IDENTIFICATION OF CLIMATE CHANGE IMPACTS IN PACHAIYAR SUB -WATERSHED USING GEOSPATIAL TECHNOLOGY

A PROJECT REPORT

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in partial fulfillment of the award of degree

of

BACHELOR OF ENGINEERING

IN

GEOINFORMATICS ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

ANNA UNIVERSITY REGIONAL CAMPUS TIRUNELVELI

ANNA UNIVERSITY: CHENNAI 600 025

MAY 2025

ANNA UNIVERSITY: CHENNAI 600 025

BONAFIDE CERTIFICATE

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INTERNAL EXAMINER EXTERNAL EXAMINER

ACKNOWLEDGEMENT

First and foremost, we immensely thank **God Almighty** for showering his grace and blessings for the successful completion of this project.

We would like to convey our heartfelt gratitude to our guide **Dr. K. Palanivel, MSc., Ph.D., Professor,** Department of Remote Sensing, Bharathidasan University, for his persistent supervision in completing the project on schedule.

We wholeheartedly thank **Dr.C. Lakshumanan, MSc., M.Tech., Ph.D., Professor and Head,** Department of Remote Sensing, Bharathidasan University, Tiruchirappalli

We would like to thank **Dr. Shenbaga Vinayaga Moorthi M.E., Ph.D.,** the dean of the Anna University Regional Campus Tirunelveli.

We wholeheartedly thank **Dr. S. Adishkumar, M.E., Ph.D.,** Head of the Department of Civil Engineering, Anna University Regional Campus, Tirunelveli.

We are grateful to **Dr. M. Suresh Karthik Kumar, M.E., Ph.D.,** Assistant Professor, Department of Civil Engineering, Anna University Regional Campus Tirunelveli for his guidance, knowledge sharing and valuable suggestions to complete the project work.

We have deep gratitude towards **Mrs. G. Devi M.Tech.,** our Project coordinator for her excellence support, valuable suggestions and constant support to complete the project.

Finally, we would like to thank our beloved parents and friends for their unwavering support and encouragement needed throughout the enriching project.

ABSTRACT

The Pachaiyar sub-watershed, a critical tributary of the Thamirabharani River in Tamil Nadu, India, faces increasing challenges due to climate change, including heightened soil erosion and flood risks. This study employs advanced geospatial technologies integrated with GIS-based modeling techniques to assess and mitigate these impacts. The Revised Universal Soil Loss Equation (RUSLE) model is used to estimate soil erosion, incorporating multiple factors such as rainfall erosivity, soil erodibility, slope length and steepness, cover management, and support practices. Concurrently, flood-prone zones are identified using the Analytic Hierarchy Process (AHP), which assigns weighted significance to various terrain and hydrological parameters. The methodology involves generating and analyzing thematic layers derived from satellite imagery (Sentinel-2), SRTM DEM, and collateral data such as land use, rainfall, and lithology. The results include detailed soil loss and flood zonation maps, providing actionable insights for sustainable watershed management. This integrated geospatial approach supports informed decision-making and the development of effective climate change mitigation strategies for the Pachaiyar sub-watershed.

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LIST OF ABBREVIATIONS

ARCGIS	Aeronautical Reconnaissance Coverage Geographic Information System
AHP	Analytical Hierarchy Process
DEM	Digital Elevation Model
DIVA GIS	Data Information Visualization Analysis Geographic Information System
DSMW	Digital Soil Map of the World
ESRI	Environmental System Research Institute
GIS	Geographic Information System
IMD	Indian Meteorological Department
LULC	Land Use and Land Cover
NASA	National Aeronautical and Space Agency
NBSS	National Bureau of Soil Survey
RUSLE	Revised Universal Soil Loss Equation
SOI	Survey of India
SPI	Stream Power Index
SRTM	Shuttle Radar Topography Mission
TCC	True Colour Composite
TRI	Topographic Roughness Index
TWI	Topographic Wetness Index
USGS	United States Geological Survey

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Climate change has emerged as one of the most significant environmental challenges, impacting ecosystems, water resources, and human settlements. Watersheds, being vital units of hydrological systems, are particularly vulnerable to the adverse effects of climate variability such as erratic rainfall, floods, and soil erosion.

Flooding is one of the most devastating natural disasters, often triggered by intense and unseasonal rainfall, poor drainage, and changes in land use patterns. In recent years, the frequency and intensity of floods have increased due to climate change, posing serious threats to both life and property. Flooding within a sub-watershed represents a significant hydrological hazard, especially in regions where land use changes, topographical variations, and extreme weather events intersect. Sub-watersheds, being smaller hydrological units within a larger drainage basin, are particularly sensitive to intense rainfall, poor drainage patterns, and reduced vegetation cover—all of which can lead to flash flooding.

Soil erosion is a critical environmental issue that leads to the loss of fertile topsoil, reduced agricultural productivity, sedimentation in water bodies, and degradation of natural ecosystems. Soil erosion is a major environmental concern in sub-watershed regions, where the interaction of topography, rainfall, vegetation, and land use significantly influences the rate of soil loss.

1.2 CLASSIFICATION OF FLOOD

Floods can be classified into several types based on their causes and characteristics. Here are the main classifications:

TABLE 1.1 CLASSIFICATION OF FLOOD

TYPES OF FLOOD	CAUSES	RAINFALL INTENSITY
River Flood	Prolonged heavy rainfall or snowmelt	Moderate to High (long-term)
Flash Flood	Intense rainfall in a short time	Very High (short-term)
Coastal Flood	Storm surges, cyclones	Varies (not always rain-related)
Urban Flood	Heavy rainfall + poor drainage	Moderate to High
Groundwater Flood	Sustained rainfall leading to rising water table	Low to Moderate (long-term)

1.3 CLASSIFICATION OF SOIL EROSION

Here's a table for the classification of soil erosion, including rainfall intensity as a contributing factor and their causes.

TABLE 1.2 CLASSIFICATION OF SOIL EROSION

TYPES OF SOIL EROSION	CAUSES	RAINFALL INTENSITY
Splash Erosion	Impact of raindrops on bare soil	Low to Moderate
Sheet Erosion	Surface runoff from rainfall	Moderate to High
Rill Erosion	Concentrated runoff forming small channels	High
Gully Erosion	Advanced rill erosion from intense runoff	Very High or Continuous
Stream Bank Erosion	River or stream water flow	Linked to Heavy Rainfall

1.4 GOVERNMENT MITIGATION PLAN FOR CLIMATE CHANGE IMPACTS

The Government of Tamil Nadu has implemented a multifaceted approach to address flood risks and soil erosion, focusing on both structural and non-structural measures.

FLOOD MITIGATION STRATEGIES

1.State Disaster Management Plan (2023)

The Tamil Nadu State Disaster Management Plan outlines comprehensive strategies for disaster risk reduction, including flood management.

2.Flood Management Programme (FMP)

Under the Flood Management Programme, the state has undertaken various projects to control floods. These include the construction of embankments, strengthening of riverbanks, and improvement of drainage systems to mitigate flood risks.

SOIL EROSION CONTROL MEASURES

1.National Guidelines for Management of Floods

The guidelines advocate for the construction of soil erosion control structures and the implementation of afforestation programs to stabilize soil and prevent erosion.

2.Coastal and River Erosion Management

The government has recognized the need for a policy to address displacement caused by coastal and river erosion. Efforts include the construction of erosion control structures and the resettlement of displaced populations, particularly in coastal areas.

INSITUTIONAL FRAMEWORK

1.Tamil Nadu State Disaster Management Authority (TNSDMA)

TNSDMA coordinates disaster risk reduction efforts across the state, ensuring the implementation of flood and erosion control measures.

2.Tamil Nadu Disaster Risk Reduction Agency (TNDRRA)

NDRRA serves as the executive agency for TNSDMA, overseeing the execution of disaster risk reduction projects, including those related to flood and soil erosion mitigation.

1.5 AIM AND OBJECTIVE

The main aim of the study is to delineate the climate change impacts such as Flood prone areas, Soil eroded areas in Pachaiyar sub-watershed in Thamirabharani river basin.

- ✓ To prepare Basic, geologic and terrain thematic layers in GIS.
- ✓ To identify flood prone areas by Weighted overlay analysis using AHP In ARCGIS.
- ✓ To Quantify Soil Erosion in Pachaiyar sub-watershed using RUSLE MODEL .
- ✓ To suggest Mitigation plans for minimising impacts of climate change in Pachaiyar sub-watershed.

1.6 NEED FOR THE STUDY

- ✓ Studying the watershed helps understand its contribution to local livelihoods and identify potential vulnerabilities.
- ✓ Assessing the potential impacts of climate change on the water availability and ecological health of the sub-watershed.
- ✓ Analyzing rainfall patterns, including seasonal and annual variations ,is essential for understanding the water cycle and its impact on the sub-watershed.
- ✓ A watershed study identifies erosion-prone zones and helps design effective soil and water conservation measures.
- ✓ Analyzing hydrological patterns helps in identifying flood-prone, enabling timely interventions and disaster preparedness.

1.7 CONCLUSION

From this chapter, an overview of the Flood and Soil erosion, its classification, the mitigation plan and the objective of the study are explained.

CHAPTER 2
REVIEW OF LITERATURE

2.1 GENERAL

This chapter discusses the literature that have been reviewed in order to conduct the entire study.

2.2 REVIEW OF LITERATURE

Pragya Shree Mahanta (2024) The study aims to evaluate the soil erosion in majuli island in India. The parameters used are Rainfall erosivity factor R , Soil erodibility factor K, Slope length and steepness LS ,Cover management factor C ,Support practice factor P. Statistical RUSLE Equation was used in this case study. The study emphasizes the significance of GIS based RUSLE models in assessing Soil erosion dynamics particularly in Majuli island.

Ananya Saikia (2024) The main purpose this study is to estimate the soil loss and to determine soil loss zones in the Morigaom District of Assam.The five parameters of RUSLE namely, Rainfall-Runoff erosivity,Soil erodibility,Topographic factor,Cover management and Conservation practices are used in this case study.The result indicates the soil loss estimation maps of the study area reveal that about 46.89% of the district is in the moderate zone of soil loss and 15.36% area is in the high soil loss zone.

K.R.Sooryamol et al., (2022) The study was carried out to simulate climate change impacts on soil erosion for a small watershed of Lesser Himalayan region employing calibrated SWAT model. The study used several key parameters,including Surface runoff,Sediment yield,Peak runoff rate,Soil texture,Rainfall intensity and Land use/Land cover. Soil and water assessment tool (SWAT) includes Modified Universal soil loss equation (MUSLE) for soil erosion estimation.

Azazkhan Ibrahimkhan Pathan (2022) This study presents a flood risk assessment of Navsari city in Gujarat, India using Analytic Hierarchy Process (AHP). Physical parameters used are Slope, Landuse and Land Cover, Drainage Density and Soil type. SRTM DEM was used to derive Slope etc. The study effectively demonstrated that AHP within GIS Based framework offers a reliable and systematic approach for urban flood risk assessment.

Y Berkat et al., (2021) Flood occurs when the surface water overflow (runoff) exceeds drainage and water bodies. Rainfall, Temperature, LULC, Soil type, Slope and Elevation, NDVI, Streamflow are the parameters used in this study. Supervised classification (Maximum Likelihood Method) for Land cover classification is used in this study. This study used remote sensing and GIS techniques to identify the character of areas and flood susceptibility zones in Semarang.

Kishore Chandra Swain (2020) This study highlights that flood Susceptibility mapping is essential for characterizing Flood risk zones. The parameters used are Geology, TWI, SPI, Rainfall, LULC. The Google earth engine, AHP and SRTM DEM are the tools used in this study. The study concluded that high resolution flood susceptibility map that could assist urban planning, Flood risk assessment and Disaster management.

SK Ajim Ali (2019) The study focuses on identifying and mapping areas in the Sundarban region that are vulnerable to flood insecurity. The physical parameters involved are LULC, Soil quality, Rainfall Distribution.AHP is used to assign weights to various parameters based on their relative importance in flood vulnerability. The study concluded that the flood vulnerable map is an important aspect for planning suitable land use in flood prone areas.

Farid Radwan (2018) This study applies the Analytic Hierarchy Process(AHP) Method for flood risk assessment in semi-arid regions.The main parameters they used are Slope, LULC, Soil Type, Rainfall and Drainage Density.AHP is used to determine the weights of different parameters based on pairwise comparison and expert input.This study concluded that flash floods happen during or after an excessive precipitation event over a very short period.

Surya Gupta (2017) The study was to estimate the impact of climate change on soil erosion in a watershed of the Himalayan region using RUSLE model. Here in this case study, they use five parameters representing Rainfall Erosivity (R), Soil Erodibility (K), Slope length and Steepness (LS), Vegetation cover (C). ASTER digital elevation model (DEM) was used to generate the spatial input parameters required by RUSLE model. Result indicates that the mid Himalayan have more soil erosion.

Nigussie Haregeweyn (2016) The case study describes the soil erosion by water results in significant consequences in Upper Blue Nile River (UBNR) basin of Ethiopia. Here in this case study, they use several parameters representing Soil loss rate, Slope variation, Soil and water conservation (SWC) interventions, Revised Universal Soil Loss Equation (RUSLE) factors. Sediment Delivery Ratio (SDR) model has been used to estimate the fraction of eroded soil that reaches water bodies. The study concluded that The UBNR basin is experiencing significant problems related to erosion by water.

2.3 CONCLUSION

From the review of literature, it is evident that Remote sensing and GIS technology plays a major role in identifying flood prone and soil eroded area

CHAPTER 3

STUDY AREA AND ITS DESCRIPTION

3.1 GENERAL

This chapter deals with the study area and its description.

