated approach leverages GIS's capability for spatial data analysis and visualization with AHP's method for multi-criteria decision making, offering a nuanced understanding of complex natural hazards.

AHP comes into play by providing a structured method to weigh these various factors based on their relative importance in causing floods or erosion. Through pairwise comparisons, experts or stakeholders can assign significance to each element, like rainfall intensity versus land use or soil type versus slope angle. This process involves constructing a hierarchical model where the objective (flood risk or erosion mapping) is at the top, followed by criteria and sub-criteria. The weights derived from AHP are then applied in GIS, usually through a weighted overlay analysis where each data layer's influence on the risk or erosion potential is quantified according to its weight.

For flood risk mapping, combining GIS with AHP results in maps that not only show where flooding is likely but also indicate the severity of potential impacts by considering the vulnerability of areas due to population density, infrastructure, or economic value. This aids in strategic planning for flood mitigation, emergency response, and urban development. In the context of water erosion, the approach helps in identifying areas where soil loss is most critical, factoring in how different land uses might alter erosion rates. This is vital for agricultural planning, where soil conservation practices can be tailored to specific landscapes, or for environmental policy-making to guide land use decisions that prevent degradation.

Both applications allow for scenario analysis where altering the weights of criteria can simulate different environmental or policy scenarios, providing insights into how changes might affect flood or erosion patterns. This sensitivity analysis is crucial for adaptive management, ensuring that strategies remain effective as conditions evolve.

4.5 Land Use and Land cover maps (LULC)

A Land Use Land Cover (LULC) map is a thematic map that represents the distribution of different land use and land cover types over a geographical area. It serves as a critical tool for understanding how land is utilized by humans and the natural cover of the Earth's surface. Here's an in-depth look at what a LULC map entails:

Definition and Purpose:

Land Use: Refers to human activities or economic functions associated with a specific piece of land, like agriculture, urban development, or recreation.

Land Cover: Describes the physical material at the surface of the Earth, such as vegetation, water bodies, bare soil, or artificial structures.

LULC maps are designed to provide a snapshot of how these elements are distributed across landscapes, offering insights into environmental conditions, human impact, and planning needs.

Types of LULC Maps:

- Scale: Can range from local, where detailed classifications are possible, to global, providing a broad but less detailed categorization.
- Classification Systems: Various systems exist like the Anderson Land Use and Land Cover Classification System or more recent ones like the CORINE Land Cover for Europe, each with specific classes tailored to regional characteristics or intended use.

LULC maps are fundamental in bridging the gap between environmental science, policy, and practical land management, offering a visual and analytical tool for decision-making across various sectors

4.6 Land Use and Land cover maps (LULC) applications

Land Use Land Cover (LULC) maps have a wide array of applications across multiple disciplines, reflecting their utility in both environmental management and socio-economic planning. Here are some key applications:

1. Environmental Management:

- Wildlife Corridors: Mapping can show connectivity between habitats, aiding in the design of wildlife passages or green corridors.
- Land Degradation Assessment: By comparing LULC over time, areas undergoing degradation can be pinpointed for restoration efforts.

2. Urban and Regional Planning:

- Zoning: Provides a foundation for zoning laws, ensuring that development is aligned with land suitability and environmental impact assessments.
- Infrastructure Planning: Determines optimal locations for new constructions based on existing land use, minimizing environmental impact.

3. Water Resource Management:

- Watershed Analysis: Understanding land use within watersheds helps manage water quality, predict runoff, and plan for water conservation.
- Flood Risk Management: Identifying areas prone to flooding by examining land cover types like impervious surfaces or wetlands.

4. Disaster Risk Reduction:

- Hazard Mapping: By analyzing land cover, maps can indicate areas at higher risk from natural disasters like landslides, wildfires, or floods.
- Emergency Response: Post-disaster LULC maps aid in damage assessment and guide relief efforts.

4.7 Topographic Wetness Index

The Topographic Wetness Index (TWI) is a fundamental parameter used in hydrological and geomorphic studies to estimate the spatial distribution of soil moisture and predict areas prone to water erosion. Conceptually introduced to quantify how topography influences soil moisture, TWI has become an essential tool for understanding and mapping water-related erosion processes.

TWI is calculated using the formula:

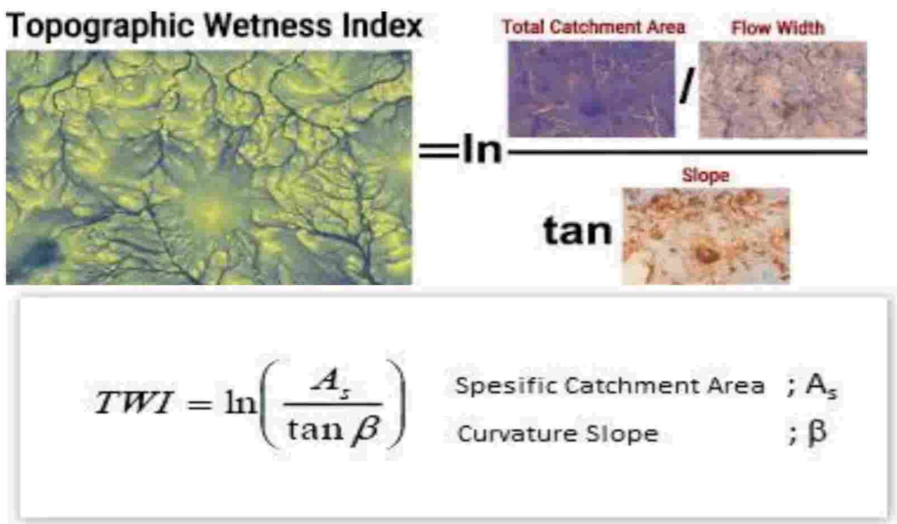


Fig 4.1: Image showing TWI index formula

where:

- a is the specific catchment area, representing the upslope area per unit width orthogonal to the flow direction, essentially how much water might accumulate at a given point from the surrounding higher ground.
- beta is the local slope angle at that point in radians. The tangent of the slope angle reflects how quickly water might drain away.

This index essentially balances the accumulation of water (a) with how steeply it can flow away (tan β), providing a measure of the potential for saturation and thus erosion in different parts of a landscape.

Application to Water Erosion includes:

- Soil Moisture and Erosion: Higher TWI values indicate areas where water is likely to accumulate, leading to higher soil moisture content. This can lead to increased soil saturation, reducing soil stability and making it more susceptible to erosion, especially during heavy rainfall when the soil's capacity to hold water is exceeded.
- Identification of Erosion-Prone Areas: By mapping TWI across a landscape, areas with high TWI can be identified as zones where water erosion might be more likely. These areas could include valley bottoms, concave slopes, or regions with impeded drainage.
- Predicting Erosion Types: TWI can help distinguish between different types of water erosion:
- Sheet Erosion: On gently sloping areas with moderate TWI, sheet erosion might dominate as water flows uniformly over the surface.
- Rill and Gully Erosion: Higher TWI values, often in steeper or more concentrated flow areas, can lead to concentrated runoff, fostering the development of rills and eventually gullies.
- Modeling and Management: TWI is integrated into erosion models like the USLE or RUSLE to refine predictions. It helps in planning conservation practices by indicating where measures like terraces, grassed waterways, or buffer strips might be most effective.
- Temporal Dynamics: TWI can also reflect seasonal changes in soil moisture, aiding in understanding how erosion risk varies with time, particularly in climates with distinct wet and dry seasons.

CHAPTER 5

METHODOLOGY

5.1 Flood risk mapping

Here are the basic steps followed for flood risk mapping using Arc GIS software:

1. Collection of DEM: - Digital elevation model (Aster DEM) is downloaded from NASA Earth data. DEM should be in raster format.
2. Mosaic DEMs: Mosaic the DEMs if the study area don't lie completely in a single DEM.
3. Fill and correct DEM: - Use the Fill tool to remove sinks or depressions where water would not drain. Ensure preprocessing of DEM which includes projecting the DEM into common output coordinate system.
4. Extract study area: - Extract the study area from DEMs using Extract by mask tool.
5. Collection of Sentinel 2: - Download Sentinel 2 imagery from Esri website to prepare LULC maps
6. Prepare LULC maps: - Prepare LULC maps for study area by reclassifying the raster image of sentinel 2 imagery.
7. Collection of Landsat images: - Download landsat 9 images from USGS earth explorer
8. Raster calculator: - Use raster calculator to define the formula to obtain NDVI image
9. Prepare NDVI raster: - Prepare NDVI map after obtain the result from raster calculator and do reclassification as per requirements.

1. <u>Collection of AsterDEM</u>:-

To download DEMs from the NASA Earth Data, login in NASA Earth Data or create your account. Search for your area, select "Digital Elevation" data sets like SRTM or NED, choose the resolution, and download the data in formats like GeoTIFF. Ensure that the DEM file is in raster format. Make sure that the cloud coverage is negligible and study area falls within the selected DEM by observing its footprint. If the study area falls between two DEMs we need to mosaic the two DEMs using mosaic tool and then extract the study area.

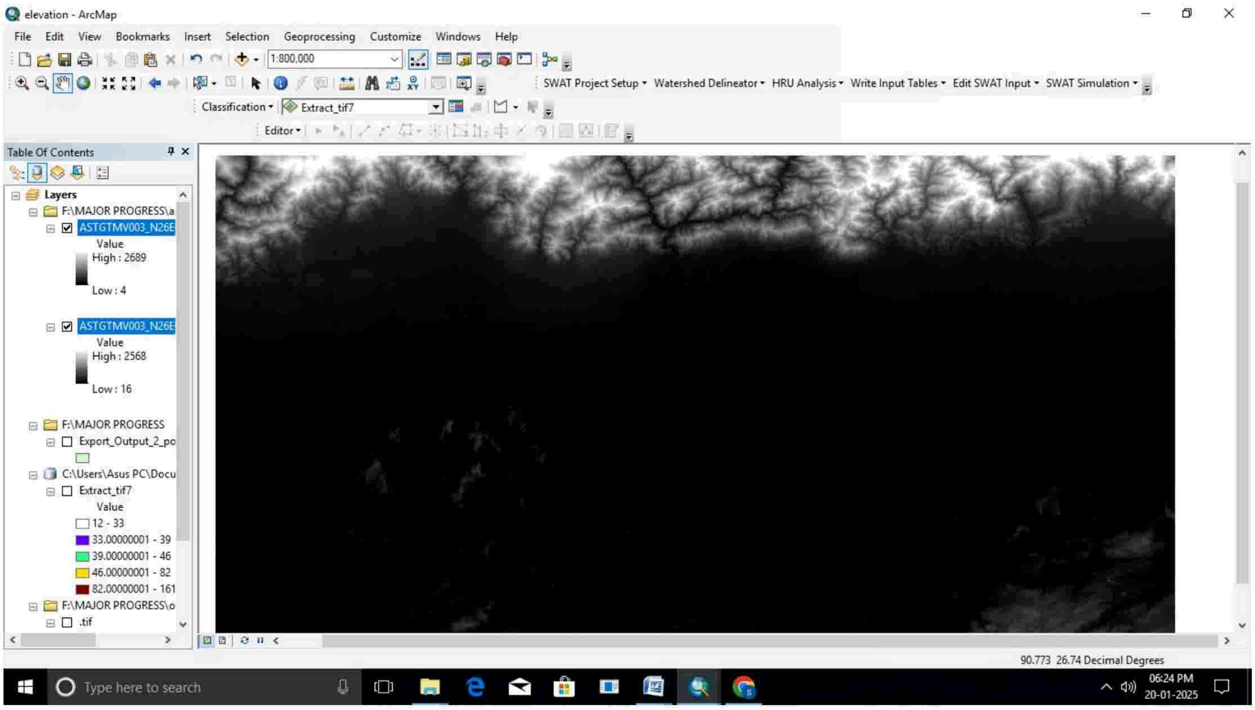


Figure 5.1: DEM file downloaded from NASA Earth Data

2. <u>Mosaic and Fill DEM</u>:-

The "Fill" tool in ArcGIS is used to remove depressions or 'sinks' in Digital Elevation Models (DEMs).Sinks are areas in a DEM where the elevation drops below the surrounding terrain, creating a 'hole' where water should flow but can't because of the data's topography. The Fill tool elevates these points to the lowest pour point around them, ensuring there's a path for water to flow out. Filling sinks corrects errors in elevation data which might occur due to data collection inaccuracies, noise, or problems with interpolation methods used to create the DEM. This leads to a more accurate representation of the terrain.

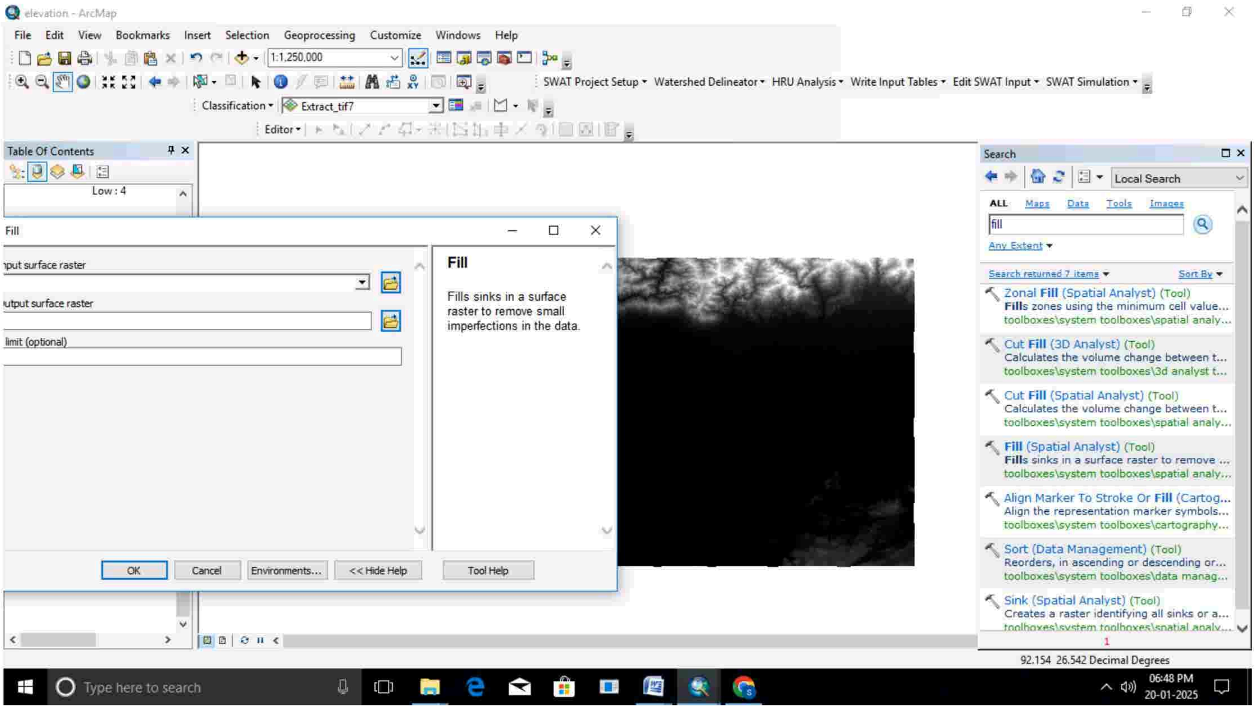


Figure 5.2: Fill DEM file

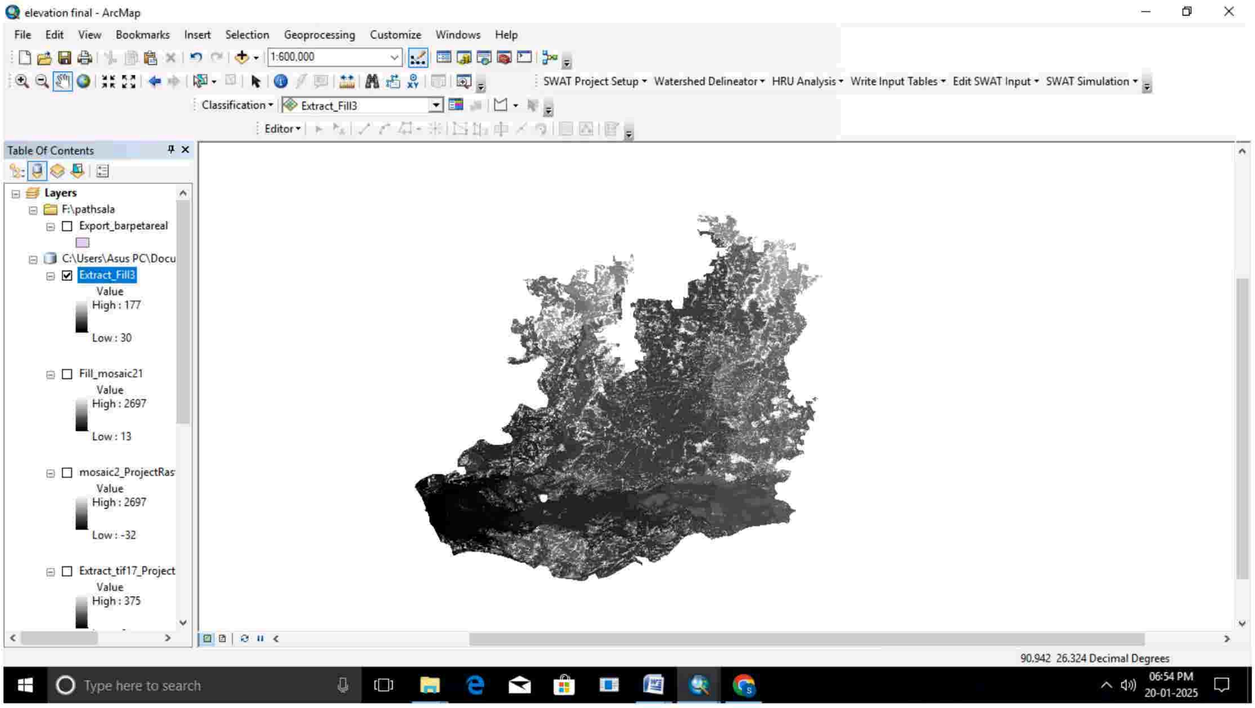


Figure 5.3: Extracting study area after filling and projecting to output coordinate system

3. <u>Create elevation map</u>:-

To analyze an elevation map in ArcGIS:

- Add Data: Add extracted DEM or similar elevation dataset to ArcGIS project.
- Symbology: Change the symbology to show elevation, often using a color ramp or contours.
- Tools: Use tools like "Surface Analysis" for slope, aspect, or hillshade to enhance the visualization or understanding of the terrain.

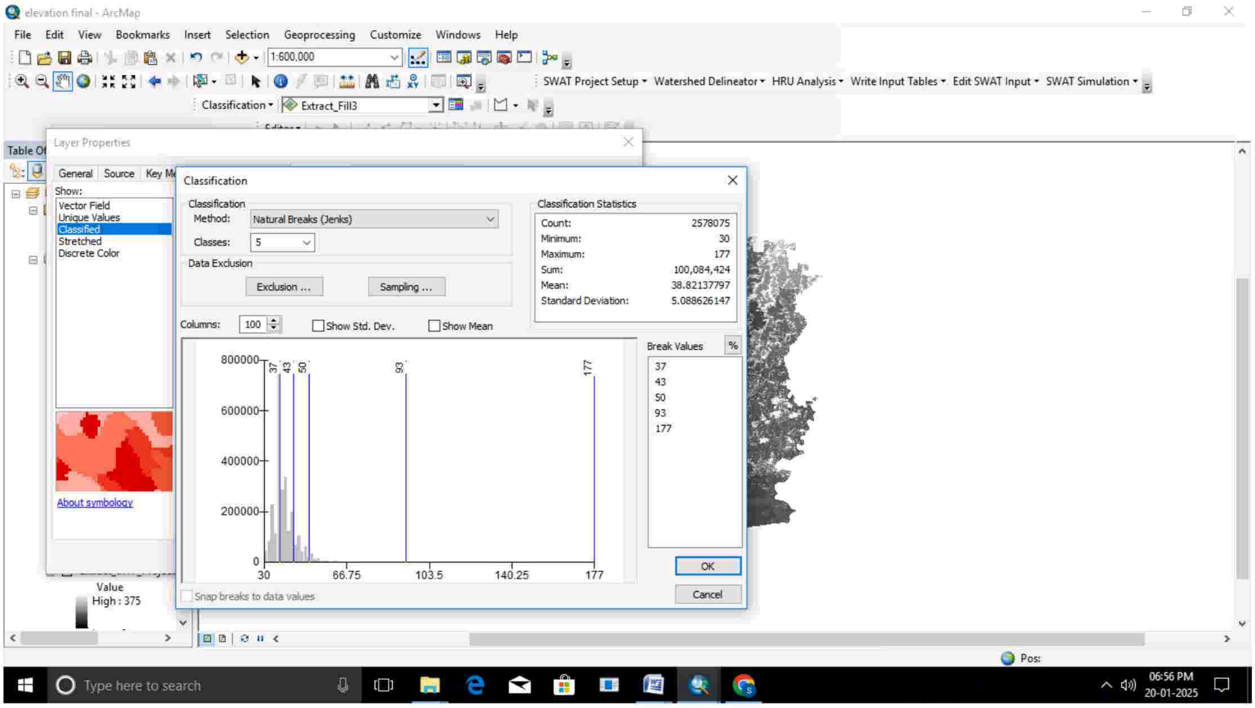


Figure 5.4: Creating elevation map

4. <u>Create LULC map:-</u>

Land Use-Land Cover (LULC) map of study area can be prepared using Sentinel 2 imagery. The Sentinel-2 10-Meter Land Use/Land Cover Time Series provides detailed annual snapshots of global land cover from 2017 to 2023. The deep learning models trained on billions of human-labeled pixels have been noted for high accuracy, with assessments showing over 75% accuracy for some iterations of the maps.

- Visit Esri website.
- Download Sentinel 2 imagery for the required year.
- Add tif file to Arc Map and extract study area.
- Classify and modify labels for better visualization.
- Analyse attribute table to calculate areas of each class

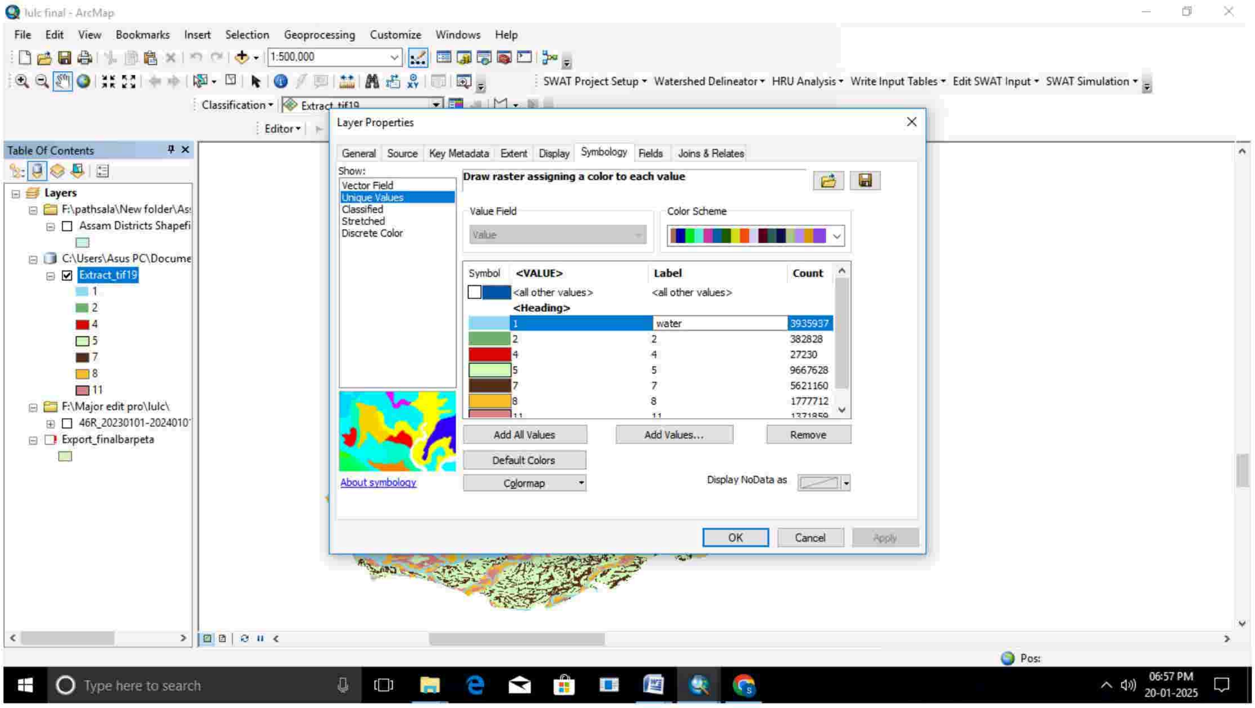


Figure 5.5: Classifying classes from Sentinel 2 imagery

5. <u>Download landsat 9 images: -</u>

Download landsat 9 images from USGS earth explorer to prepare NDVI map. Visit USGS earth explorer and download landsat 9 images for your study area and select the year based on requirement.