3.2 LOCATION OF THE STUDY AREA

The area chosen for the study is Pachaiyar sub-watershed which lies between 77°28′32′′ and 77°37′84′′East longitudes and, 8°17′40′′and8°38′65′′North latitudes. The Pachaiyar sub-watershed has a total drainage area of approximately 288.66 square kilometres(sq.km). The study area is shown in FIGURE 3.1

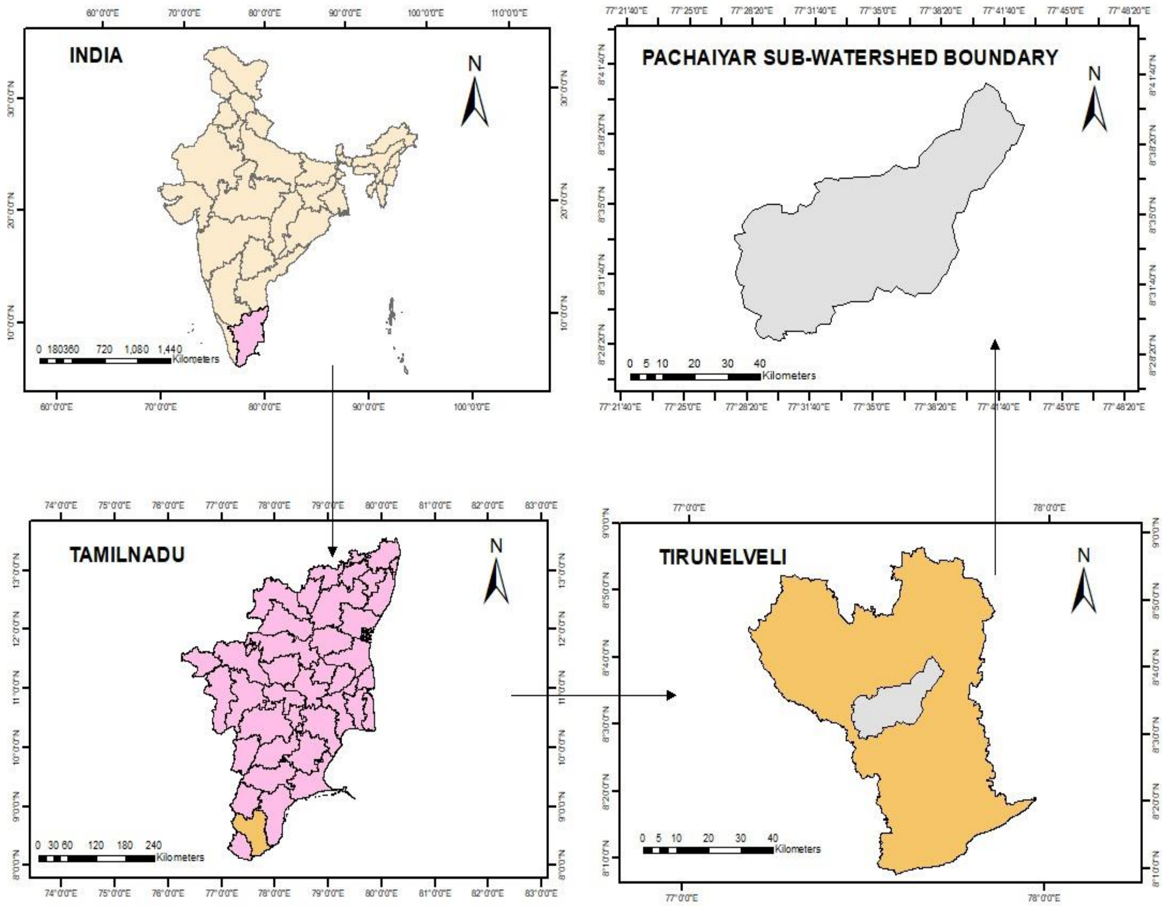


FIGURE 3.1 STUDY AREA

3.3 DESCRIPTION OF THE STUDY AREA

The Pachaiyar river is one of the tributaries of Thamirabharani river and originates on the Eastern slopes of the Western Ghats in Tamilnadu, India. It is approximately 1000 meters (3300 feet) above the sea level and flows about 32 Kilometres (20 miles) before merging with the Thamirabharani river.

The sub-watershed encompasses diverse terrains, from the high-altitude regions of the Western Ghats to the plains, supporting varied ecosystems. The area is part of the Kalakkad Mundanthurai Tiger Reserve, indicating rich biodiversity and ecological importance.

The river Pachaiyar has three tributaries which are Kahayan Odai, Anaikidangu Odai and Uppan Odai. These tributaries join the river Pachaiyar in the villages Arasppattu, Vadagarai and Padmaneri respectively.

The fertile lands within the sub-watershed are utilized for cultivating various crops, contributing to the local economy. The sub-watershed contributes to groundwater recharge, essential for sustaining wells and borewells used in agriculture and domestic purposes.

3.4 TOPOGRAPHY OF THE STUDY AREA

The Pachaiyar sub-watershed is located in southern Tamil Nadu, India, and forms part of the Thamirabarani River Basin. It begins in the Western Ghats at an elevation of around 1,000 meters above sea level. The topography of the area varies, with steep and hilly terrain in the upper regions and flatter land as it moves toward the east. The watershed is made up of ancient hard rocks, which influence the soil type-thin and rocky in the hills, and deeper and more fertile in the lower areas. The upper hilly regions are mostly covered with forests, the mid-level zones are used for farming, and the lower areas are more populated with larger agricultural fields.

3.5 CLIMATE OF THE STUDY AREA

The pachaiyar sub-watershed experience a Tropical monsoon climate, influenced by its location near the western ghats. The region receives rainfall from both the Southwest (June to September) and Northeast (October to December) monsoons. Due to the presence of the western ghats, the upper part of the watershed receives more Rainfall.Annual Rainfall in the region is generally Moderate to High, with the upper reaches receiving over 1,200 mm per year, while the lower areas receive slightly less.

3.6 CONCLUSION

The study area and its description have been explained in this chapter.

CHAPTER 4

MATERIAL AND METHODOLOGY

4.1 GENERAL

This chapter deals with the Materials, Methodology and Software that have been used in this study.

4.2 DATA USED

The data used for assessing the flood prone and soil eroded areas are shown in the TABLE 4.1

TABLE 4.1 DATA USED

SNO	DATASETS	SOURCE
1	Landuse And Land Cover	Sentinel - 2
2	Slope	SRTM DEM – 30m (USGS Earth Explorer)
3	Flow Accumulation	SRTM DEM – 30m (USGS Earth Explorer)
4	Stream Power Index (SPI)	SRTM DEM – 30m (USGS Earth Explorer)
5	Topographic Roughness Index (TRI)	SRTM DEM – 30m (USGS Earth Explorer)
6	Topographic Wetness Index (TWI)	SRTM DEM – 30m (USGS Earth Explorer)
7	Relief	SRTM DEM – 30m (USGS Earth Explorer)
8	Lineament	SRTM DEM – 30m (USGS Earth Explorer)
9	Lineament Density	SRTM DEM – 30m (USGS Earth Explorer)
10	Soil Map	Digital Soil Map of the World (DSMW)
11	Rainfall Map	IMD Rainfall Data
12	Geomorphology	Geological Survey of India (GSI)
13	Lithology Map	Geological Survey of India (GSI)
14	Soil Type Map	National Bureau of Soil Survey (NBSS)
15	Drainage and Drainage Density	Survey of India Toposheets

4.3 DATA DESCRIPTION

4.3.1 DEM

A Digital Elevation Model (DEM) is a 3-Dimentional representation of the Topography of a land surface or terrain. DEMs are often used in GIS and are the most common basis for digitally produced relief maps. In the study, we used SRTM (Shuttle Radar Topography Mission) DEM with a 30m spatial resolution to perform slope, flow accumulation, SPI, TWI, TRI, relief, lineament and lineament density. The data was downloaded from the USGS Earth Explorer.

4.3.2 Sentinel – 2

Sentinel-2 is an Earth Observation mission from the Copernicus program that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission currently operates three satellite Sentinel 2A, Sentinel 2B and 2C. The Sentinel 2 mission comprises a constellation of 2 polar orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other.

In this study, we used Sentinel 2A data with a 10m resolution to identify the changes in land use land cover patterns. This data was downloaded from ESA Copernicus Open Access Viewer. In total it has 13 multispectral bands. Thus, the information of the Spectral Bands of Sentinel 2A are shown in the TABLE 4.2

TABLE 4.2 SPECIFICATONS OF SENTINEL 2A

Spectral Band	Resolution (m)	Wavelength (nm)	Description
B1	60m	443nm	Ultra Blue (Coastal and Aerosol)
B2	10m	490nm	Blue
B3	10m	560nm	Green
B4	10m	665nm	Red
B5	20m	705nm	Visible and Near Infrared (VNIR)
B6	20m	740nm	Visible and Near Infrared (VNIR)
B7	20m	783nm	Visible and Near Infrared (VNIR)
B8	10m	842nm	Visible and Near Infrared (VNIR)
B8a	20m	865nm	Visible and Near Infrared (VNIR)
B9	60m	940nm	Short Wave Infrared (SWIR)
B10	60m	1375nm	Short Wave Infrared (SWIR)
B11	20m	1610nm	Short Wave Infrared (SWIR)
B12	20m	2190nm	Short Wave Infrared (SWIR)

4.3.3 GEOLOGICAL SURVEY OF INDIA (GSI)

The GSI conducts detailed geological mapping and exploration to understand the geological structure, composition, and history of India. A geological survey is the systematic investigation of the geology beneath a given piece of ground for the purpose of creating a geological map or model and it's used to the study area is lithology map, geomorphology map. A Geomorphology map represents the physical features and landforms of the Earth's surface, such as mountains, valleys, plateaus, plains, and coastal features. A Lithology map displays the types and distribution of rocks (igneous, sedimentary, metamorphic) found at the Earth's surface.

4.3.4 SURVEY OF INDIA TOPOSHEETS

A Toposheet is a detailed and accurate map prepared by the Survey of India (SOI). These maps represent the three-dimensional features of the Earth's surface on a two-dimensional sheet, using symbols, contour lines, and scales. In this study we used following toposheets (58H6,58H7,58H10,58H11) to perform drainage map. These maps display a terrain, along with features such as rivers, hills, forests, roads, settlements, railways, and land use patterns.

4.3.5 DIGITAL SOIL MAP OF THE WORLD (DSMW)

DSMW provides detailed information about soil properties and their spatial distribution, enabling better understanding and management of land resources. Digital compilation of soil information from around the world, including data on soil types, properties, and their spatial distribution. In this study we deal about two types of soil. One is Lc (Chromic Luvisols) and another one is I (Lithosols).

4.3.6 NATIONAL BUREAU OF SOIL SURVEY (NBSS)

NBSS provides detailed information on the distribution, characteristics, and classification of soils in a given area. These maps include data on soil texture, depth, drainage, fertility status, and capability for agricultural use. By analyzing various soil properties. In this study we use soil types data to prepare soil types map.

4.3.7 INDIA METEOROLOGICAL DEPARTMENT(IMD)

India Meteorological Department (IMD), which is the main government body responsible for monitoring weather and climate in India. IMD rainfall data includes measurements and analyses of rainfall over different periods (daily, weekly, monthly, seasonal, and annual) across various regions in India. This data is collected from thousands of rain gauge stations spread across the country. In this study we used rainfall data for 2023 to identify annual rainfall of the year.

4.4 SOFTWARE USED

GIS software are computer-based programs and tools that allows the user to visualize, analyze, interpret and store the geographic datasets. The software that has been for the study are,

1. ArcGIS Desktop
2. ArcGIS Pro
3. MS Excel

4.4.1 ARCGIS DESKTOP

ArcGIS is a Desktop software developed by ESRI which can be used primarily to view, edit, create, and analyze geospatial datasets. ArcMAP 10.8 has been used in particular, which is a part of the ArcGIS desktop suite.

ArcMAP is the former main component of ESRI's ArcGIS suite of geospatial processing programs. ArcMap allows the user to explore data within a data set, symbolize features accordingly, and create maps. The ArcMap interface has two main sections, including the table of contents on the left and the data frames which display the map. Items in the table of contents correspond with the layers on the map.

4.4.2 ARCGIS PRO

ArcMAP is the former main component of ESRI's ArcGIS suite of geospatial processing programs. ArcMap allows the user to explore data within a data set, symbolize features accordingly, and create maps. The ArcMap interface has two main sections, including the table of contents on the left and the data frames which display the map. Items in the table of contents correspond with the layers on the map.

4.4.3 MS – EXCEL

Microsoft Excel has the basic features of all spreadsheets, using a grid of cells arranged in numbered rows and letter-named columns to organize data manipulations like arithmetic operations. It has a battery of supplied functions to answer statistical, engineering and financial needs. In addition, it can display data as line graphs, histograms and charts with a very limited three-dimensional graphical display. Spreadsheet applications such as MS Excel use a collection of cells arranged into rows and columns to organize and manipulate data. It permits users to arrange data in order to view various factors from different perspectives.

4.5 METHODOLOGY

The methodology mainly focuses in identification of Flood prone zones and soil eroded areas in our Study area.