- Landsat 9 images have a spatial resolution of 30 meters for most bands, with the panchromatic band at 15 meters. The satellite collects approximately 1,400 scenes per day.
- Landsat 9 was launched on September 27, 2021, joining Landsat 8 in orbit to provide a combined revisit time for data collection every 8 day.
- The imagery is used for monitoring natural resources, understanding climate change impacts, disaster response, and mapping land use changes over time.
- Landsat 9 data is publicly available through the U.S. Geological Survey (USGS). Users can download the images from platforms like the USGS Earth Explorer, with options to filter by cloud cover, date, and specific geographic areas.

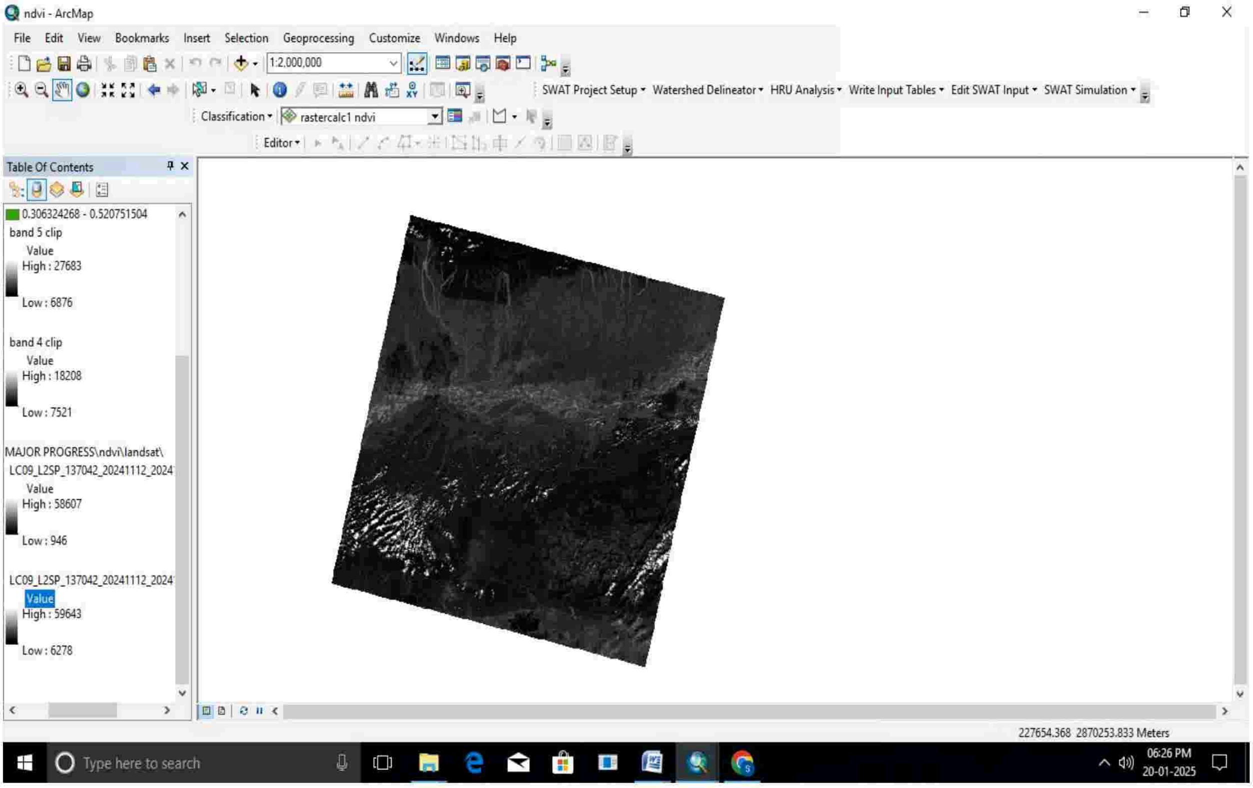


Figure 5.6: Downloading landsat 9 images

6. <u>Raster Calculator</u>:-

- Load the satellite imagery intor GIS software. Ensure that the images are properly georeferenced and have the necessary bands (red and NIR) for NDVI calculation.
- ArcGIS, you can access the Raster Calculator via the "Spatial Analyst Tools" > "Map Algebra" > "Raster Calculator".
- The formula in the calculator for Landsat 8/9 in ArcGIS is : ("NIR" - "RED") / ("NIR" + "RED").
- Specify an output file name and location where the NDVI map will be saved. Ensure to choose a format compatible with your GIS software, like GeoTIFF.

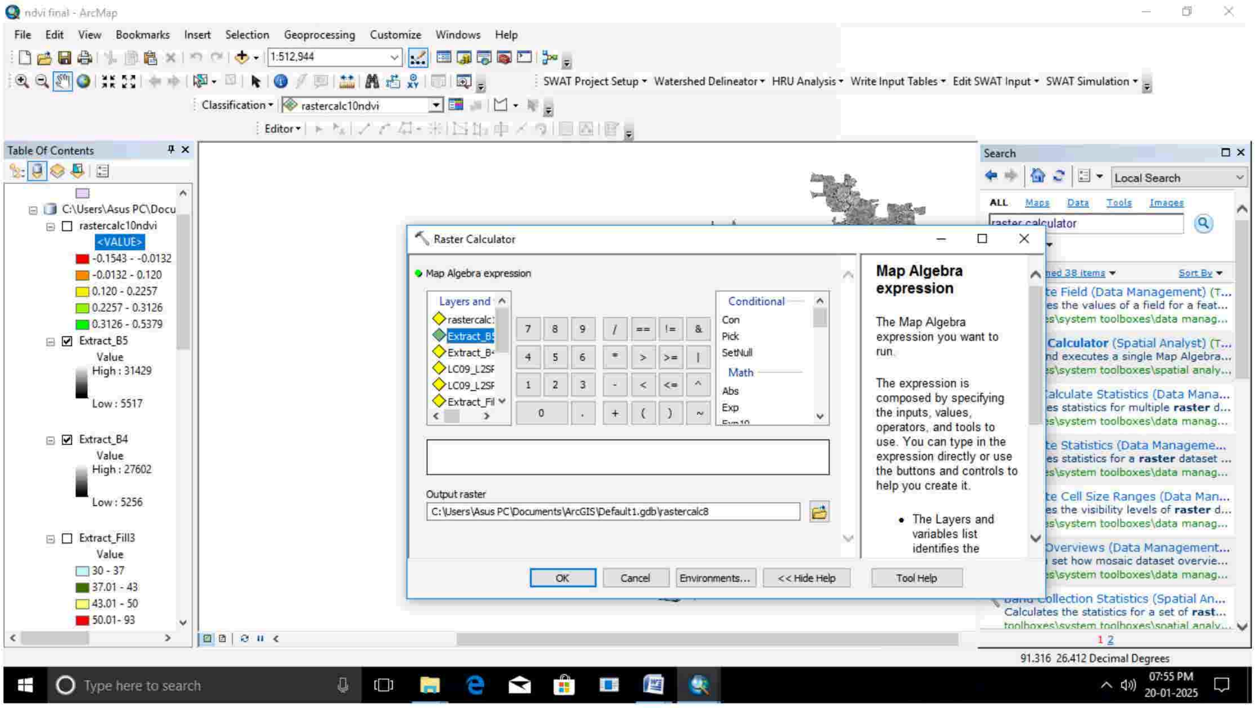


Figure 5.7: Using raster calculator

7. <u>Prepare NDVI map:</u>

An NDVI (Normalized Difference Vegetation Index) map is a visual representation derived from satellite imagery that quantifies vegetation health and density. It uses the contrast between near-infrared (NIR) light, which vegetation strongly reflects, and red light, which it absorbs.

- After using raster calculator, ensure that the output raster has common projected coordinate system.
- In the output raster click properties and go to symbology.
- Make necessary changes in the symbology tab for better visualization.
- Classify the values into required number of classes.
- Assign desired colour to each class as per requirements.

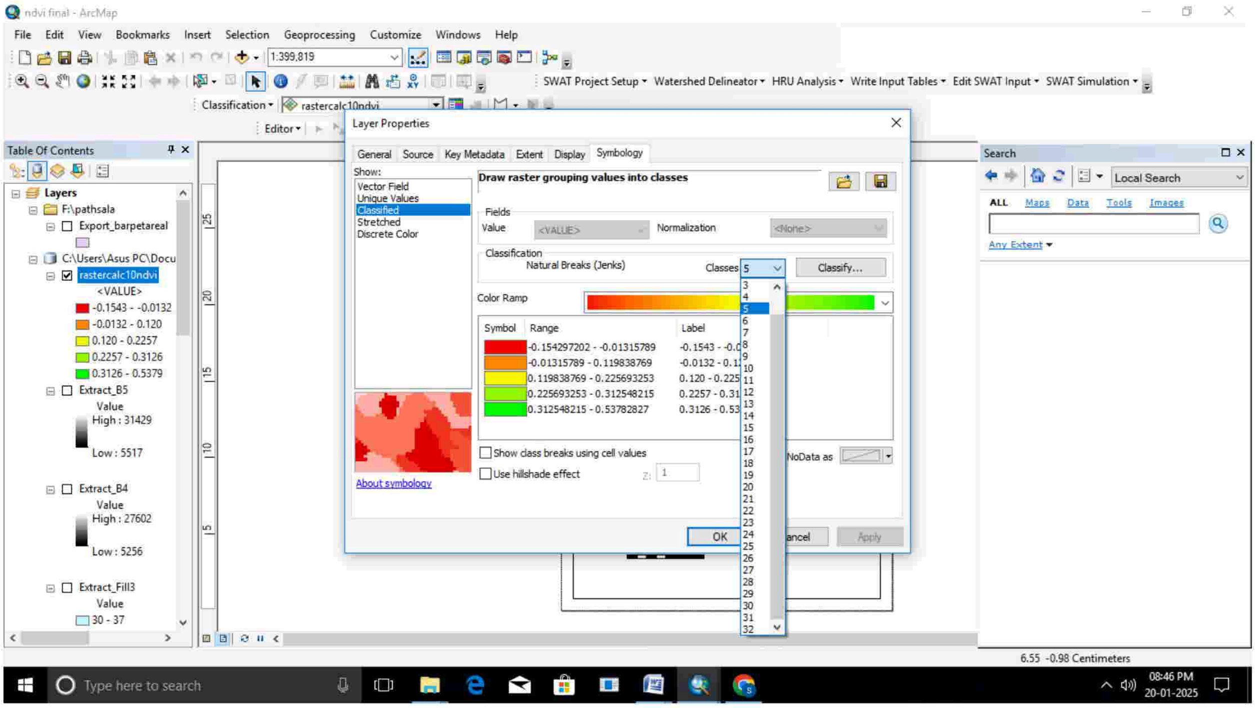


Figure 5.8: Classifying into different number of classes

5.2 Water Erosion mapping

Here are the basic steps for water erosion mapping using Arc GIS software:-

1. Data Collection: - Download Aster DEM or SRTM DEM from USGS.
2. Pre-processing:- Perform radiometric corrections and geometric corrections if necessary to ensure image is usable.
3. Extraction of study area: - Study area is extracted from Aster DEM by “Extract by Mask” tool under “Spatial Analyst Tools” from Arc Toolbox.
4. Prepare Slope map: - Prepare slope map from extracted study area using Arc toolbox.
5. Create flow direction :- Generate flow direction raster using input extracted study area DEM
6. Generate flow accumulation: - Create flow accumulation map using flow direction raster as the input file.
7. Raster Calculator: - After creating slope map, flow direction and flow accumulation map

use raster calculator perform calculations to prepare TWI map

8. TWI map: - With the help of raster calculator perform necessary calculations and ensure its conditions and cell size requirements are met. Perform necessary changes in symbology for better visualization.
9. Stream order: - Obtain stream order using raster calculator on flow accumulation raster. Take flow direction as the input raster to derive stream order.
10. Euclidean distance for streams:- Generate Euclidean distance map for streams using stream order as the input.
11. Download FAO global soil data:- Download global digital soil map from Food and Agriculture Organization (FAO) website.
12. Extract study area:- Extract study area from global soil map. Ensure both study area and global soil map has same coordinate system.
13. Add FAO excel table;- Analyze FAO excel data and add its soil data to our study area attribute table based on type of soil present in our study area.
14. Classify soil map: - Classify study area to raster format based on soil properties analyzed from the soil excel data.