The flowchart of methodology is shown in FIGURE 4.1

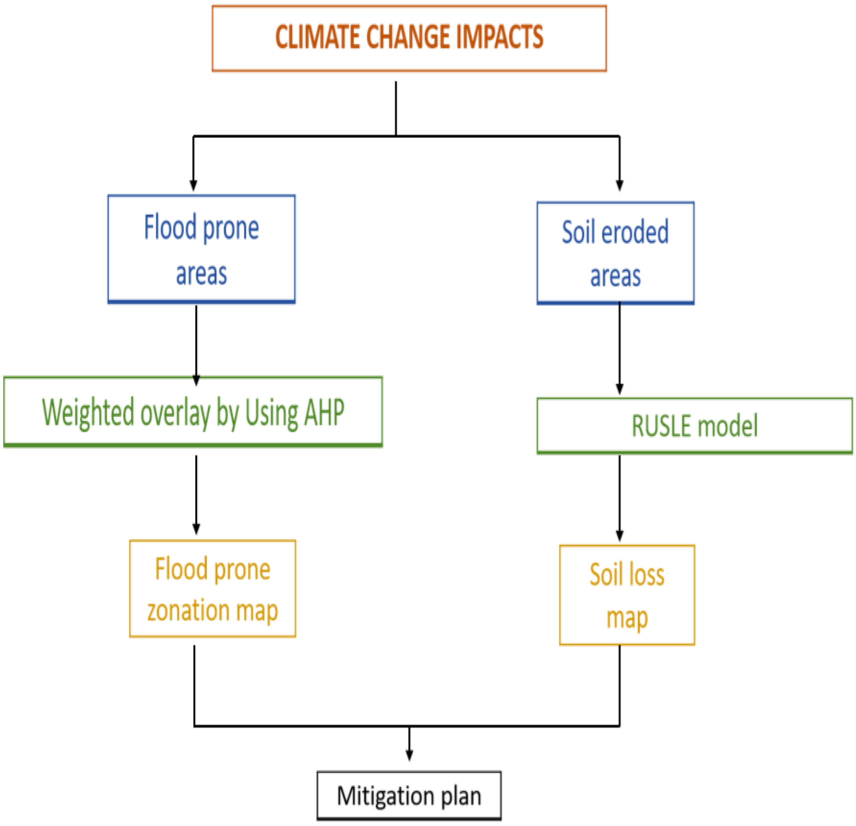


FIGURE 4.1 FLOW CHART OF THE METHODOLOGY

4.5.1 METHODOLOGY FOR FLOOD PRONE MAP

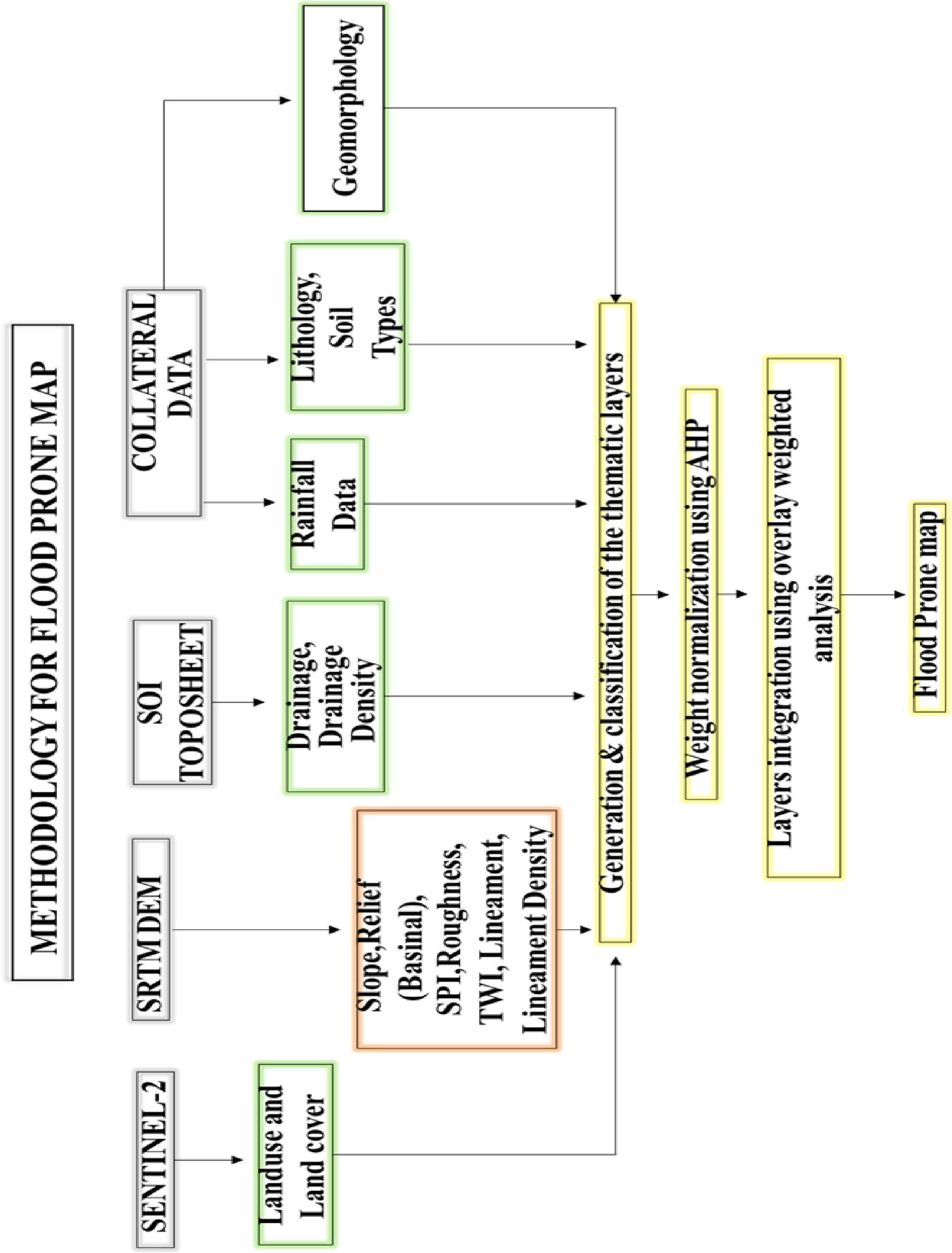


FIGURE 4.2 FLOW CHART OF THE METHODOLOGY FOR FLOOD PRONE MAP

4.5.2 METHODOLOGY FOR RUSLE

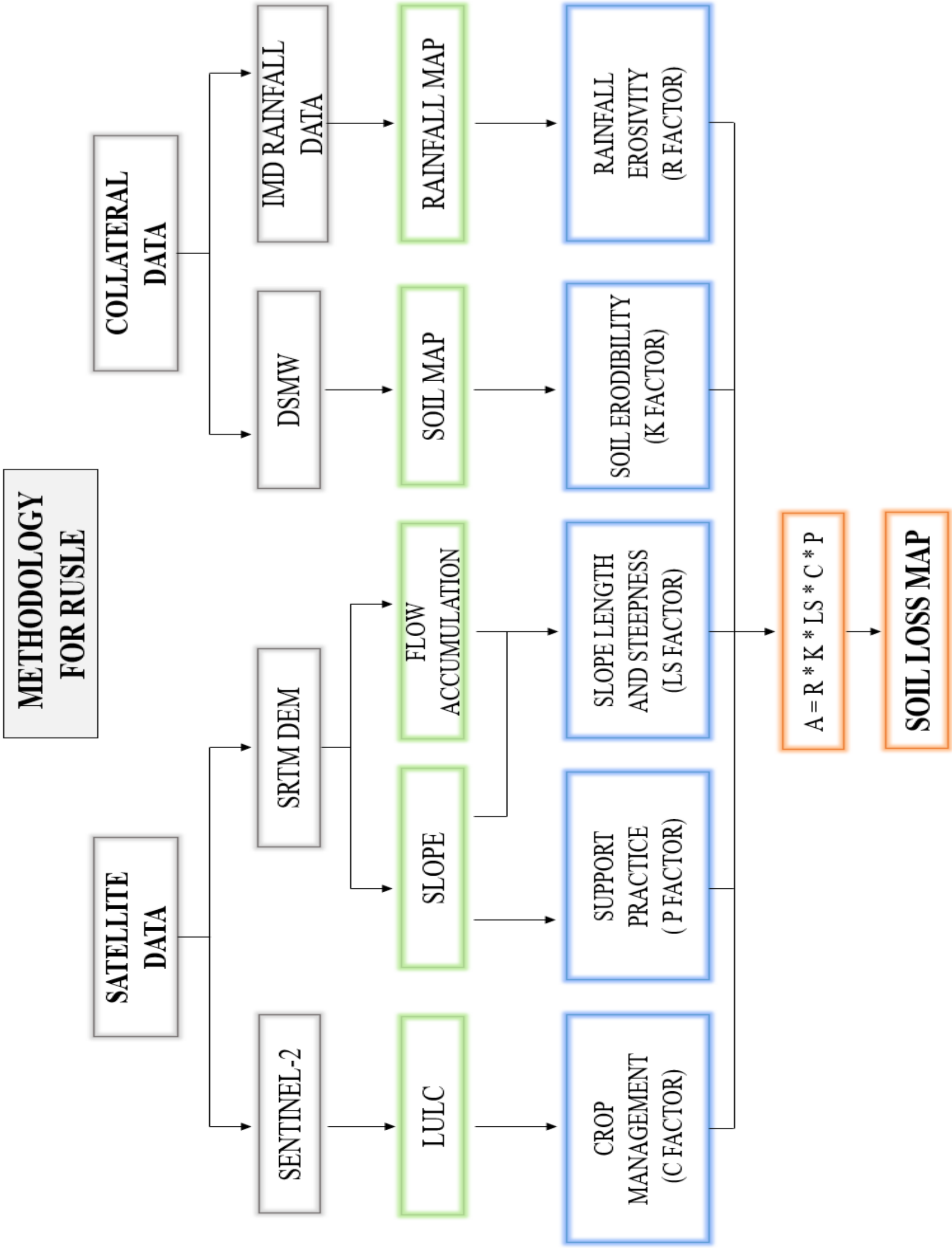


FIGURE 4.3 FLOW CHART OF THE METHODOLOGY FOR SOIL LOSS MAP

4.6 CRITERIA FOR CLIMATE CHANGE IMPACTS

The criteria for assessing climate change impacts in the Pachaiyar sub-watershed study area were based on both environmental and hydrological parameters derived using geospatial techniques. Key criteria included:

- ✓ **Flood Prone Zones** – Identified through weighted overlay analysis using AHP with layers like slope, landuse and land cover, drainage, Geomorphology, TWI, TRI, SPI, Relief, Rainfall, Lithology, Lineament etc.

- ✓ **Soil Erosion** – Quantified using the RUSLE model, considering rainfall erosivity, soil erodibility, slope, vegetation cover, and conservation practices.

4.7 CRITERIA FOR FLOOD PRONE MAP

A flood prone map is a geospatial tool that identifies and classifies areas at varying levels of flood risk based on physical, climatic, and environmental parameters. The methodology for preparing this map involves the integration of multiple thematic layers derived from diverse data sources such as satellite imagery (e.g., Sentinel-2), SRTM DEM, Survey of India toposheets, and collateral data including rainfall, lithology, soil types, and geomorphology. These maps highlight zones that are at risk of inundation during heavy rainfall, river overflow, or dam release events.

4.7.1 LANDUSE AND LAND COVER

Land cover is simply what covers earth's surface and land use describes how the land is used. Landuse and Land Cover (LULC) is a valuable indicator for flood and soil erosion assessment.

In this study, Sentinel-2 data with 10 m spatial resolution was used to generate the LULC map. In ArcGIS, the following bands 4,3,2 of the Sentinel 2A data were used for True Colour Composite (TCC). Then Digitization was performed to prepare LULC map. The ROI were classified into Built-up area, Waterbody, Cropland, Barenland, Rangeland, Vegetation and Forest.

4.7.2 SLOPE

Slope refers to the changes in the physical features of the land with its elevation, orientation and topography. Slope can be expressed either in degree or percentage. This study utilized the SRTM DEM data with 30m spatial resolution, which was obtained from USGS Earth Explorer. Using spatial analyst tool in ArcGIS, the slope for the study area is created.

4.7.3 RELIEF

Relief refers to the difference in elevation between the highest and lowest points in a specific area of the earth's surface. For the study area the relief map was created using SRTM DEM data in GIS. Elevation differences were extracted to calculate basinal relief. Thematic classification was applied to visualize terrain variation. This map supported flood and analysis in the study.

4.7.4 STREAM POWER INDEX(SPI)

SPI is a hydrological metric that represents the erosive power of flowing water in a landscape. SPI map for this study area was created using SRTM DEM in GIS. Flow accumulation and slope layers were derived from the DEM.SPI was calculated using the formula,

SPI=ln(Flow accumulation*Slope)

The resulting SPI map was classified to assess flood-prone zones.

4.7.5 TOPOGRAPHIC ROUGHNESS INDEX(TRI)

TRI is a measure of the variability in elevation across a landscape, similar to the terrain Ruggedness index. In this study, the TRI map was prepared from SRTM DEM and used as a thematic layer in flood and erosion analysis. TRI values using tools like Focal Statistics. The resulting TRI map was classified to visualize terrain roughness for flood analysis.

4.7.6 TOPOGRAPHIC WETNESS INDEX(TWI)

TWI is a measure that indicates how likely an area is to accumulate water, based on its slope. The TWI map for the study area was created using SRTM DEM data in GIS. Slope and flow accumulation layers were derived from the DEM.TWI was then calculated using the formula,

TWI=ln (Flow accumulation/tan(slope))

The output TWI map was classified to identify areas of potential water accumulation**.**

4.7.7 LINEAMENT

A lineament is a linear feature on the Earth's surface that represents a zone of structural weakness such as a fault, fracture, or joint in the underlying rock. For this study lineament was used to prepare lineament density.

4.7.8 LINEAMENT DENSITY

Lineament density refers to the total length of lineaments per unit area in a study area region. In this study, the Lineament density map was derived from SRTM DEM. The lineaments were extracted and then converted into vector format and their total lengths were calculated. Finally, lineament density was computed as total lineament length per square kilometer and visualized as a density map.

4.7.9 DRAINAGE

Drainage maps help identify potential flood zones, analyse water movement, and support the design of effective soil and water conservation measures. For the study area, the drainage map was created using SOI Toposheets (58H6,58H7,58H10,58H11) to extract drainage patterns.

4.7.10 DRAINAGE DENSITY

A Drainage Density Map is a thematic representation that shows the total length of all the streams and rivers in a drainage basin divided by the total area of the basin. The drainage density map was created by first extracting the drainage network from the SOI Toposheets. The total length of streams was calculated within each unit area (e.g., per square kilometer). GIS tools like ArcGIS were used to compute drainage density as the ratio of stream length to area. The final map highlights variations in drainage density across the sub-watershed.