1. Slope Map:-

- Prepare Slope map of study area using Arc Toolbox.
- Use Extracted study area as input raster.
- Prepare slope map in degree format.
- Ensure output coordinate system is projected into UTM coordinate system.
- Classify the slope map into desired number of classes.

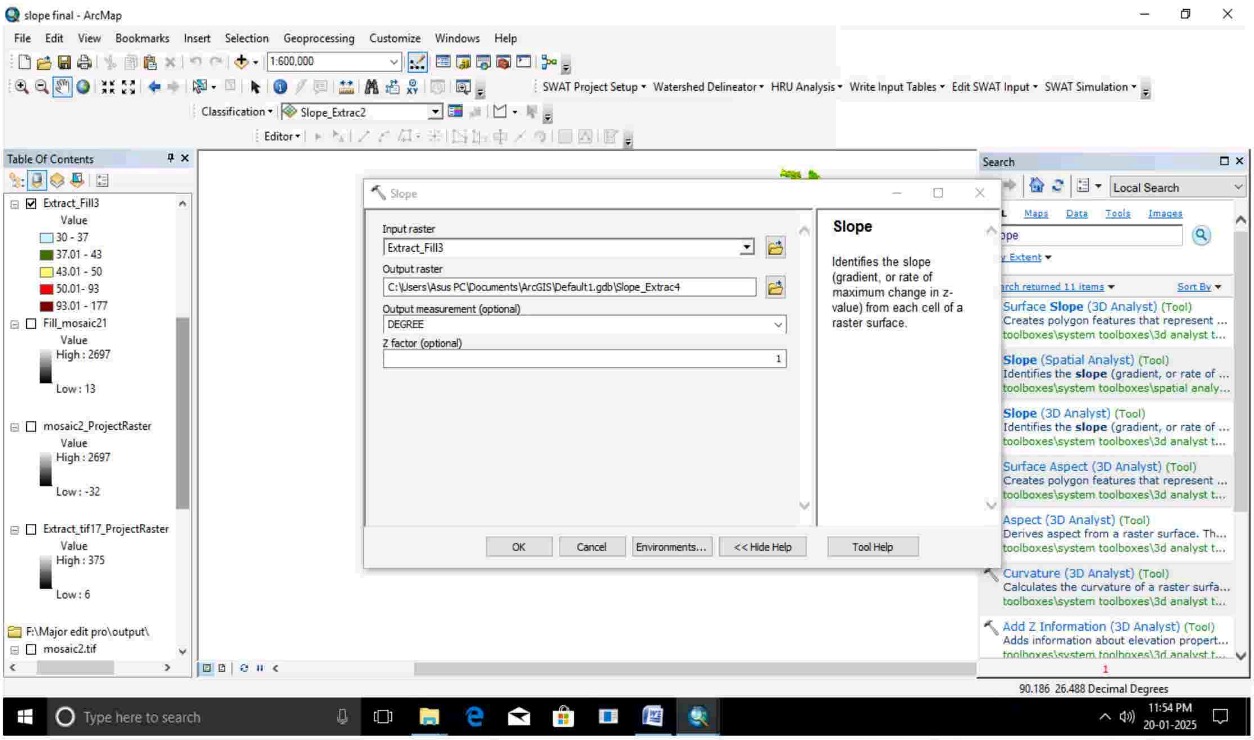


Figure 5.9:- Preparing Slope Map

2. Create flow direction:-

- Choose flow direction from spatial analyst toolbar.
- Choose extracted study area as surface raster.
- Decide desired output raster name and location.
- Ensure output raster as common projected coordinate system.

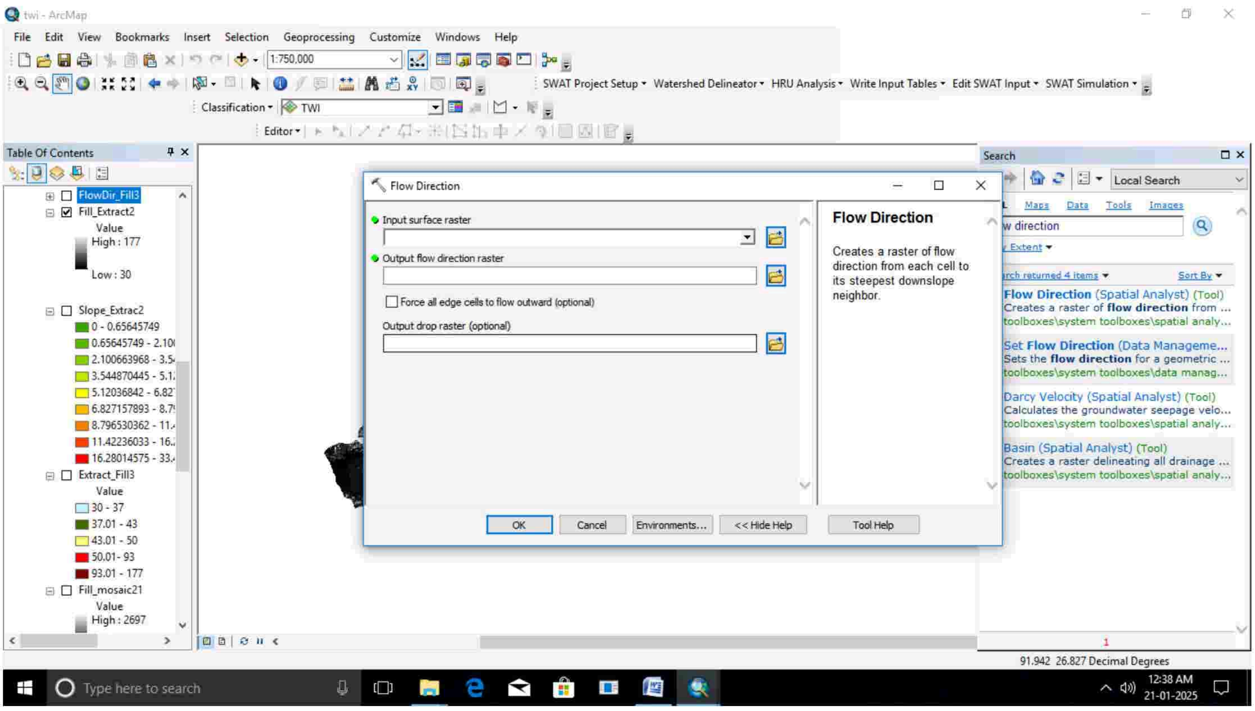


Figure 5.10:- Flow direction.

3. Flow accumulation:-

- Select flow accumulation toolbar under Spatial Analyst tool.
- Select flow direction as the input raster.
- Create desired output raster name and location.

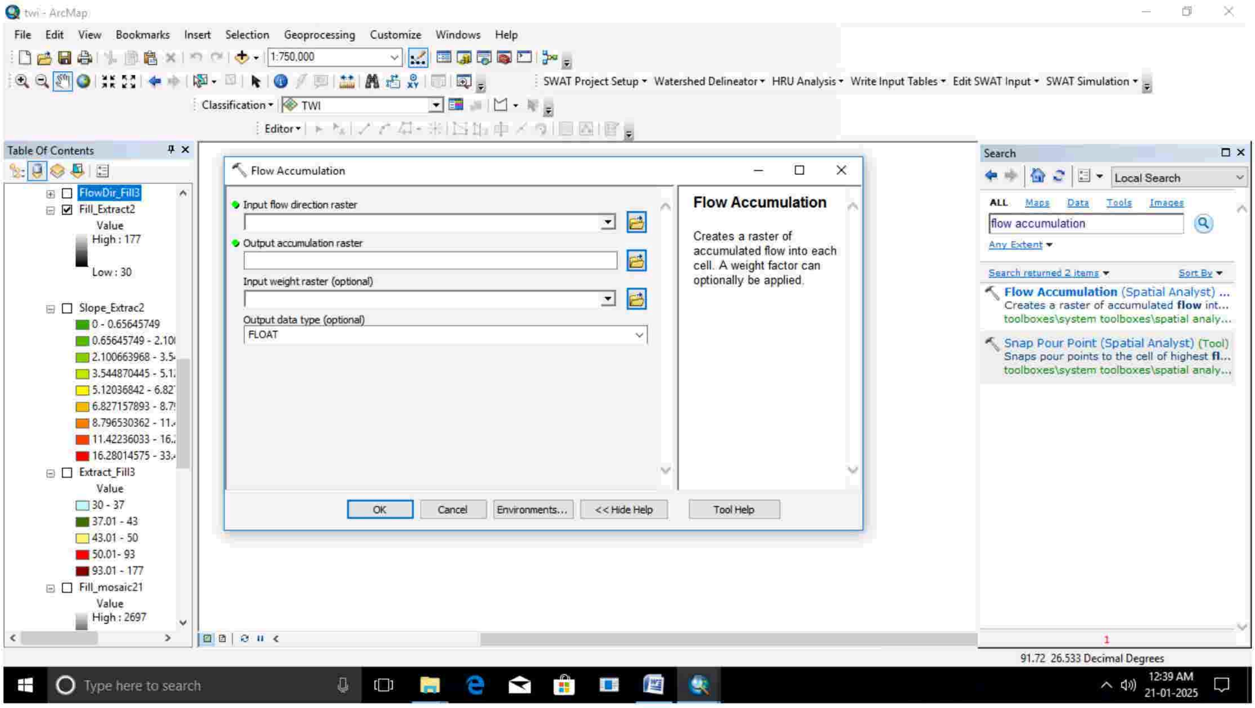


Figure 5.11:- Flow accumulation raster

4. <u>Raster Calculator</u>:-

- Select raster calculator under Map algebra toolbar.
- Obtain the formula for calculating Topographic wetness index.
- Write the formula in raster calculation by selecting elements within toolbar.
- Select desired output raster location and name.
- Ensure output raster has projected coordinate system.

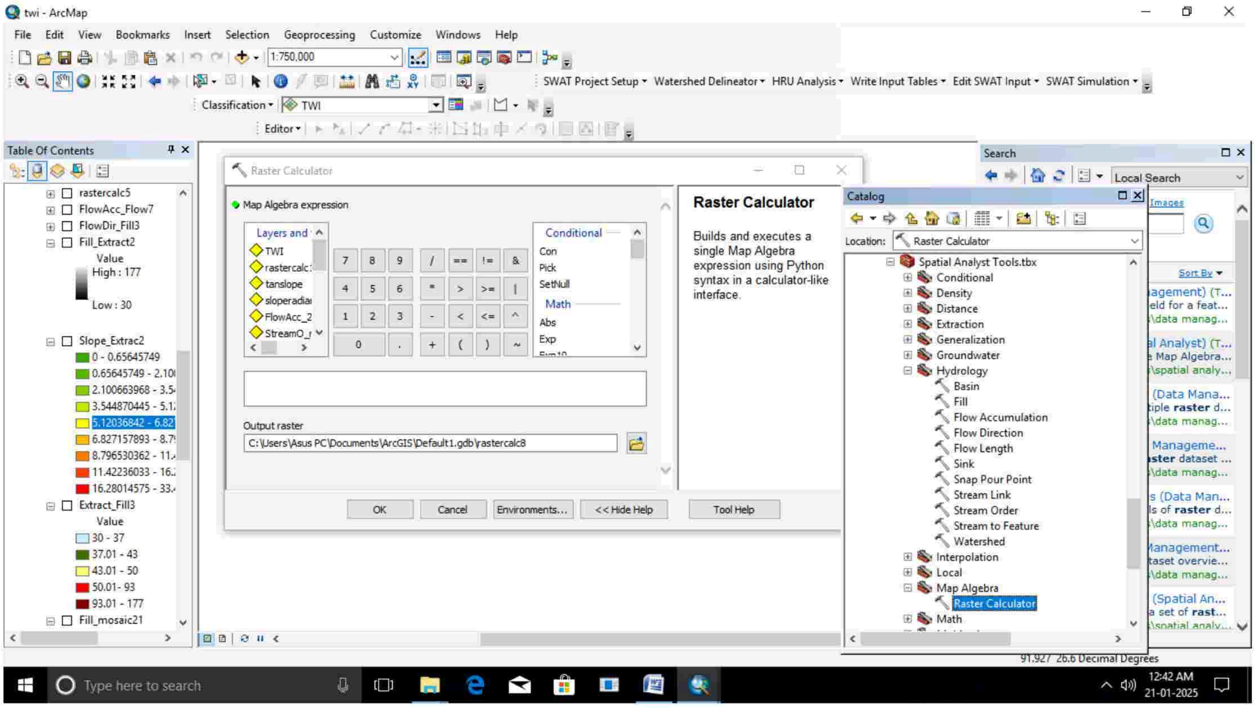


Figure 5.12: Raster calculator for TWI

5. <u>Stream Order:-</u>

- Choose stream order under spatial analyst toolbar.
- Select raster calculated from accumulated flow as the surface raster.
- Select Flow direction as the input direction raster.
- Use STRAHLER method to create stream order.
- Choose desired output raster location and name.