4.7.11 RAINFALL

A rainfall map is a thematic representation that displays the spatial distribution and intensity of rainfall over a specific area during a defined time period, such as daily, monthly, seasonal, or annual intervals. For this study, the rainfall map was created using rainfall data from the Indian Meteorological Department (IMD). Point rainfall data from various stations were interpolated using spatial interpolation techniques like IDW (Inverse Distance Weighting) in GIS. This produced a continuous surface representing rainfall distribution across the study area. The final interpolated map was then classified to show spatial variation in rainfall intensity.

4.7.12 LITHOLOGY

A lithology map is a geological representation that shows the distribution and types of different rock units present at or near the Earth's surface. For the study, the lithology map was created using collateral data from geological surveys and existing maps. This data was digitized and georeferenced in a GIS environment to match the study area. Different rock types and formations were classified and mapped using vector layers. The final lithology map shows the spatial distribution of various geological units in the sub-watershed.

4.7.13 SOIL TYPE

Soil type refers to the classification of soil based on its physical and chemical properties, primarily focusing on texture, which is determined by the proportion of sand, silt, and clay particles.

4.7.14 GEOMORPHOLOGY

A geomorphology map is a specialized map that illustrates the physical features and landforms of the Earth's surface, such as mountains, valleys, plateaus, plains, dunes, and river terraces, along with the processes that shape them. In this study, the geomorphology map was created collateral data from geological sources. Features like landforms, slope patterns, and drainage were interpreted visually and digitally in GIS. These features were classified into geomorphic units such as hills, valleys, plains, and pediments. The final map was digitized and georeferenced to represent the landform characteristics of the study area accurately.

4.8 WEIGHT NORMALIZATION USING AHP

4.8.1 ANALYTIC HIERARCHY PROCESS(AHP)

The Analytic Hierarchy Process (AHP) is a structured decision-making methodology developed by Thomas L. Saaty in the 1970s, designed to solve complex decision problems involving multiple criteria and alternatives. AHP breaks down a problem into a hierarchical structure, where the goal is at the top, followed by criteria and sub-criteria, and alternatives at the bottom. The process involves pairwise comparisons, where elements are compared in terms of their relative importance, generating a matrix of comparisons. From this matrix, the weights of criteria are derived, reflecting their relative importance. These weights are then used to rank and evaluate alternatives. AHP also includes a consistency check to ensure the reliability of the decision-making process.

4.8.2 WEIGHTED OVERLAY

The weighted overlay is a commonly used technique in remote sensing for combining multiple layers of data into a single composite layer.

It is a method of using a common scale to different inputs to find the integrated result. This technique assigns weights to each input layer based on its relative importance and combines them using a weighted sum approach.

This technique is applied to spatial criteria layer of Flood prone zones.

The steps involved in weighted overlay are,

- ✓ Selection of input layers
- ✓ Weight assignment
- ✓ Rescaling of input layers
- ✓ Weighted overlay

4.9 CRITERIA FOR SOIL LOSS MAP

The criteria for the Soil Loss Map in the study area were based on the RUSLE (Revised Universal Soil Loss Equation) model, which integrates several spatial and climatic factors. Here are the key criteria used:

- ✓ Rainfall Erosivity Factor (R)
- ✓ Soil Erodibility Factor (K)
- ✓ Slope Length and Steepness Factor (LS)
- ✓ Cover and Management Factor (C)
- ✓ Support Practice Factor (P)

4.10 RUSLE MODEL

RUSLE (REVISED UNIVERSAL SOIL LOSS EQUATION)

RUSLE developed by the U.S. Department of Agriculture is used as a decision support system in soil conservation and land use planning. It uses a set of mathematical equations to describe ecological processes related to conservation practices and erosion in a given landscape. RUSLE is a flexible tool that has been adapted to landscape and watershed scales combined with Geographic Information Systems (GIS) in soil erosion assessments. The Revised Universal Soil Loss Equation (RUSLE) is a widely used empirical model for estimating soil erosion by water.

$$\boxed{A = R*K*LS*C*P}$$

4.10.1 LANDUSE AND LAND COVER

In this study, the Land Use Land Cover (LULC) map created using Sentinel-2 satellite imagery to derive the C factor. The imagery was classified into categories like forest, agriculture, and barren land. Each class was assigned a C value based on vegetation cover and management practices. This rasterized C factor layer was then used in the RUSLE model to estimate soil loss.

4.10.2 SLOPE

For this study, the slope map for the P factor was generated from SRTM DEM using GIS tools to calculate the slope gradient of the study area. Based on the derived slope classes, appropriate P values were assigned reflecting the effectiveness of conservation practices on different slopes. This P factor map was then used in the RUSLE model to estimate soil erosion.

4.10.3 FLOW ACCUMULATION AND SLOPE

In this study, SRTM DEM was used to derive both slope and flow accumulation maps for LS factor. The DEM was preprocessed by filling sinks, then flow direction and accumulation were generated. Slope map was calculated from the DEM using terrain analysis tools. LS factor was computed by integrating flow accumulation and slope maps using a standard RUSLE formula.

4.10.4 SOIL

The soil map used for deriving the K factor in this study was created using the Digital Soil Map of the World (DSMW) along with collateral soil data. Various soil types and textures present in the study area were identified and classified from these sources. Each soil type was then assigned a specific K value, which represents the soil erodibility, based on standard reference tables correlating soil texture to K values. This classified soil map with corresponding K values was integrated into the RUSLE model to quantify the soil erodibility factor across the study area.

4.10.5 RAINFALL

The rainfall map for deriving the R factor in this study was created using IMD (India Meteorological Department) rainfall data. he mean annual rainfall for the year 2023 was collected from IMD stations across the study area. his data was then spatially interpolated using GIS techniques, such as IDW (Inverse Distance Weighting) to generate a continuous rainfall surface. The interpolated rainfall values were used to calculate the R factor for each location in the study area.

4.10.6 C FACTOR

The C factor is the Cover Management factor. The cover management factor is the ratio of soil loss from an area with specified cover and management to that of an area in tilled continuous fallow.

The C factor map for this study area was created using Land Use/Land Cover (LULC) data derived from Sentinel-2. Each LULC category was then assigned a specific C value based on its vegetation cover and management practices, using standard reference tables. The resulting map, with assigned C values, represented the Cover Management Factor and was used in the RUSLE model to estimate soil loss.

Table depicts the C values adopted for the study

TABLE 4.3 C FACTOR VALUES

TYPE	VALUE	SOURCE
Forest	0.05	Hurni,1985
Built-up Area	0.2	Tiruneh & Ayalew 2015
Cropland	0.24	Tiruneh & Ayalew 2015
Rangeland	0.01	Alelgn et al.,2021
Waterbody	0.001	Erdogan et al.,2006
Barenland	0.2	Alelgn et al.,2021
Land with scrub	0.04	Wischmeier & Smith 1978
Vegetation	0.05	Hurni,1985
Agricultural Land	0.04	Hurni,1985

4.10.7 P FACTOR

The Conservation Practices factor (p values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion, which depends on the type of conservation measures implemented, and requires mapping of conserved areas for it to be quantified.

The P factor map for the study area was created by identifying areas with conservation practices like contouring that reduce runoff and soil erosion. These practices were mapped using GIS, and appropriate P values were assigned based on the presence or absence of such measures. The resulting map was integrated into the RUSLE model to estimate soil loss accurately.

Table depicts the P values adopted for the study.

TABLE 4.4 P FACTOR VALUES

SLOPE	CONTOURING
0 - 7	0.55
7 – 11.3	0.6
11.3 – 17.6	0.8
17.6 – 26.8	0.9
>26.8	1

4.10.8 LS FACTOR

LS is the Slope Length and Slope Steepness factor, representing the effect of slope length on erosion. It is the ratio of soil loss from the field slope length to that from a 72.6-foot (22.1-meter) length on the same soil type and gradient.gth factor.

The LS factor map was created using slope length and steepness derived from the SRTM DEM data of the study area. Flow accumulation and slope gradient were computed in GIS to calculate the LS factor using standard equations. This map represents the effect of topography on erosion and was used as an input in the RUSLE model.

Formula used for identifying LS Factor,

LS = pow [(FA) * cell size /22.13] 0.4* pow [sin (slope * 0.01745 /0.0896]1.3

LS = Slope Length and Steepness

FA = Flow Accumulation

4.10.9 K FACTOR

K factor defines as Soil Erodibility factor. It is a measure of susceptibility of soil particles to detachment and transport by rainfall and runoff.

The K factor map for the study area was created based on soil texture and type obtained from the DSMW (Digital Soil Map of the World) and collateral data. Each soil type was assigned a K value representing its susceptibility to erosion, using a standard reference table. These values were mapped in GIS to generate the soil erodibility (K factor) layer for use in the RUSLE model.

Formula used for identifying K factor,

$$\textbf{K Factor} = 0.32 * (\text{silt\%}(\text{sand\%} + \text{clay\%}))$$

Table 4.5: Soil Texture, Soil Type and their K values

Soil unit symbol	Soil Type	Sand%	Silt%	Clay%	Organic carbon%	K Factor
Lc	Chromic Luvisols	64.3	12.2	23.5	0.63	0.5
I	Lithosols	58.9	16.2	24.9	0.97	0.16

4.10.10 R FACTOR

The Rainfall Erosivity factor (R) describes the erosivity of rainfall in an area based on the rainfall amount and intensity and reflects the effect of rainfall intensity on soil erosion.

The R factor map for the study area was created using mean annual rainfall data from the Indian Meteorological Department (IMD) for the year 2023.

Formula used for identifying R Factor,

$$R = (0.562 \times P) - 8.12$$

R = Rainfall Erosivity

P = Mean Annual Rainfall (2023)

4.11 CONCLUSION

The materials and methodology of the study have been explained in this chapter.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 GENERAL

This chapter deals with the discussion on flood prone zonation map and soil loss map for Pachaiyar sub-watershed, Tirunelveli.

5.1.1 STUDY AREA EXTRACTION

The study area was digitized from Survey of India Toposheets is shown in FIGURE 5.1.

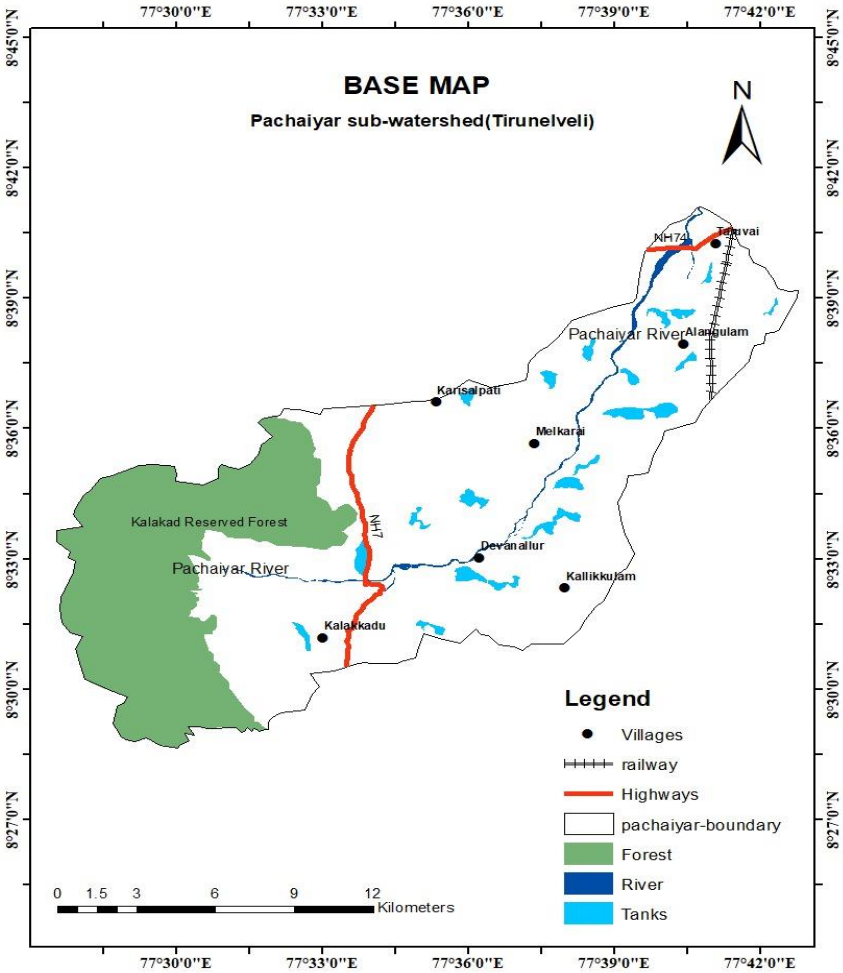


FIGURE 5.1 MAP OF STUDY AREA

5.1.2 LANDUSE AND LAND COVER

The Landuse and Land cover of study area is classified into 9 classes, namely Forest, Built-up area, Cropland, Rangeland, Waterbody, Barenland, Land with scrub, Vegetation and Agricultural land. The landuse and Land cover map for the study area is shown in the FIGURE 5.2.