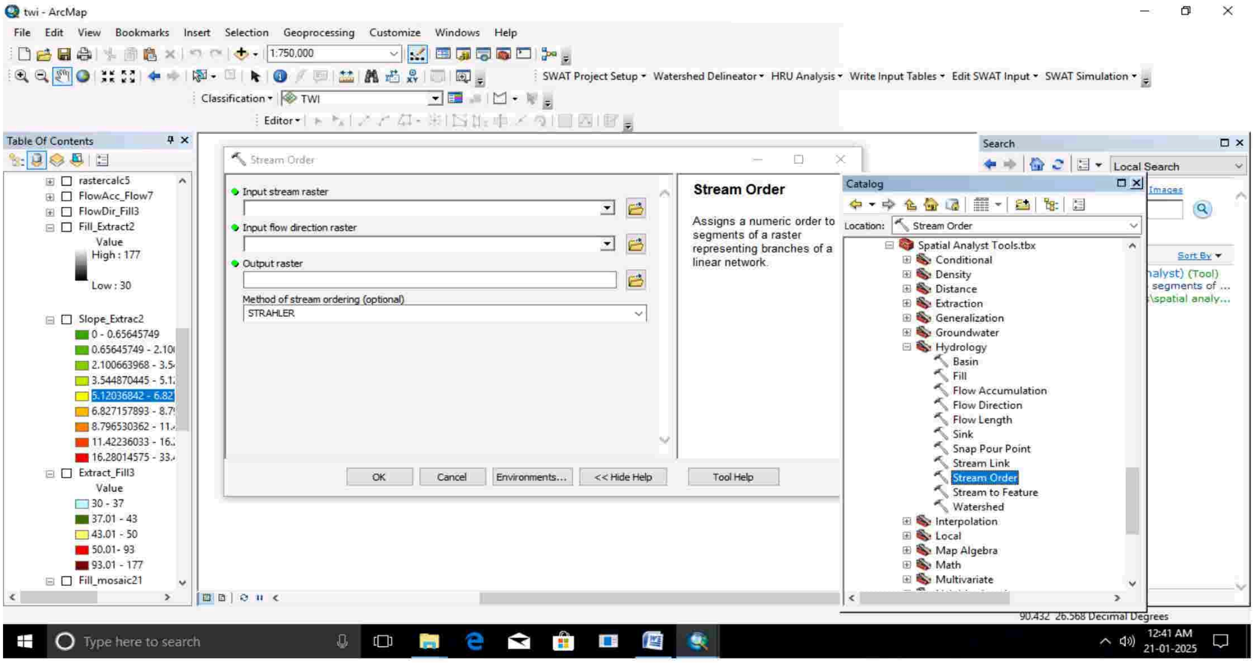


Figure 5.13: Generating stream order

6. <u>Euclidean Distance:-</u>

- Select stream order raster as the input raster.
- Enter cell size as per requirement
- Enter maximum distance as 300m
- Select desired output location and extension

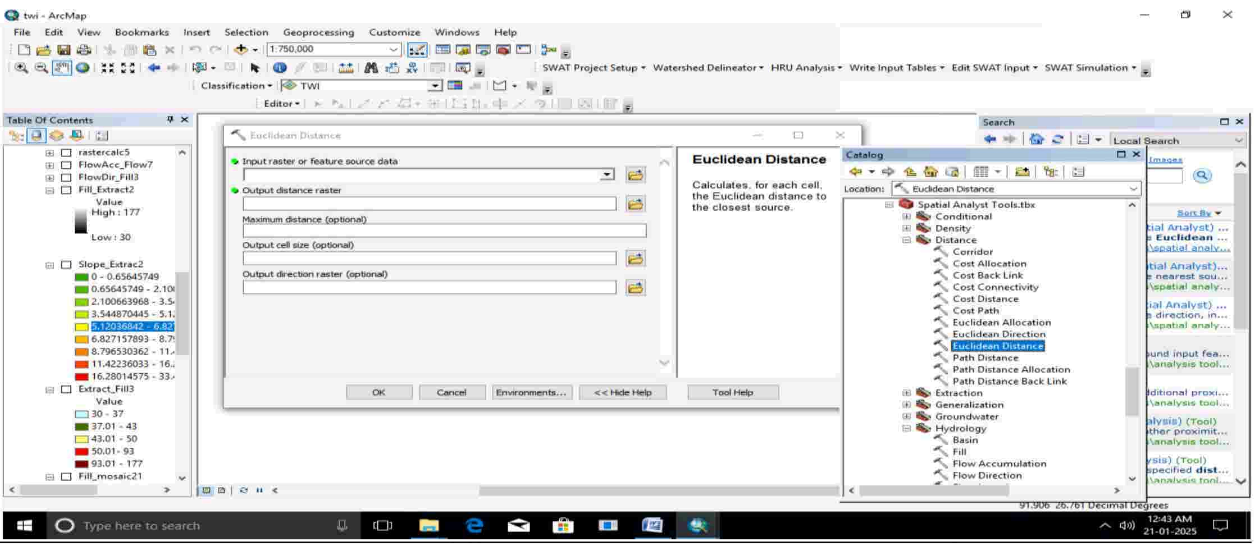


Figure 5.14: Generating Euclidean distance

7. <u>Food and Agricultural Organization Soil Data:-</u>

- Download Soil Map from Food and Agricultural Organization (FAO).
- Extract study area
- Analyze data and add into attribute table

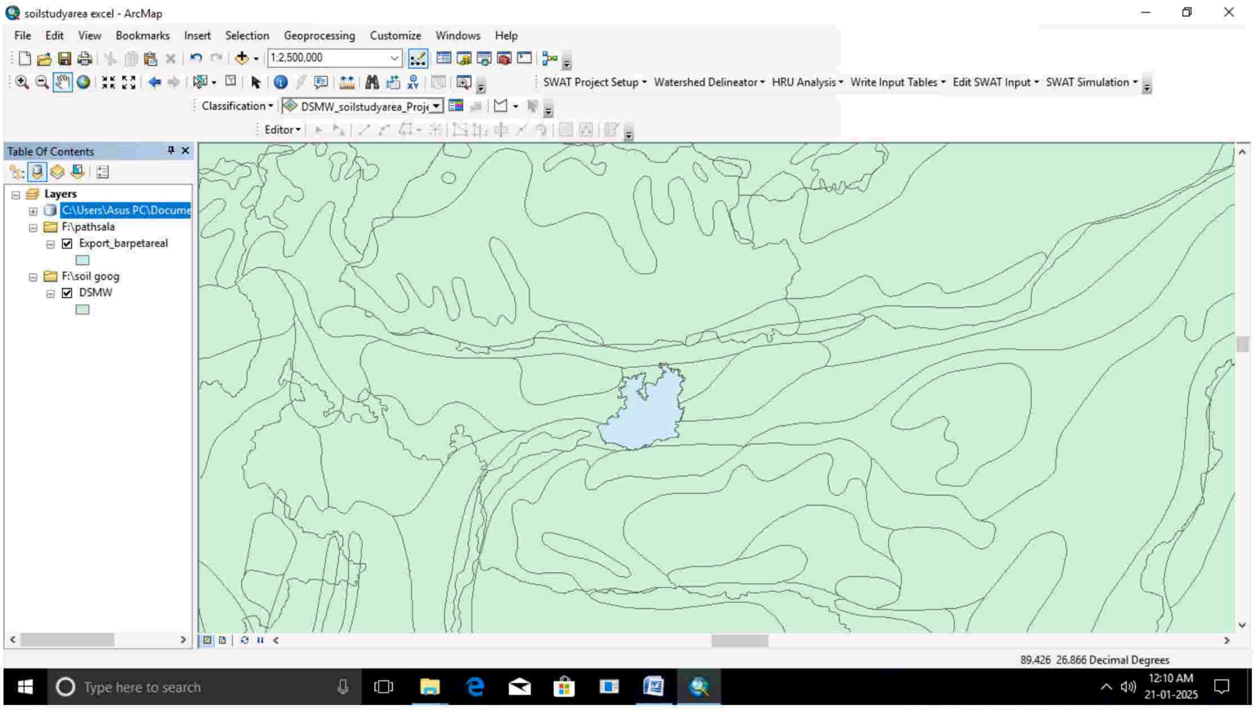


Figure 5.15: FAO Global Soil Map

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Elevation Map

An elevation map in ArcGIS displays the topography of a given area by illustrating variations in height above or below a reference level, typically sea level. These maps use color gradients or contour lines to represent different elevation levels; darker or cooler colors might indicate lower elevations, while lighter or warmer colors suggest higher altitudes.

From figure we get to know that elevation of our study area or Barpeta district varies from 30 metres to 177 metres above sea level. Most of the area falls in the range of 30-35 metres. The landscape is characterized by flat terrain but there are some notable small hillocks in the southwestern part of the district.

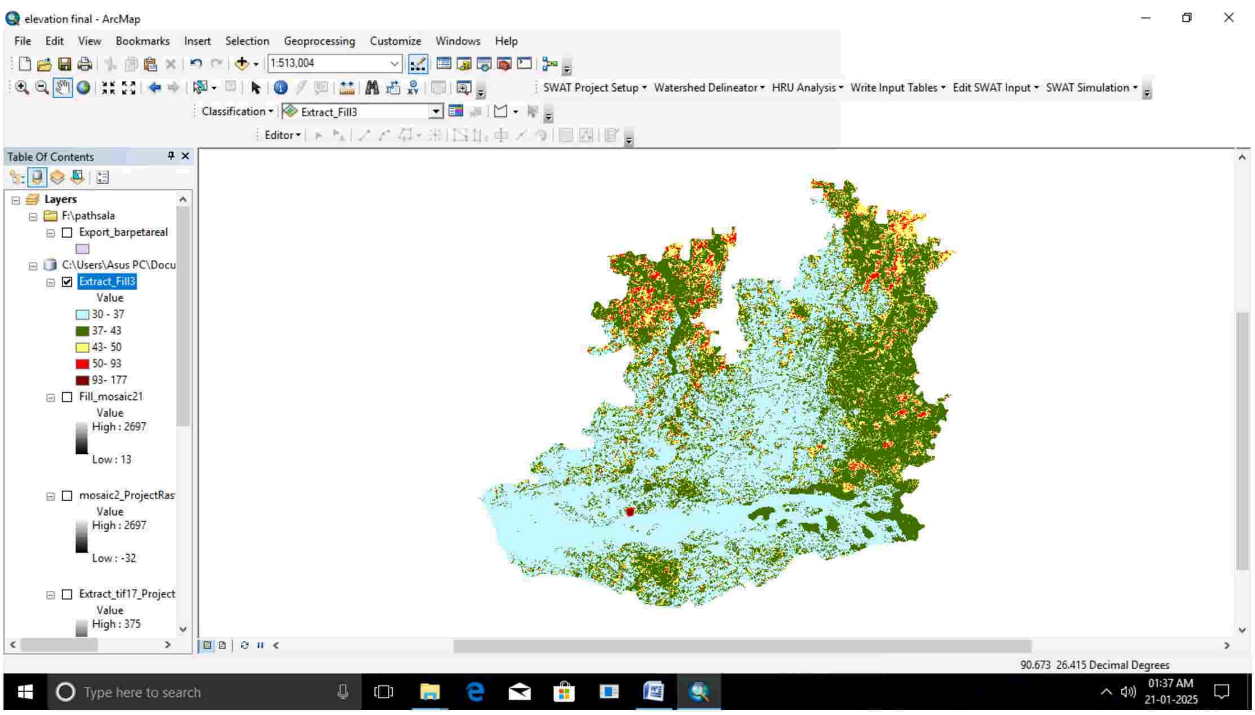


Figure 6.1: Elevation Map

6.2 LULC Map

A Land Use/Land Cover (LULC) map visually represents how land is being utilized and what types of natural or man-made cover exist on the Earth's surface within a given area. This type of map categorizes land into various classes such as: Water, Built up area, grassland, agriculture, forest etc.

From our study area it is evident that majority of the land use is occupied by crops/ agriculture land. The 2023 LULC map for Barpeta, Assam, highlights a predominance of agricultural land due to the fertile Brahmaputra floodplains, with significant areas dedicated to crops. Forests and wetlands, including areas influenced by rivers like the Beki and Manas, are also notable, indicating ecological diversity Major water bodies in Barpeta distict is composed of mighty Brahmaputra river and its tributaries such as Beki, Manas, Kaldia etc.

From attribute table of LULC, area covered by each classes has been analyzed and presented in chart form as below:

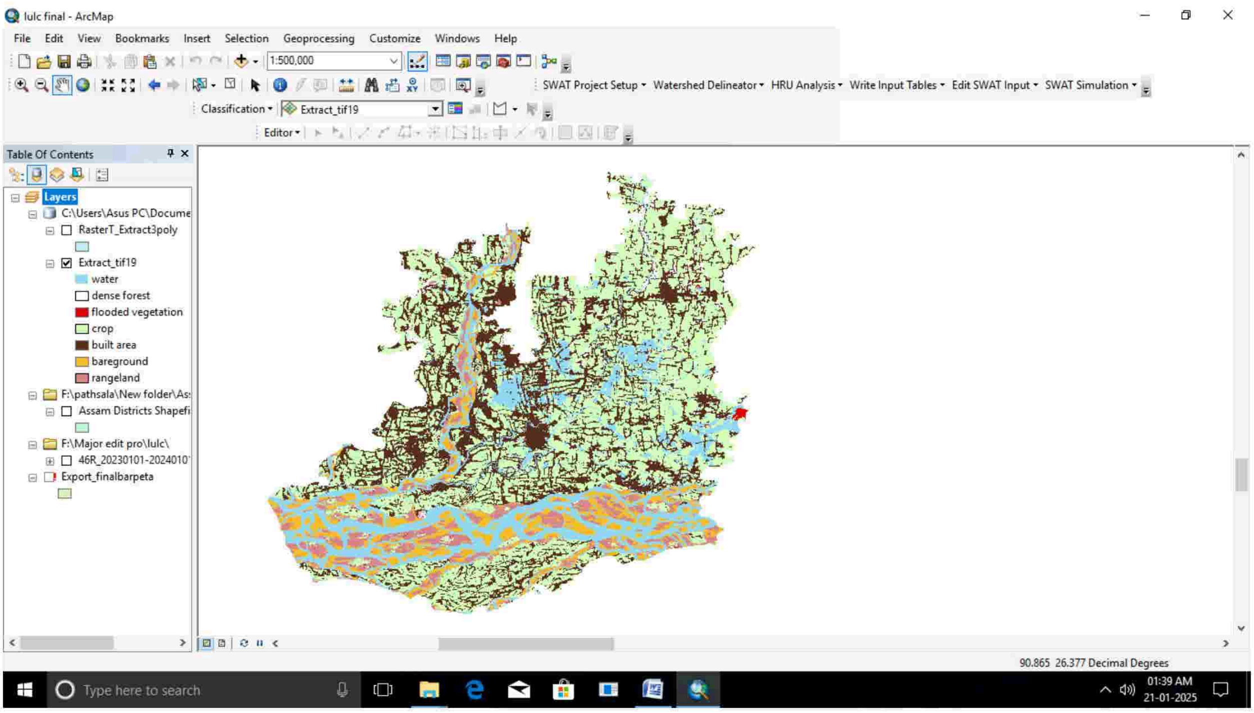


Figure 6.2: LULC Map Barpeta 2023

CLASSES	Area in km^2	Area in %
Water	393.55	17.272
Dense forest	38.12	1.673
Flood vegetation	2.72	0.119
Crops	966.95	42.439
Built area	562.21	24.675
Bare Ground	177.72	7.8001
Rangeland	137.16	6.02
TOTAL	**2278.43**	**100**

Table 6.1: Table showing area covered by each class

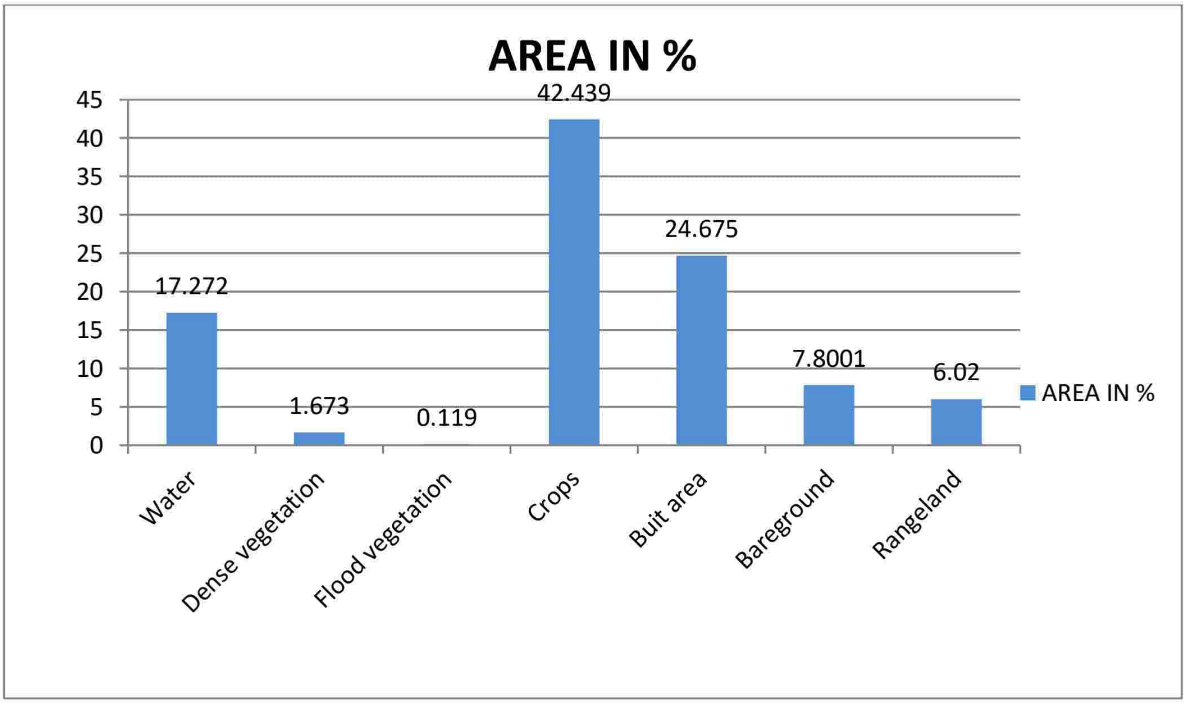


Figure 6.3: Chart showing area in % covered by each class

6.3 NDVI Map

An NDVI (Normalized Difference Vegetation Index) map is a graphical representation used to analyze remote sensing data for vegetation health and density. NDVI quantifies the greenness of vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which it absorbs).

The formula for NDVI is: (NIR - R) / (NIR + R)

Where: NIR is the near-infrared band.

Red is the red light band.

The resulting values range from -1 to +1, where: High values (close to +1) indicate dense, healthy vegetation with high photosynthetic activity. Values around zero suggest bare soil or sparse, stressed vegetation. Negative values typically correspond to water or snow, which reflect more in the visible red than in the NIR.

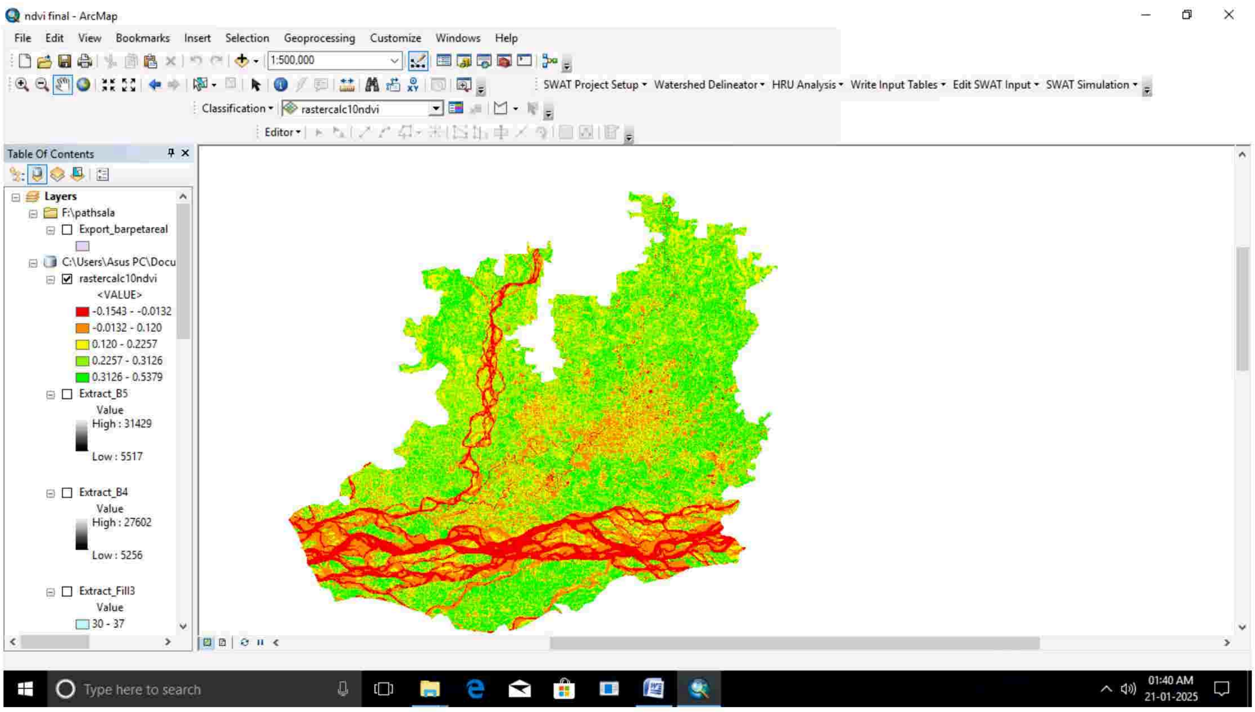


Figure 6.4: NDVI map of Barpeta District

6.4 Slope Map

In ArcGIS, a slope map indicates the steepness or inclination of the terrain across a landscape, measured in degrees. The slope is calculated from elevation data where each cell in the raster dataset represents the maximum rate of change between that cell and its neighbors. Slope in Degrees:

0° represents flat terrain with no slope.
1° to 3° are considered very gentle slopes.
3° to 5° are gentle slopes.
5° to 15° are moderate slopes.
15° to 30° are steep slopes.
Above 30° are very steep to extremely steep slopes

As slope increases, water velocity increases, leading to greater erosive force. On steeper slopes, water tends to converge into channels, intensifying erosion in those areas. Steeper angles reduce soil stability, making it easier for soil particles to be dislodged and transported away by water or wind.