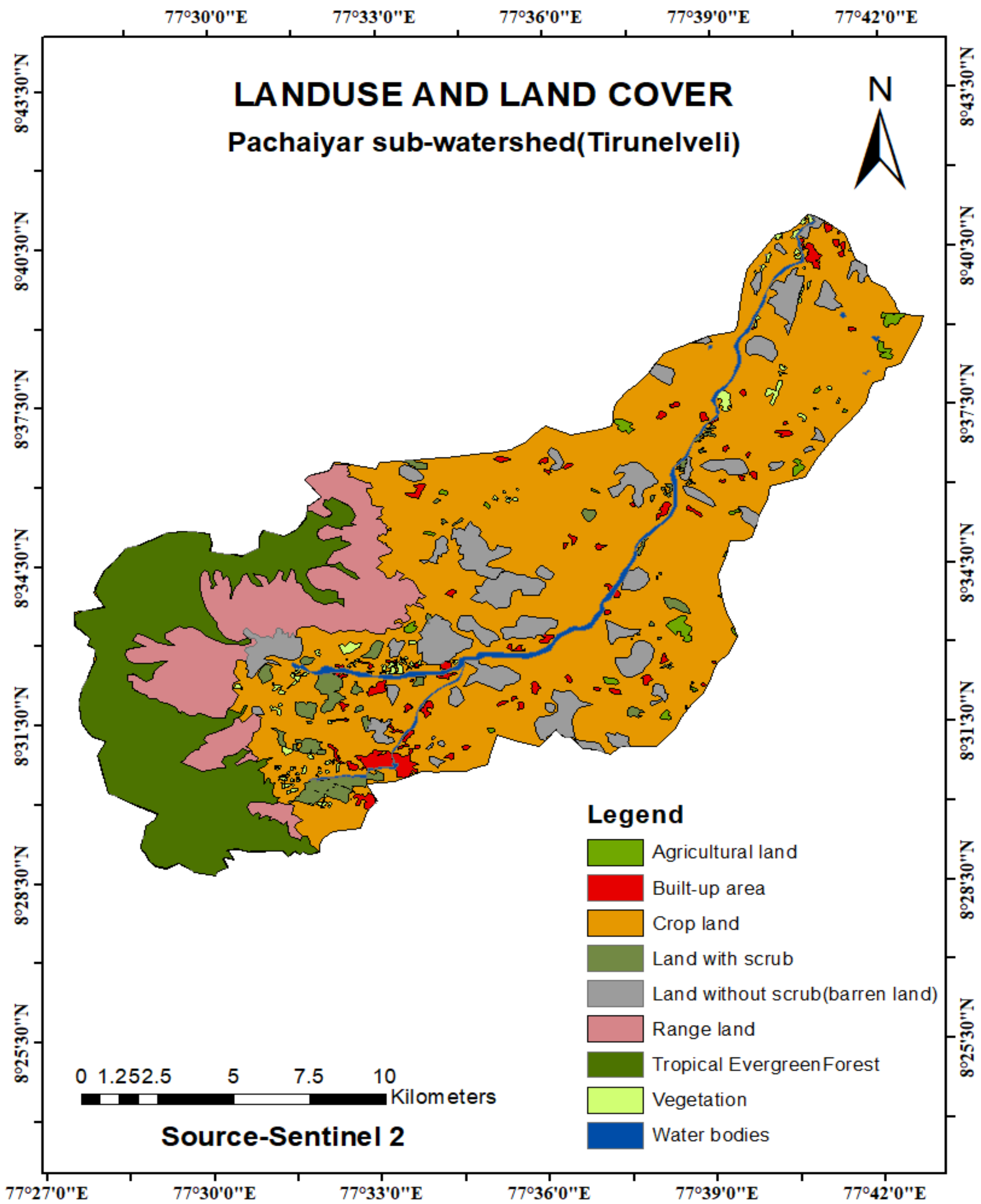


FIGURE 5.2 LANDUSE AND LAND COVER MAP

5.1.3 SLOPE

The slope map of the study area was created using SRTM DEM. Areas with gentle slope are highly vulnerable to flood and soil erosion where areas with steep slope are less vulnerable. The slope map is shown in FIGURE 5.3.

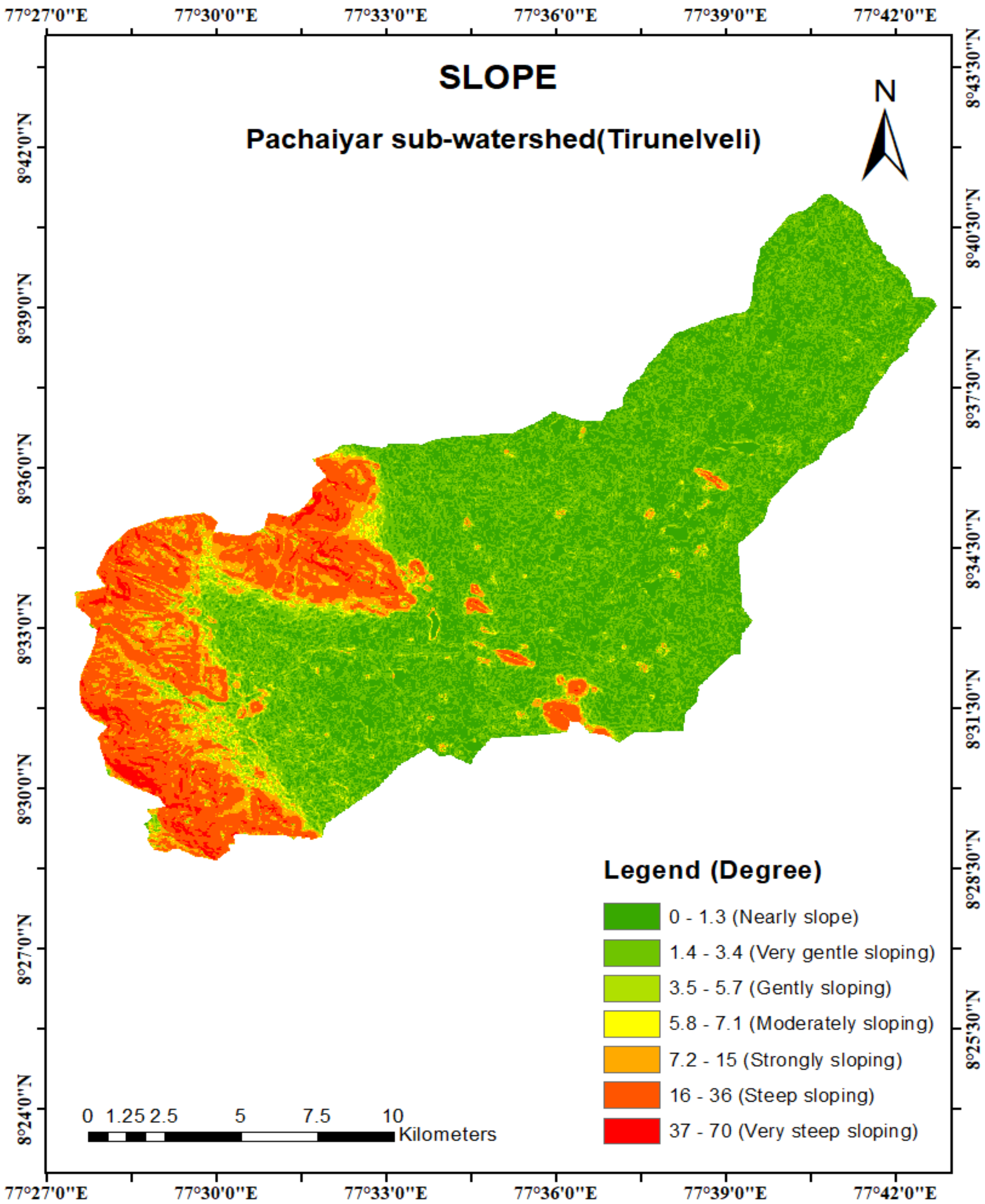


FIGURE 5.3 SLOPE MAP

5.1.4 FLOW ACCUMULATION

The flow accumulation map of the study area was created using SRTM DEM. Higher values indicating areas where more water accumulates. The flow accumulation map is shown in FIGURE 5.4.

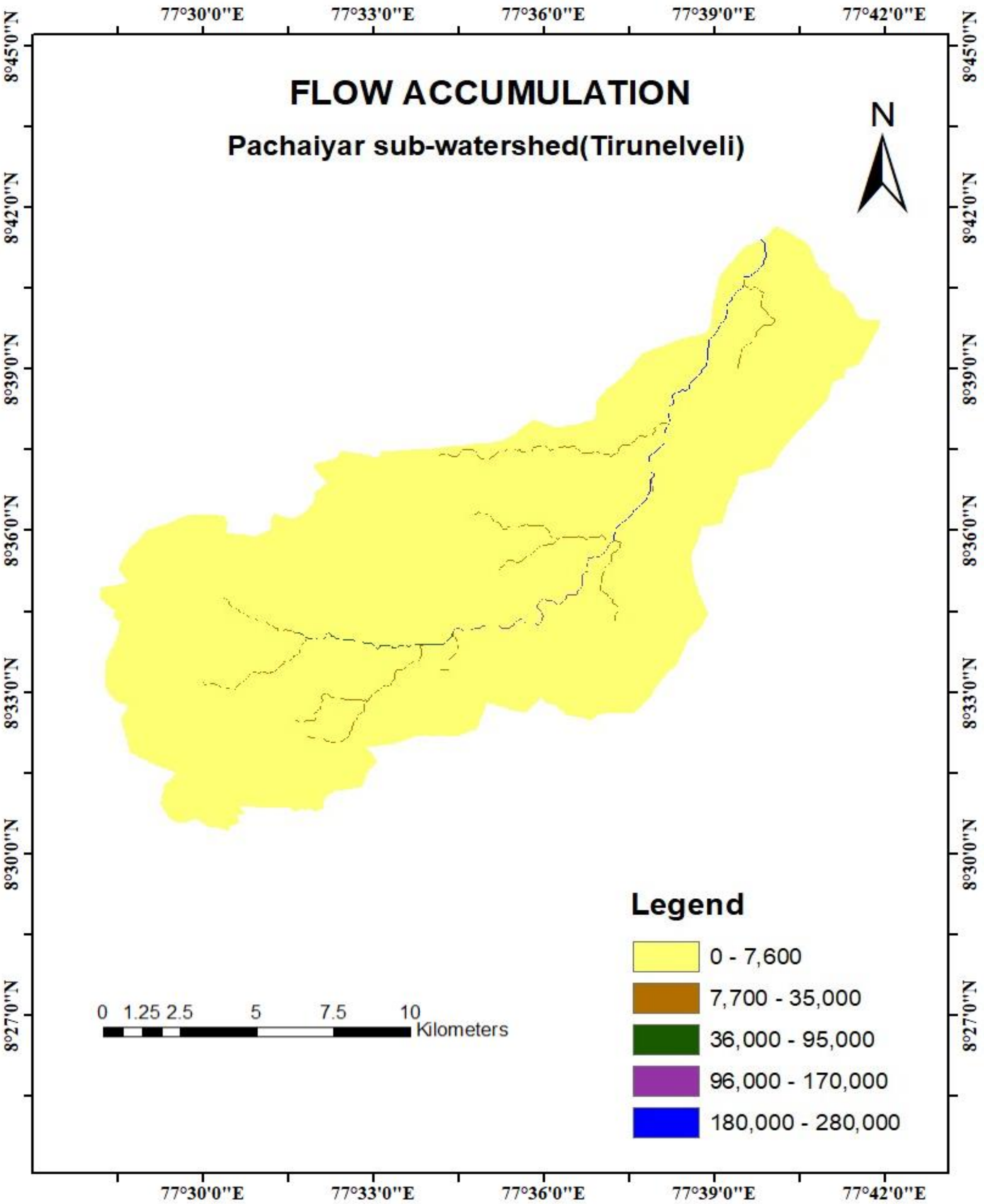


FIGURE 5.4 FLOW ACCUMULATION MAP

5.1.5 RELIEF (BASINAL)

The relief map of the study area was created using SRTM DEM. High-relief areas are more prone to erosion and have more dynamic drainage patterns. The relief map was shown in FIGURE 5.5.

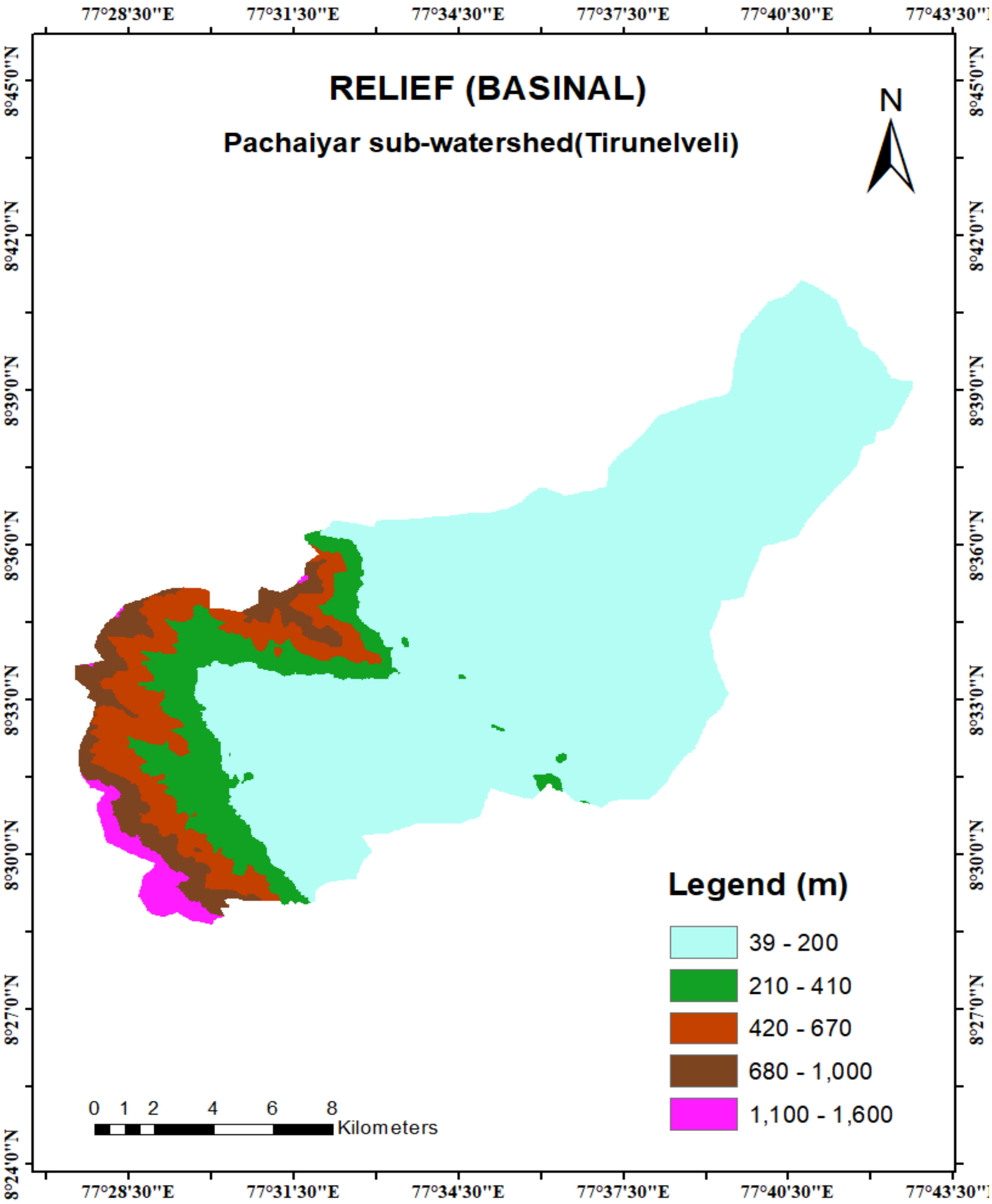


FIGURE 5.5 RELIEF MAP

5.1.6 STREAM POWER INDEX(SPI)

The SPI map of the study area was created using SRTM DEM. It illustrates rainfall anomalies to assess wetness conditions. The SPI map was shown in FIGURE 5.6.