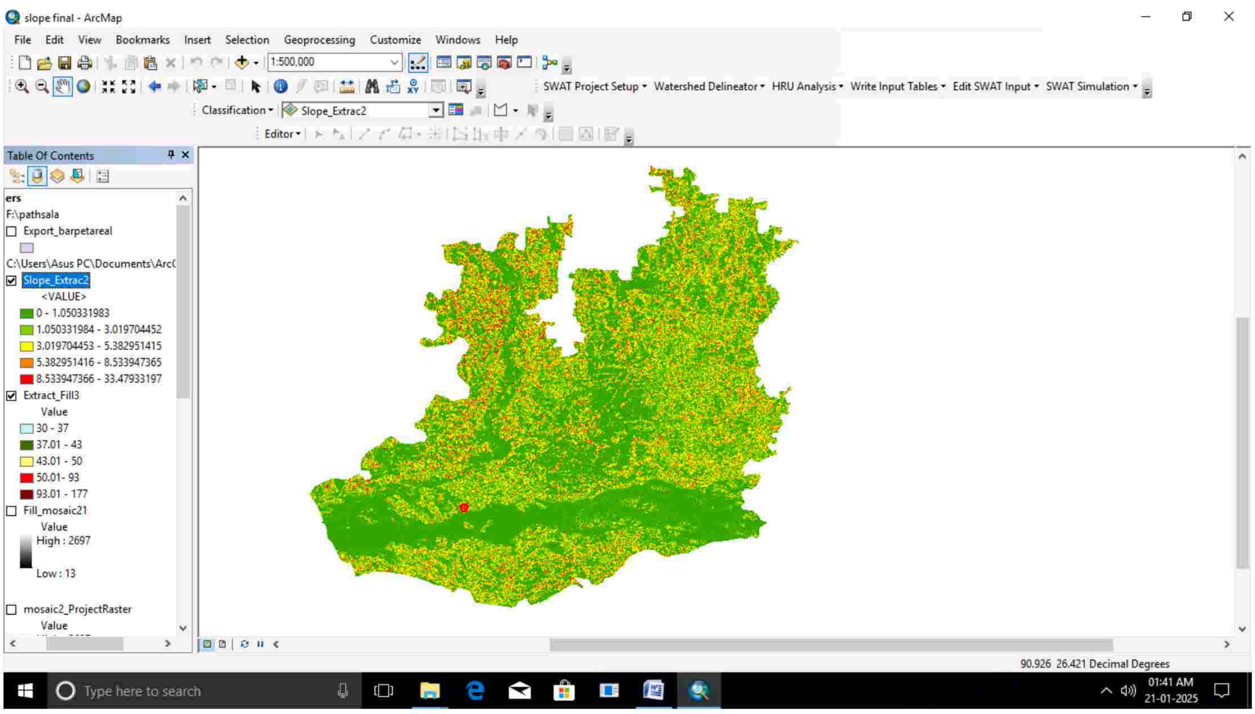


Figure 6.5:- Slope Map of study area

6.5 Topographic wetness index

The Topographic Wetness Index (TWI) in ArcGIS is a hydrologic index that quantifies the potential for soil saturation and the accumulation of water in a given area based on its topographic characteristics.

.The formula for TWI is: TWI = ln(adjusted_flow_accumulation / tan_slope)

TWI identifies areas where water is likely to accumulate due to topography. Higher TWI values indicate zones where water collects, increasing the potential for water erosion. This is because standing or slowly moving water can saturate the soil, reducing its cohesion and making it more susceptible to being moved by subsequent flows. In areas with lower TWI values, runoff might occur more rapidly due to steeper slopes, but the volume of water passing through might be lower. Conversely, high TWI areas might have slower runoff due to flatter terrain, but with a higher volume of accumulated water. This can lead to different types of erosion; rapid runoff can cause rill or gully erosion, while high water volume can exacerbate sheet erosion or even lead to mass movements like landslides in saturated soils.

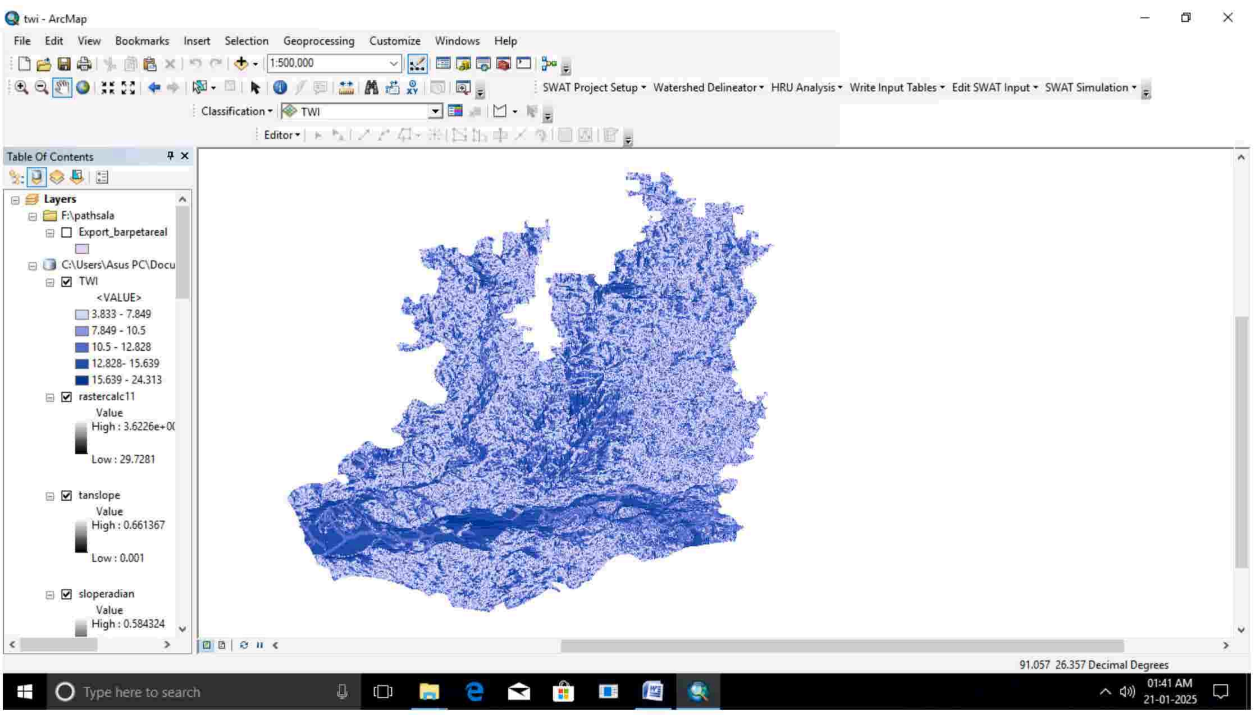


Figure 6.6:- TWI map

6.6 Euclidean distance from streams

Euclidean distance in ArcGIS represents the straight-line distance from each cell in a raster to the nearest source or target location, often used for proximity analysis. In the context of water erosion, this measure can indicate how far each point on the landscape is from potential water sources like rivers, streams, or areas prone to water accumulation. This distance is crucial because it influences the path, speed, and volume of water flow across the terrain. Areas closer to water bodies or with shorter Euclidean distances to them are likely to experience more direct and frequent water flow, potentially leading to increased erosion. Conversely, areas further away might see less direct impact from water unless influenced by other factors like slope or soil type. The concept of Euclidean distance helps in mapping out how water might spread or concentrate, aiding in the prediction of erosion patterns.

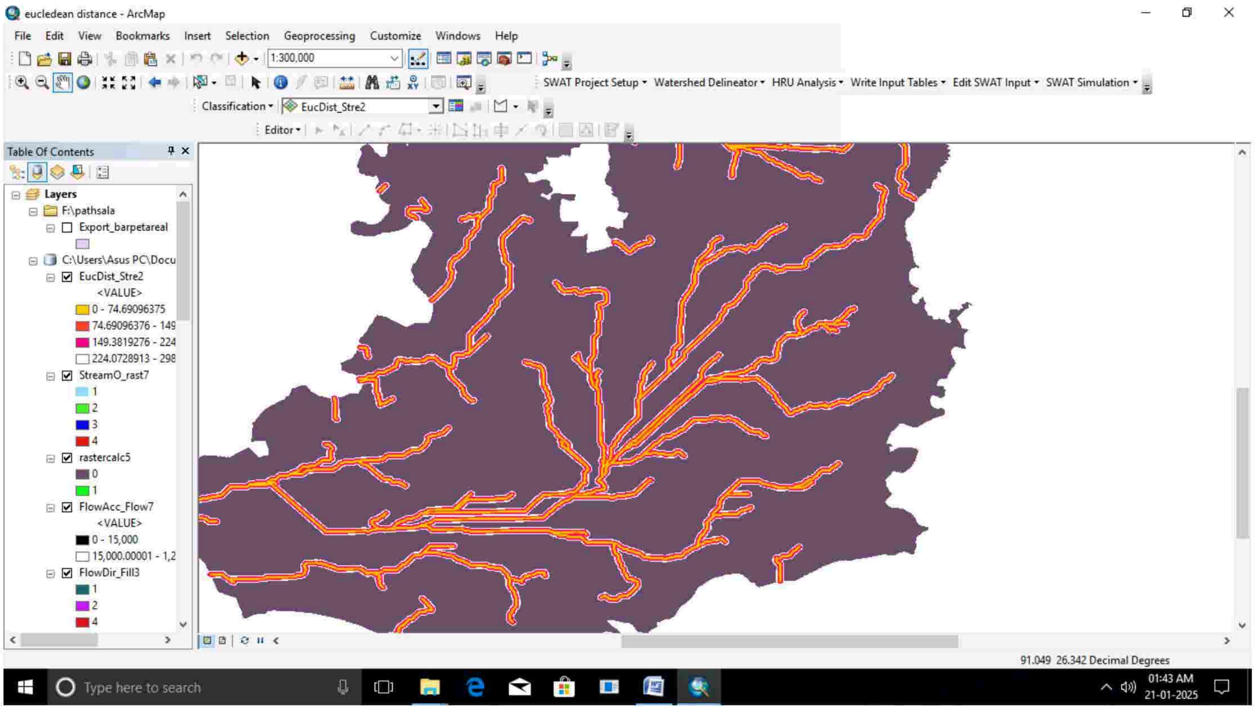


Figure 6.7 : Euclidean distance map

6.7 Soil Texture thematic layer

After adding FAO global soil data, extracting our study area and analyzing the attribute table we get to know that there are three dominant type of soil layers in Barpeta district. They are : Ao, Rd and Be. According to the FAO soil data, specifically the soil classification system and erosion susceptibility, here's how the soil types AO, RD, and BE rank in terms of water erosion susceptibility:

AO (Orthic Acrisols): These soils are typically found in humid tropics and subtropics, characterized by a low base status and a subsurface accumulation of low activity clays. They have a moderate to high susceptibility to water erosion due to their structure and the often steep slopes where they are found.

RD (Dystric Regosols): These are young soils with weakly developed profiles, often on unconsolidated materials. They are generally more susceptible to erosion because of their loose, unconsolidated nature and low organic matter content, which does not bind the soil particles well. Therefore, RD soils tend to have a high susceptibility to water erosion.

BE (Eutric Cambisols): These soils have a cambic horizon (a subsurface layer showing evidence of soil-forming processes) and are relatively fertile with a higher base status. They are less susceptible to water erosion compared to AO and RD because they typically have better structure, more organic matter, and often occur on gentler slopes where water flow is less erosive.