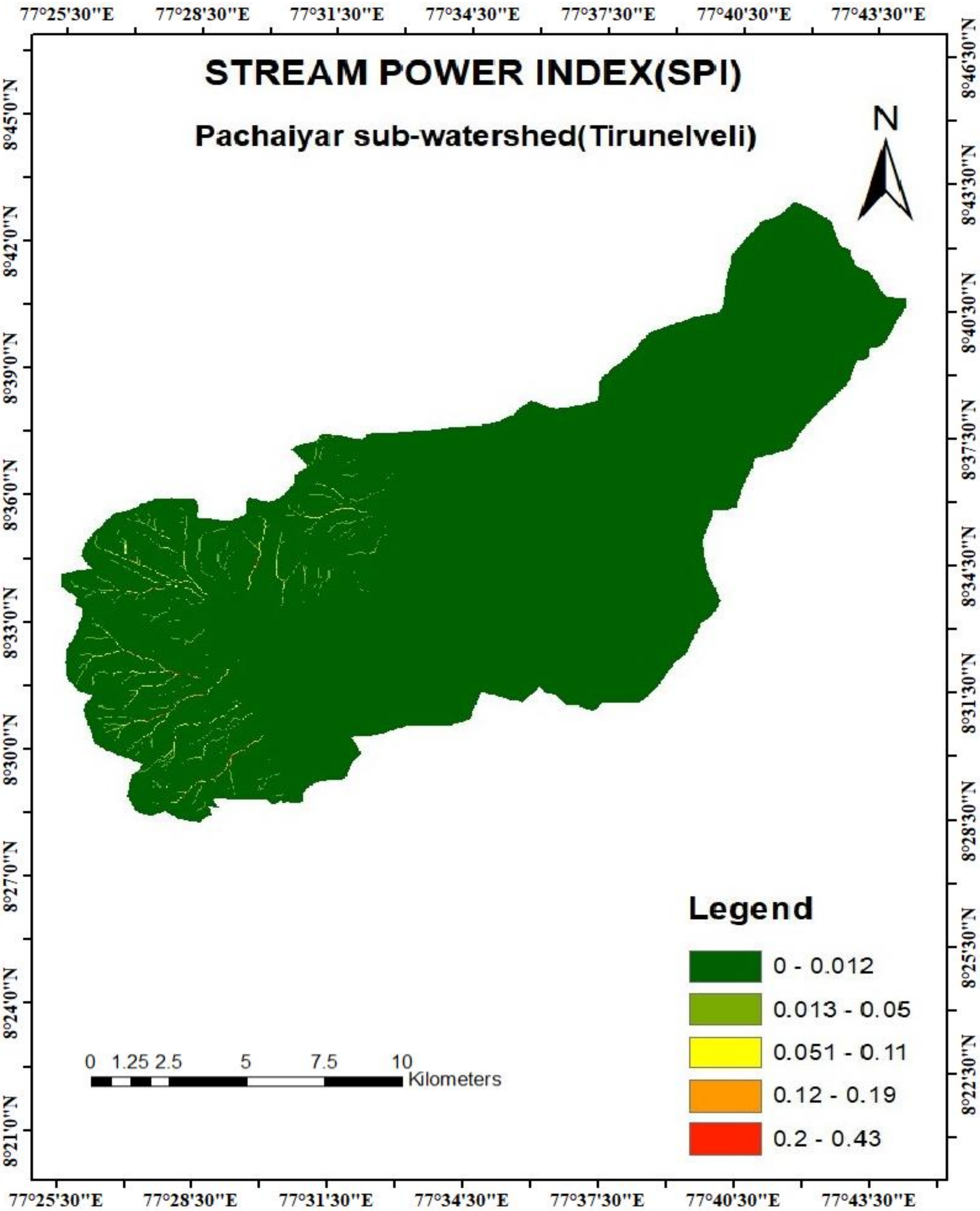


FIGURE 5.6 STREAM POWER INDEX MAP

5.1.7 TOPOGRAPHIC ROUGHNESS INDEX(TRI)

The TRI map of the study area was created using SRTM DEM. Areas with higher values indicate more rugged, uneven terrain, while lower values denote flatter areas. The TRI map was shown in FIGURE 5.7.

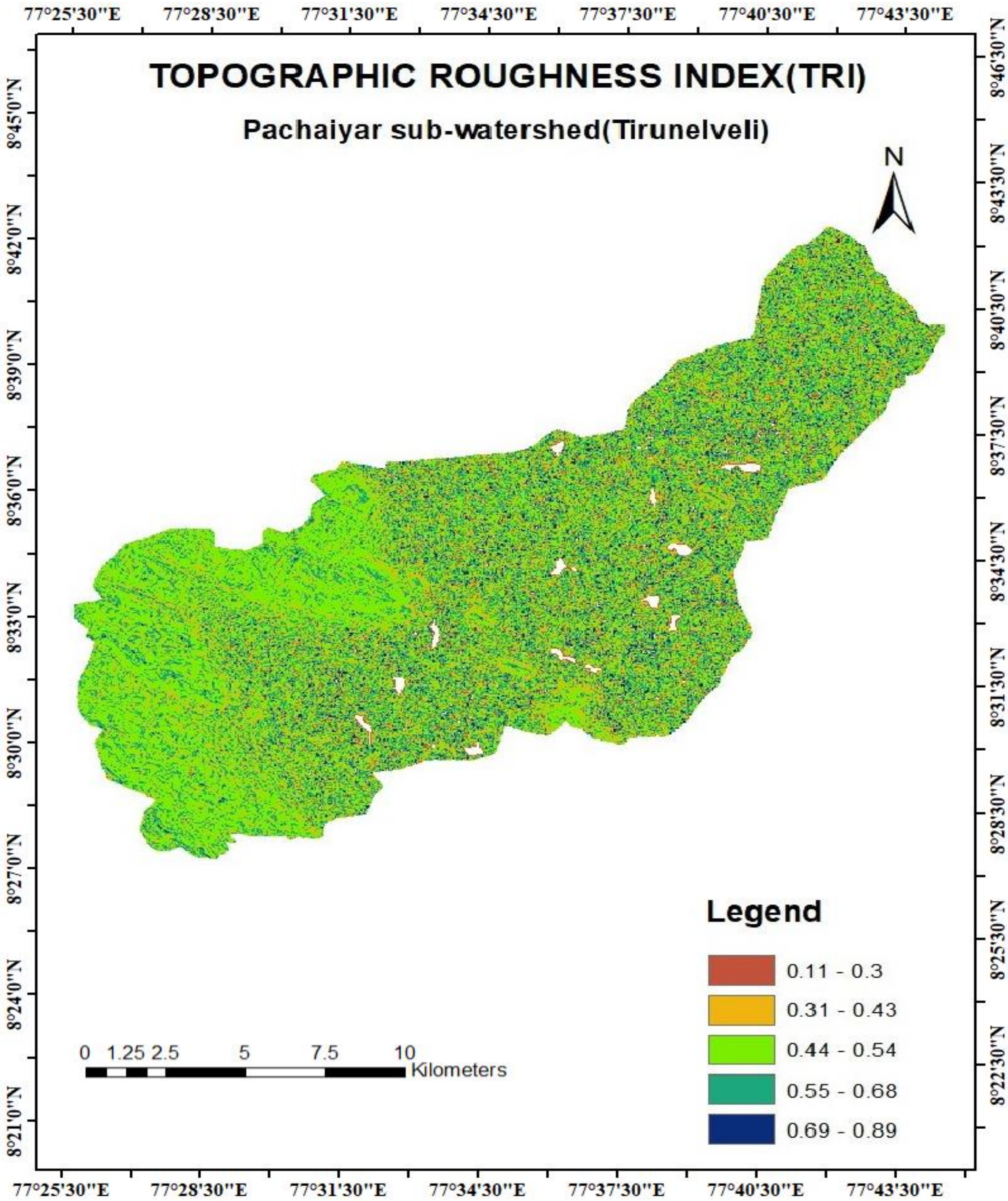


FIGURE 5.7 TOPOGRAPHIC ROUGHNESS INDEX MAP

5.1.8 TOPOGRAPHIC WETNESS INDEX(TWI)

The TWI map of the study area was created using SRTM DEM. Higher TWI values (in blue) indicate areas more prone to water accumulation, while lower values (in red) represent drier zones. The TWI map was shown in FIGURE 5.8.

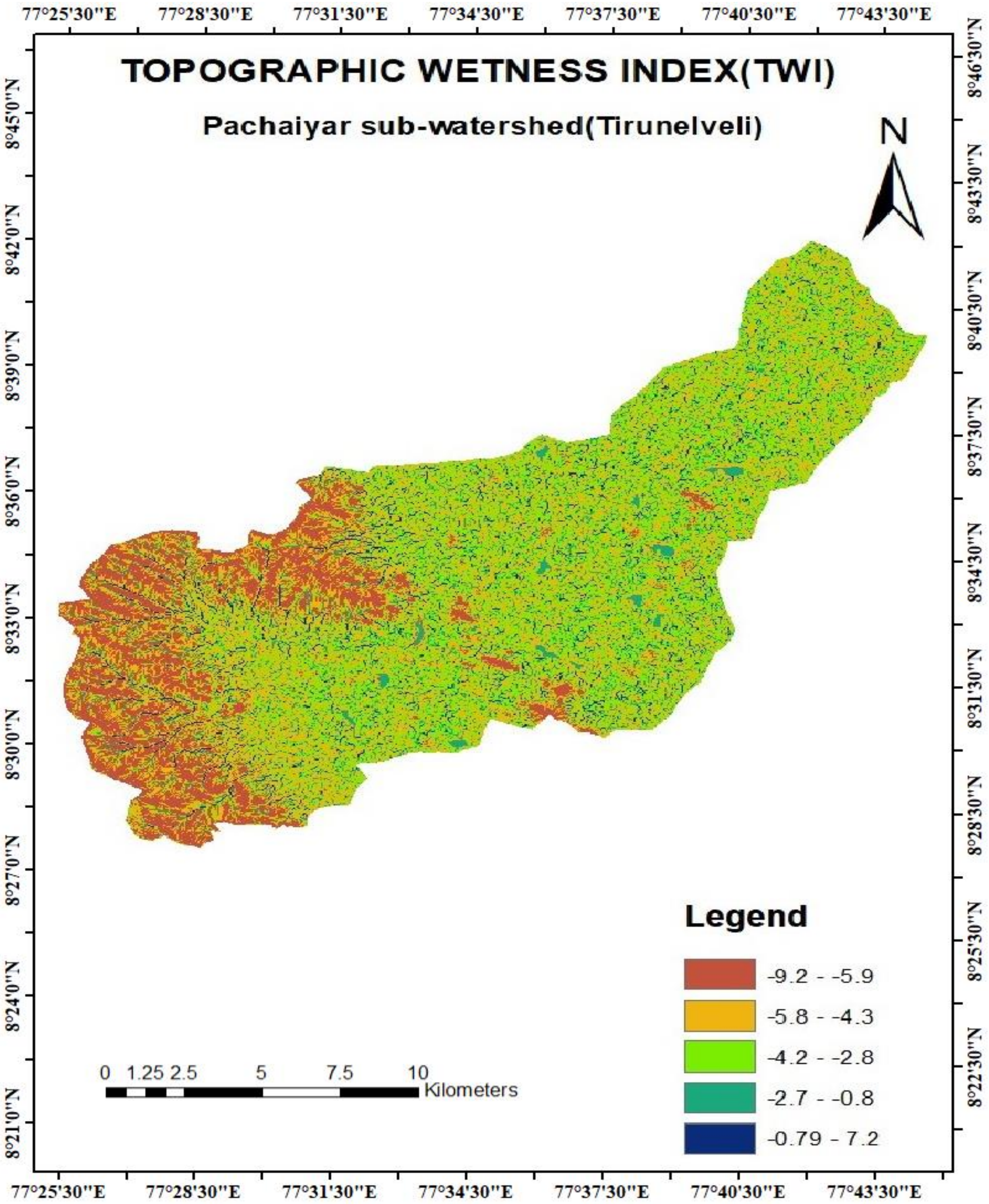


FIGURE 5.8 TOPOGRAPHIC WETNESS INDEX MAP

5.1.9 LINEAMENT

The Lineament map of the study area was created using SRTM DEM. Lineament showing linear geological features such as faults or fractures. The lineament map was shown in FIGURE 5.9.

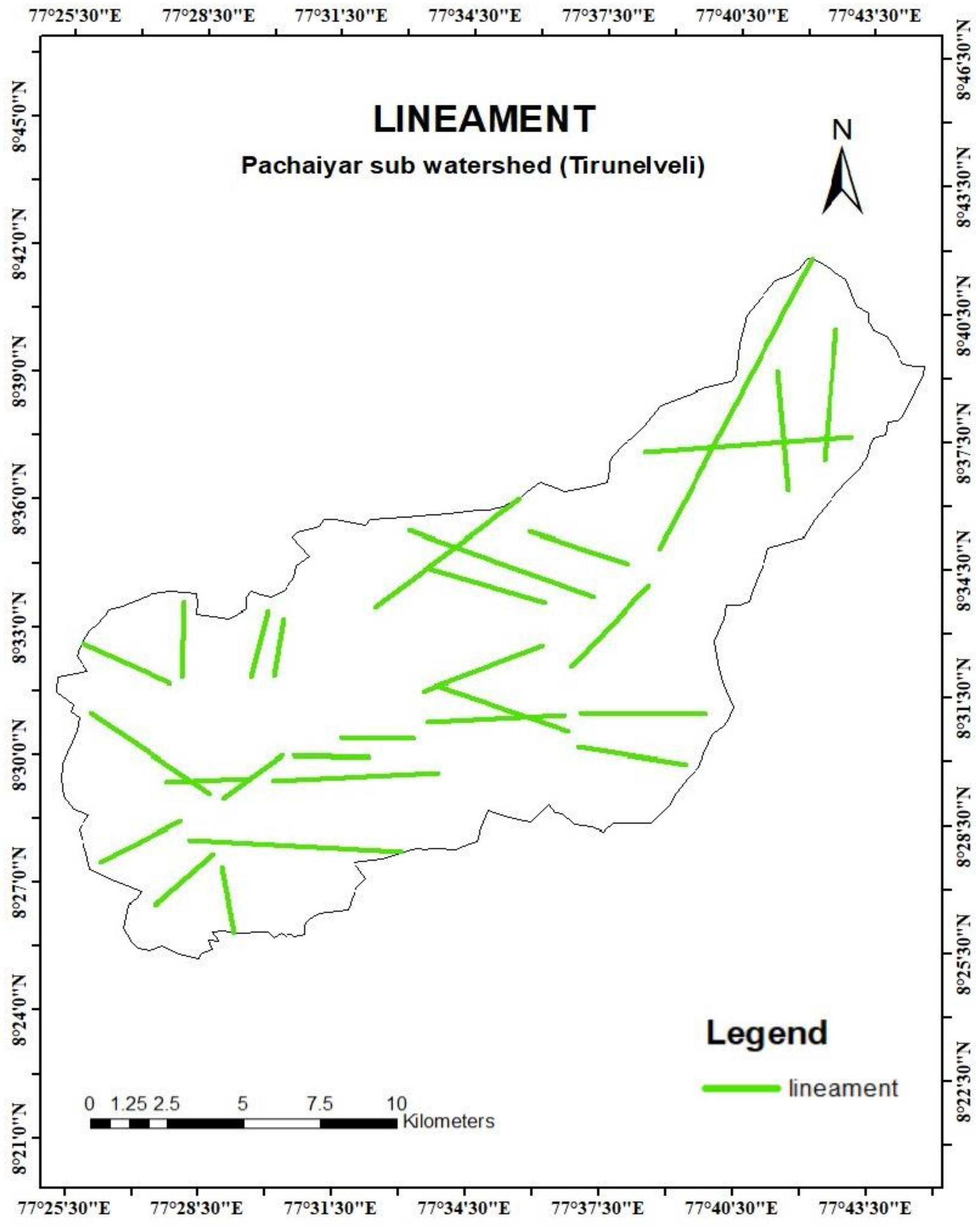


FIGURE 5.9 LINEAMENT MAP

5.1.10 LINEAMENT DENSITY

The Lineament density map of the study area was created using SRTM DEM. Areas with Higher density suggest greater structural complexity, which may influence groundwater potential. The lineament density map was shown in FIGURE 5.10.

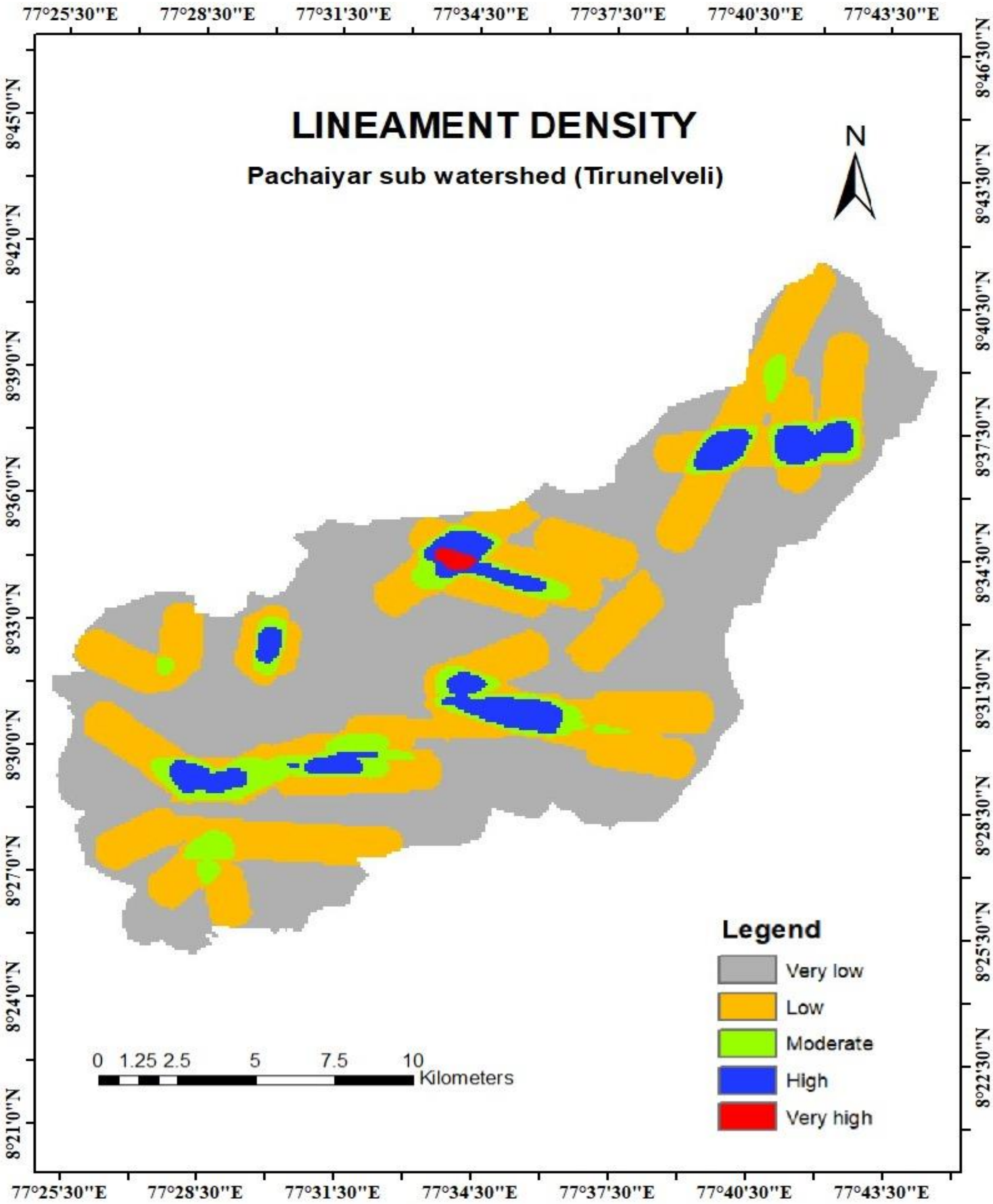


FIGURE 5.10 LINEAMENT DENSITY MAP

5.1.11 DRAINAGE

The Drainage map of the study area was created using Survey of India Toposheets. This map depicting the network of streams and the main river flowing through the region. The Drainage map was shown in FIGURE 5.11.

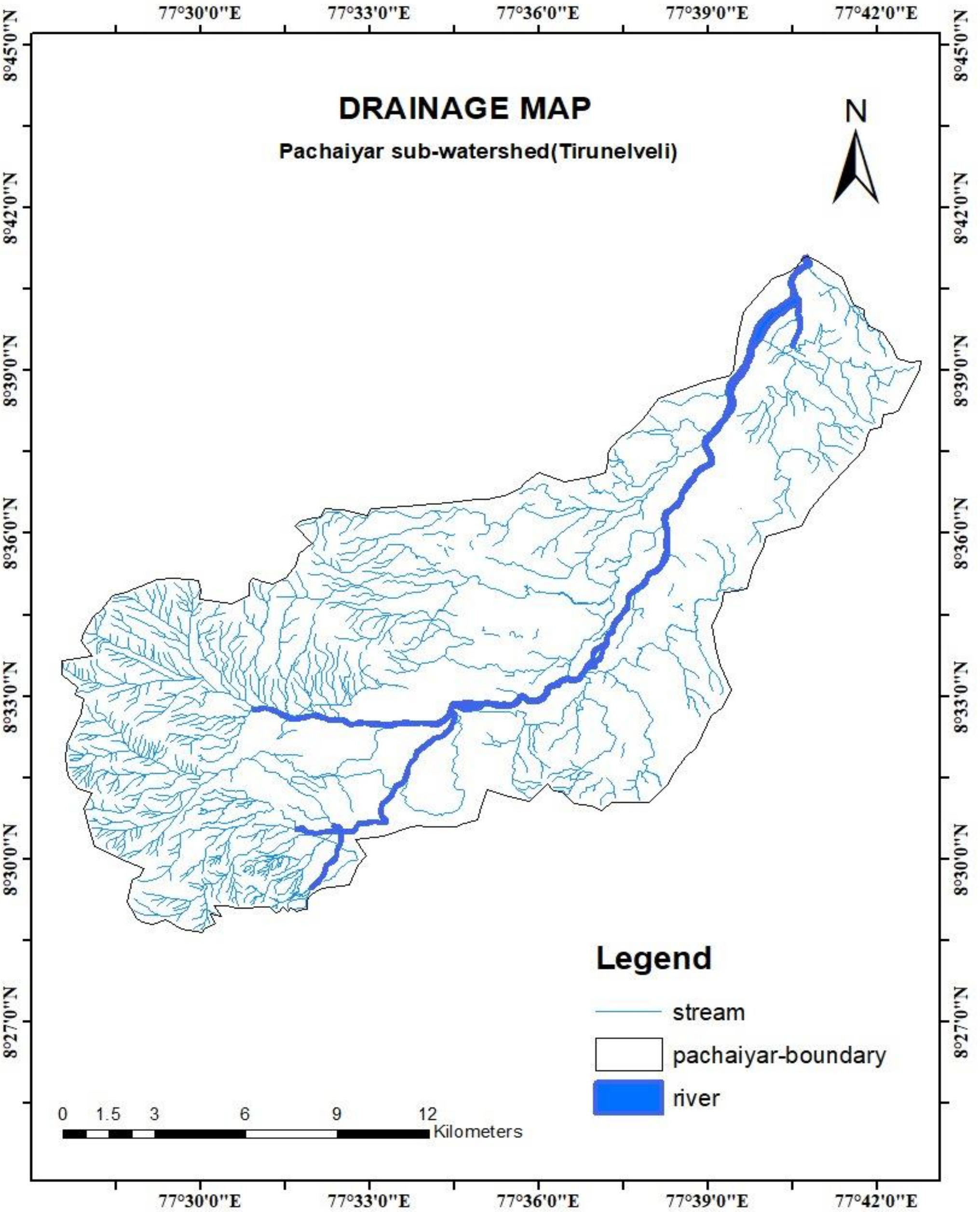


FIGURE 5.11 DRAINAGE MAP

5.1.12 DRAINAGE DENSITY

The Drainage density map of the study area was created using Drainage map. Areas with higher drainage density (marked in red and orange) indicate more intense stream networks. The Drainage density map was shown in FIGURE 5.12.

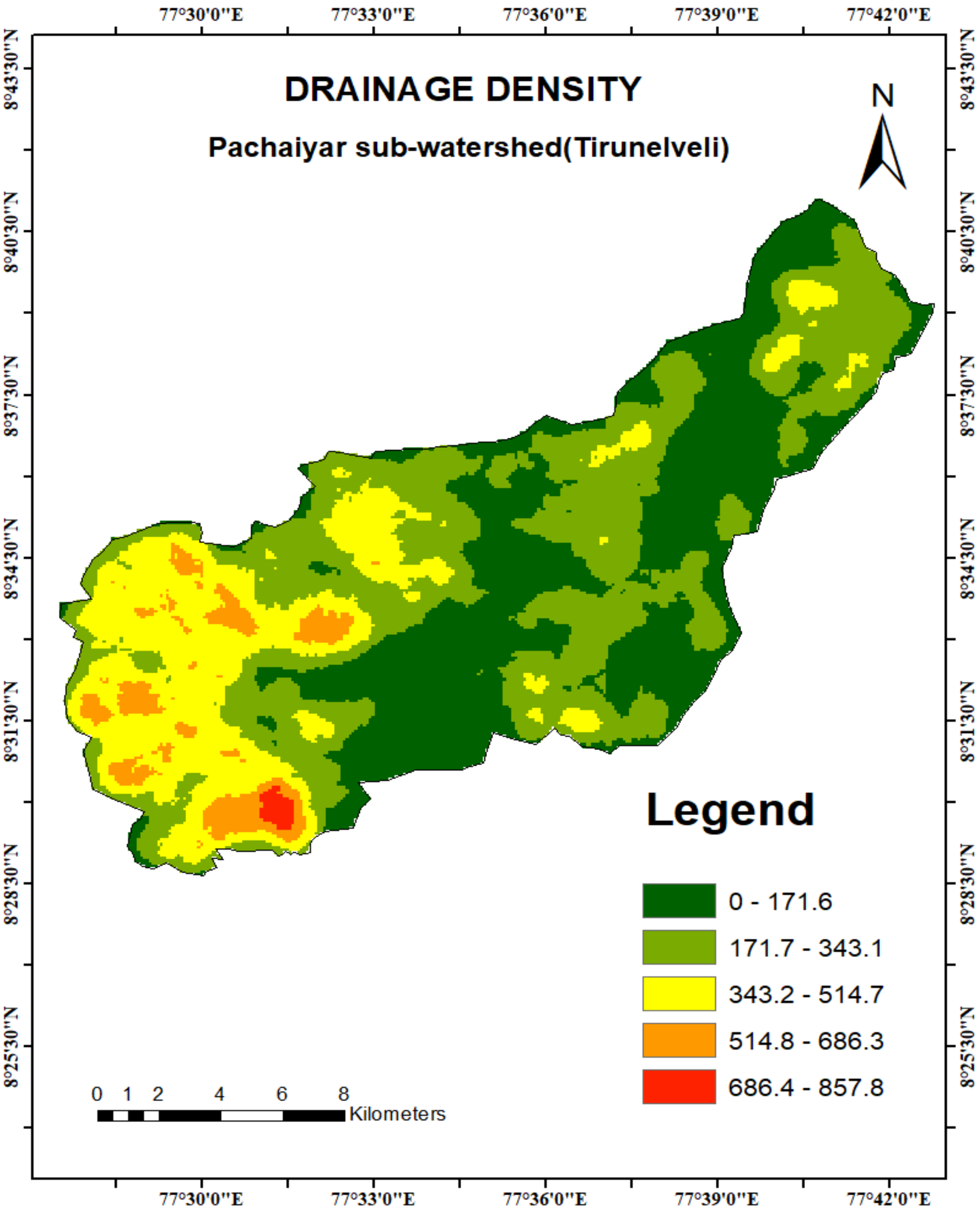


FIGURE 5.12 DRAINAGE DENSITY MAP

5.1.13 STREAM ORDER

The stream order map of the study area was created using SRTM DEM through hydrological modeling in GIS. Steps included sink filling, flow direction and accumulation, and applying the Strahler method for stream ordering. The stream order map was shown in FIGURE 5.13