Ranking Based on Water Erosion Susceptibility:

RD (Dystric Regosols) - High susceptibility

AO (Orthic Acrisols) - Moderate to High susceptibility

BE (Eutric Cambisols) - Lower susceptibility

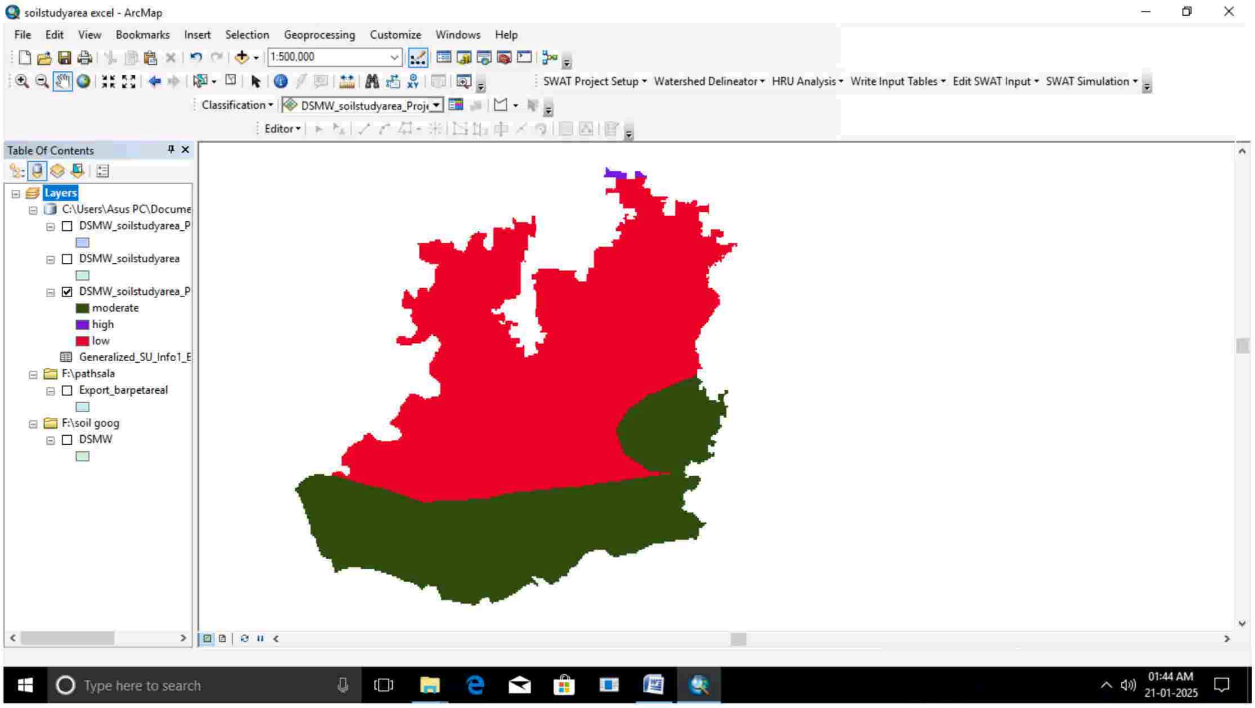
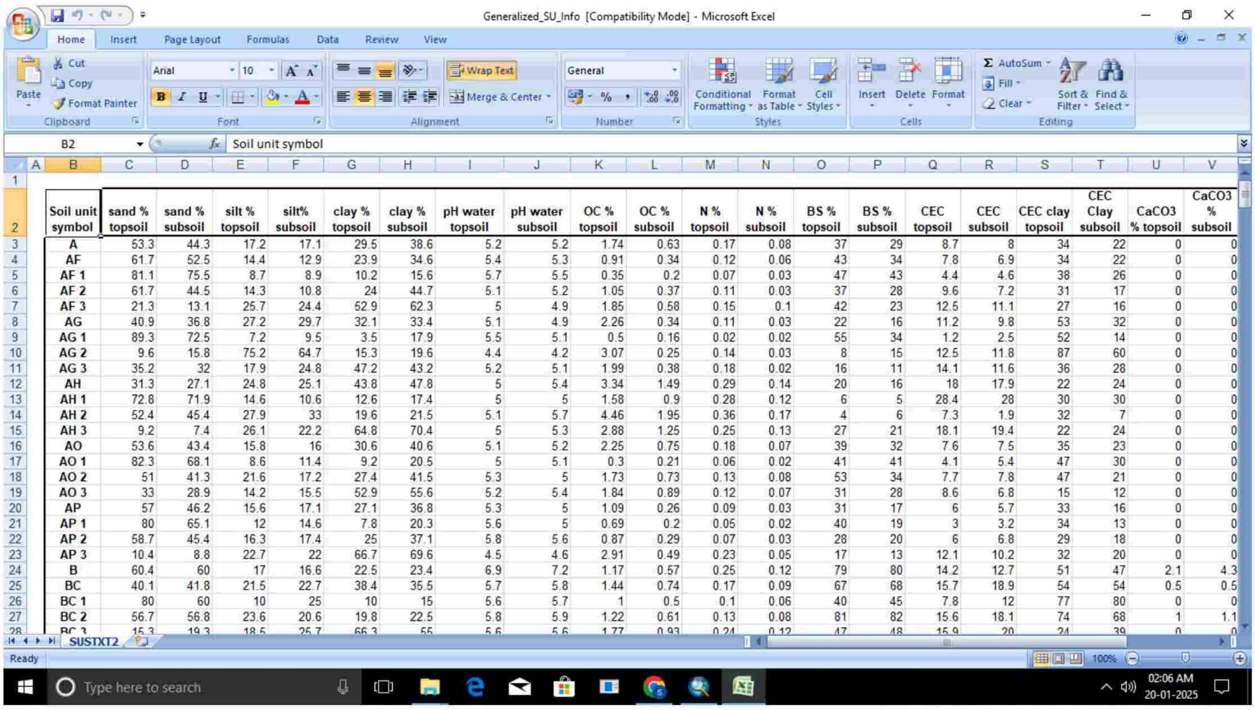


Figure 6.8: Soil map



Soil unit symbol	sand % topsoil	sand % subsoil	silt % topsoil	silt% subsoil	clay % topsoil	clay % subsoil	pH water topsoil	pH water subsoil	OC % topsoil	OC % subsoil	N % topsoil	N % subsoil	BS % topsoil	BS % subsoil	CEC topsoil	CEC subsoil	CEC clay topsoil	CEC Clay subsoil	CaCO3 % topsoil	CaCO3 % subsoil
A	53.3	44.3	17.2	17.1	29.5	38.6	5.2	5.2	1.74	0.63	0.17	0.08	37	29	8.7	8	34	22	0	0
AF	61.7	52.5	14.4	12.9	23.9	34.6	5.4	5.3	0.91	0.34	0.12	0.06	43	34	7.8	6.9	34	22	0	0
AF 1	81.1	75.5	8.7	8.9	10.2	15.6	5.7	5.5	0.35	0.2	0.07	0.03	47	43	4.4	4.6	38	26	0	0
AF 2	61.7	44.5	14.3	10.8	24	44.7	5.1	5.2	1.05	0.37	0.11	0.03	37	28	9.6	7.2	31	17	0	0
AF 3	21.3	13.1	25.7	24.4	52.9	62.3	5	4.9	1.85	0.58	0.15	0.1	42	23	12.5	11.1	27	16	0	0
AG	40.9	36.8	27.2	29.7	32.1	33.4	5.1	4.9	2.26	0.34	0.11	0.03	22	16	11.2	9.8	53	32	0	0
AG 1	89.3	72.5	7.2	9.5	3.5	17.9	5.5	5.1	0.5	0.16	0.02	0.02	55	34	1.2	2.5	52	14	0	0
AG 2	9.6	15.8	75.2	64.7	15.3	19.6	4.4	4.2	3.07	0.25	0.14	0.03	8	15	12.5	11.8	87	60	0	0
AG 3	35.2	32	17.9	24.8	47.2	43.2	5.2	5.1	1.99	0.38	0.18	0.02	16	11	14.1	11.6	36	28	0	0
AH	31.3	27.1	24.8	25.1	43.8	47.8	5	5.4	3.34	1.49	0.29	0.14	20	16	18	17.9	22	24	0	0
AH 1	72.8	71.9	14.6	10.6	12.6	17.4	5	5	1.58	0.9	0.28	0.12	6	5	28.4	28	30	30	0	0
AH 2	52.4	45.4	27.9	33	19.6	21.5	5.1	5.7	4.46	1.95	0.36	0.17	4	6	7.3	1.9	32	7	0	0
AH 3	9.2	7.4	26.1	22.2	64.8	70.4	5	5.3	2.88	1.25	0.25	0.13	27	21	18.1	19.4	22	24	0	0
AO	53.6	43.4	15.8	16	30.6	40.6	5.1	5.2	2.25	0.75	0.18	0.07	39	32	7.6	7.5	35	23	0	0
AO 1	82.3	68.1	8.6	11.4	9.2	20.5	5	5.1	0.3	0.21	0.06	0.02	41	41	4.1	5.4	47	30	0	0
AO 2	51	41.3	21.6	17.2	27.4	41.5	5.3	5	1.73	0.73	0.13	0.08	53	34	7.7	7.8	47	21	0	0
AO 3	33	28.9	14.2	15.5	52.9	55.6	5.2	5.4	1.84	0.89	0.12	0.07	31	28	8.6	6.8	15	12	0	0
AP	57	46.2	15.6	17.1	27.1	36.8	5.3	5	1.09	0.26	0.09	0.03	31	17	6	5.7	33	16	0	0
AP 1	80	65.1	12	14.6	7.8	20.3	5.6	5	0.69	0.2	0.05	0.02	40	19	3	3.2	34	13	0	0
AP 2	58.7	45.4	16.3	17.4	25	37.1	5.8	5.6	0.87	0.29	0.07	0.03	28	20	6	6.8	29	18	0	0
AP 3	10.4	8.8	22.7	22	66.7	69.6	4.5	4.6	2.91	0.49	0.23	0.05	17	13	12.1	10.2	32	20	0	0
B	60.4	60	17	16.6	22.5	23.4	6.9	7.2	1.17	0.57	0.25	0.12	79	80	14.2	12.7	51	47	2.1	4.3
BC	40.1	41.8	21.5	22.7	38.4	35.5	5.7	5.8	1.44	0.74	0.17	0.09	67	68	15.7	18.9	54	54	0.5	0.5
BC 1	80	60	10	25	10	15	5.6	5.7	1	0.5	0.1	0.06	40	45	7.8	12	77	80	0	0
BC 2	56.7	56.8	23.6	20.6	19.8	22.5	5.8	5.9	1.22	0.61	0.13	0.08	81	82	15.6	18.1	74	68	1	1.1
BC 3	15.3	19.3	18.5	25.7	66.3	55	5.6	5.6	1.77	0.93	0.24	0.12	47	48	15.9	20	24	39	0	0

Table 6.2: Excel table for FAO Global soil map

CHAPTER 7

CONCLUSION

Arc GIS software was used to evaluate and analyze various criterions to prepare flood risk maps and water erosion maps at Barpeta district. Based on the findings so far, several conclusions can be drawn

- The elevation map of Barpeta was prepared using Arc GIS. Elevation profile of Barpeta district was mostly found to be flat terrain along with presence of few hillocks in the southwestern parts of the district.
- The LULC Map of Barpeta displayed several classes using Arc GIS. Among all the classes crop/agriculture land occupied the highest area.
- The NDVI map prepared by Arc GIS using raster calculator showcases health of vegetation in Barpeta district.
- The slope map displays the steepness of terrain, measured in degrees or percent. It indicates how land elevation changes, affecting water flow, erosion, and land use planning.
- The Topographic Wetness Index (TWI) shows areas prone to water accumulation based on landscape shape. It indicates soil moisture, potential for flooding, and vegetation type by analyzing slope and upslope contributing area, aiding in hydrological and ecological assessments.

All the criterions are essential for preparing flood risk and erosion maps. Other criterions like Precipitation, drainage density, curvature can also be analysed to prepare risk maps. Integration of AHP (Analytical Hierarchial Process) with GIS along with other criterions will increase the accuracy of risk maps.

REFERENCES

Arabameri, A., Pradhan, B., Rezaei, K., (2019). "Flood susceptibility mapping using GIS and multi-criteria decision analysis in Dibrugarh District of Assam, North-East India." Journal of Cleaner Production, Vol. 237, pp. 117683.

Toosi, A. S., Tousi, E. G., Ghasemi, S., (2019). "Identifying flood vulnerable and risk areas using the integration of analytical hierarchy process (AHP), GIS, and remote sensing: A case study for southern Oromia, Ethiopia." Sustainable Cities and Society, Vol. 44, pp. 740-751.

Mishra, K., Sinha, R., (2020). "Flood risk assessment in Assam, India using GIS-AHP approach." Journal of Environmental Management, Vol. 255, pp. 109882.

Ghosh, A., Mukhopadhyay, S., Das, S., (2021). "Application of the GIS based multi-criteria decision analysis and analytical hierarchy process (AHP) in the flood susceptibility mapping of the Baramulla district." Journal of Environmental Management, Vol. 284, pp. 112048.