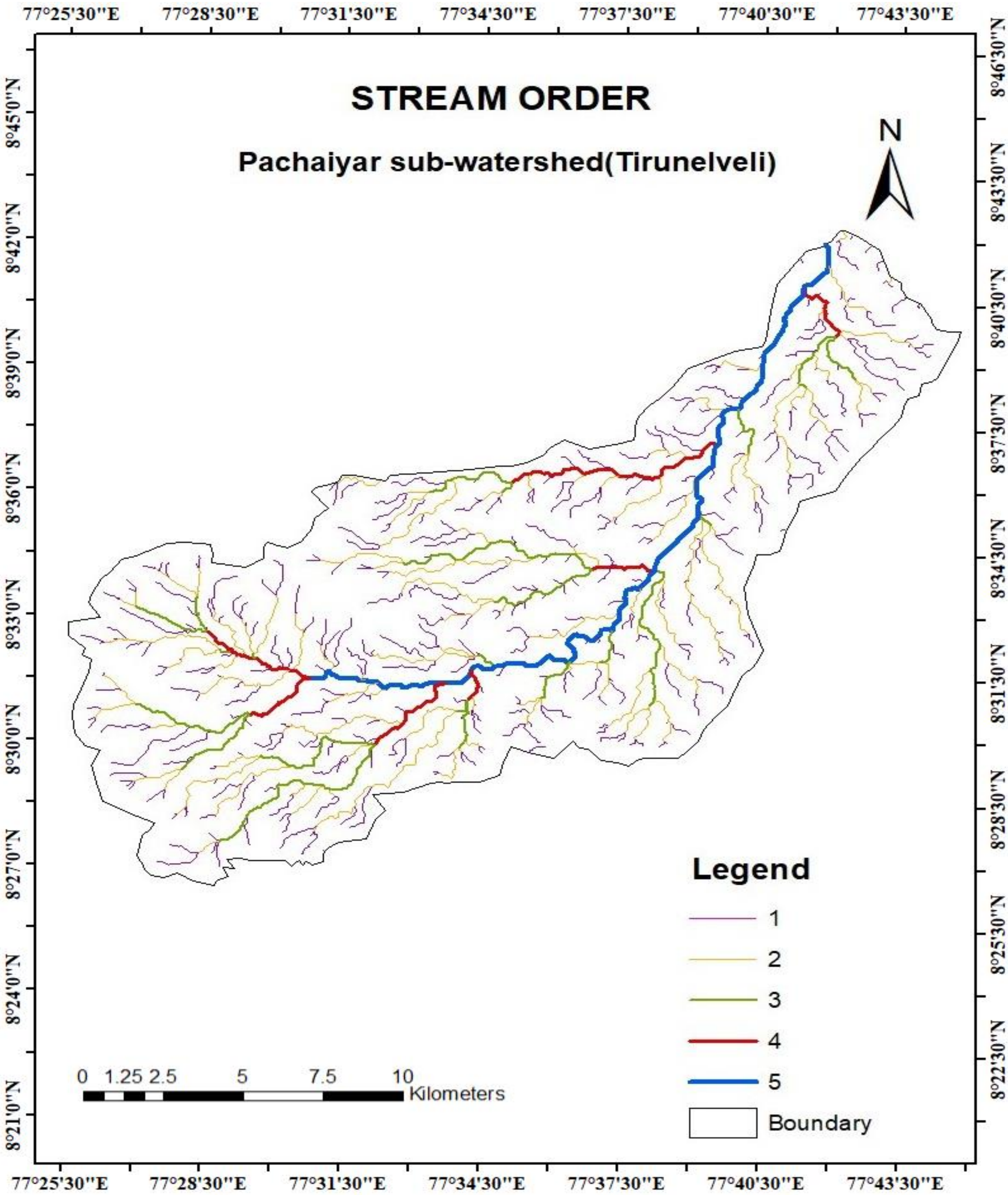


FIGURE 5.13 STREAM ORDER MAP

5.1.14 RAINFALL

The Rainfall map of the study area was created using IMD rainfall data. Rainfall intensity is defined as the ratio of the total amount of rain falling during a given period at a specific location. It is expressed in mm. The rainfall map was shown in FIGURE 5.14.

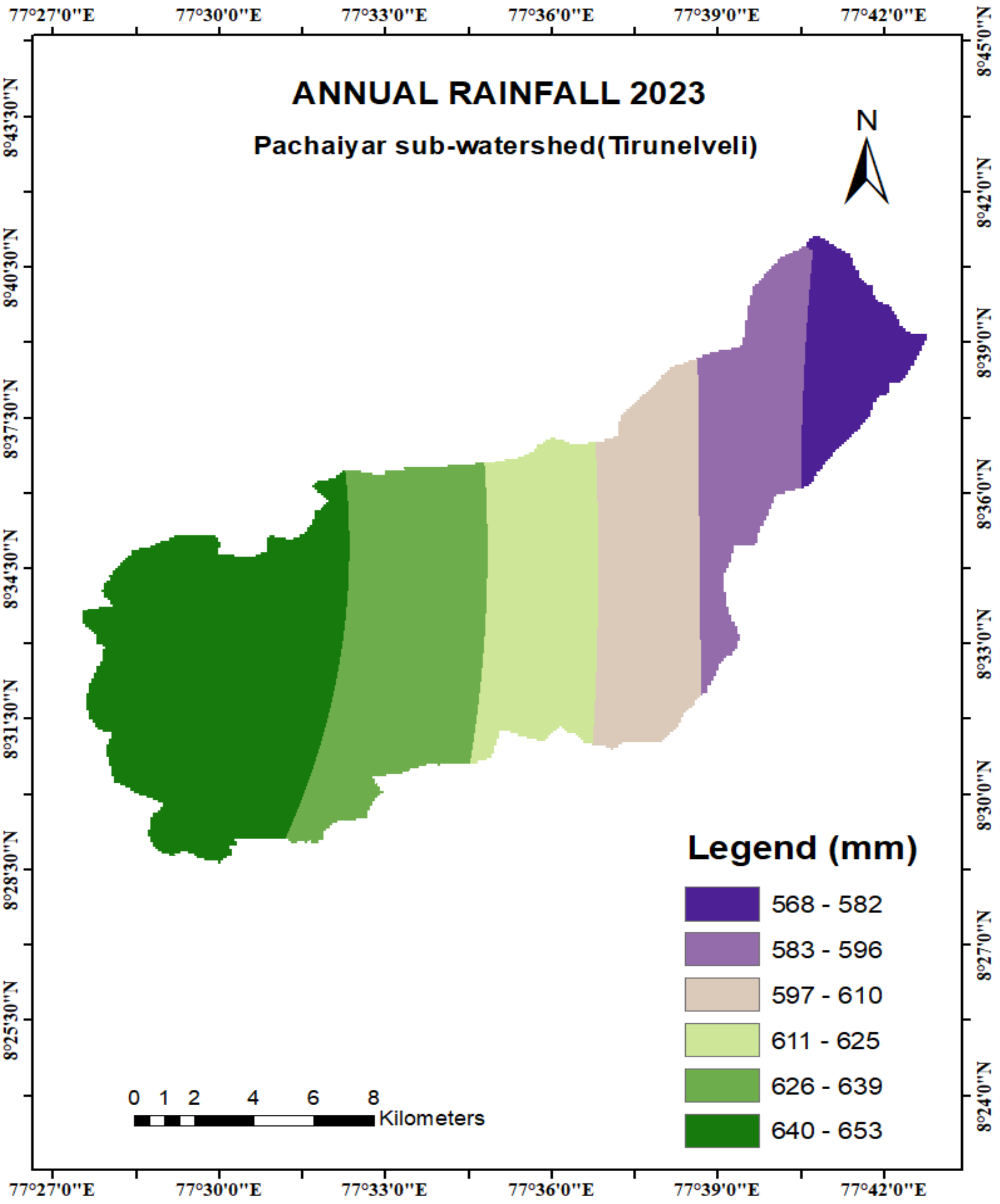


FIGURE 5.14 RAINFALL MAP

5.1.15 LITHOLOGY

The Lithology map of the study area was created using Geological Survey of India (GSI). It is highlighting different rock types such as garnet-biotite gneiss, hornblende-biotite gneiss, and quartzite. The Lithology map was shown in FIGURE 5.15.

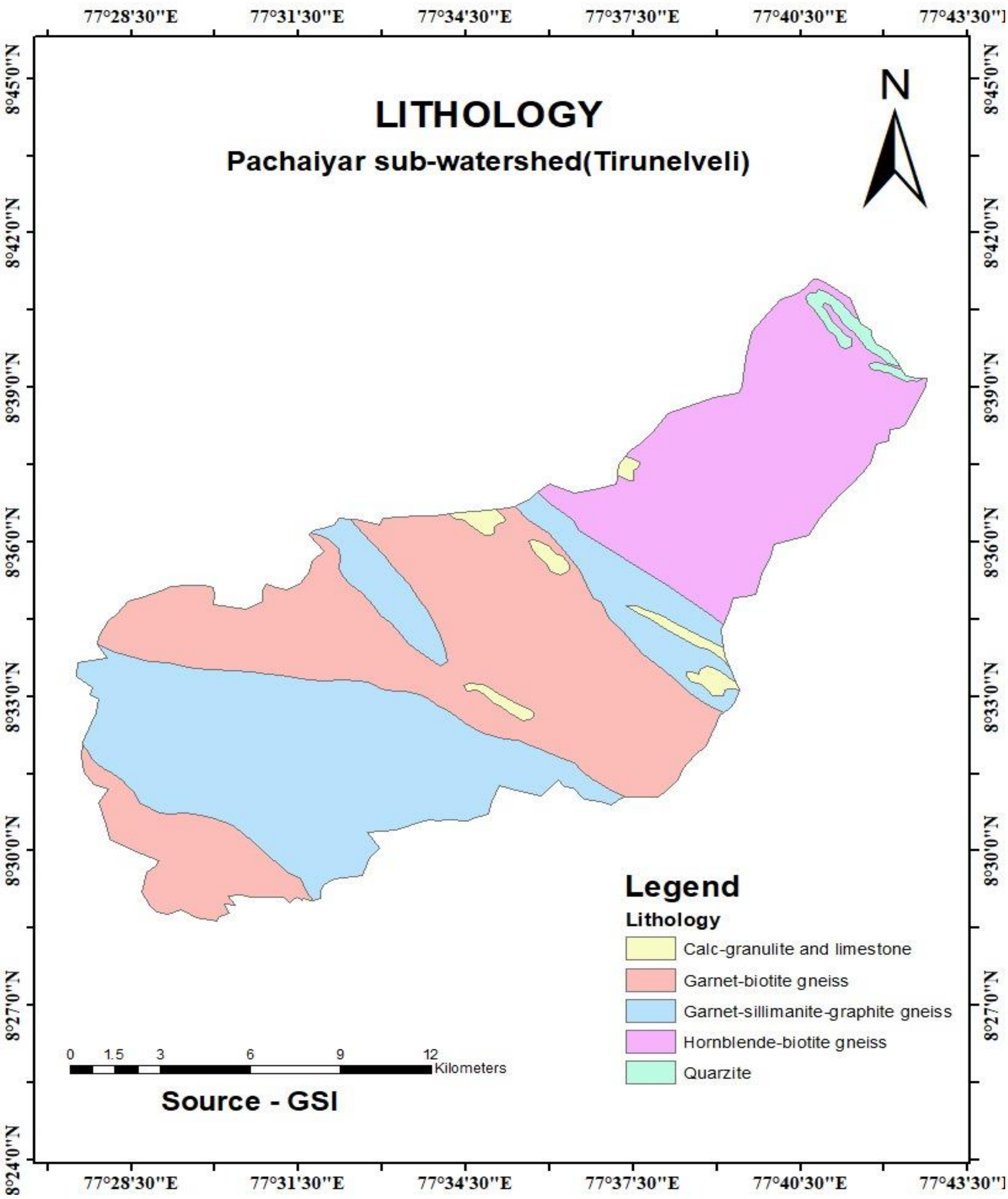


FIGURE 5.15 LITHOLOGY MAP

5.1.16 SOIL

The Soil map of the study area was created using Digital soil map of the world (DSMW). This map depicts the soil distribution and categorizing it into two main soil types labelled “I” (Lithosols) and “Lc” (Chromic Luvisols). The soil map was shown in FIGURE 5.16.

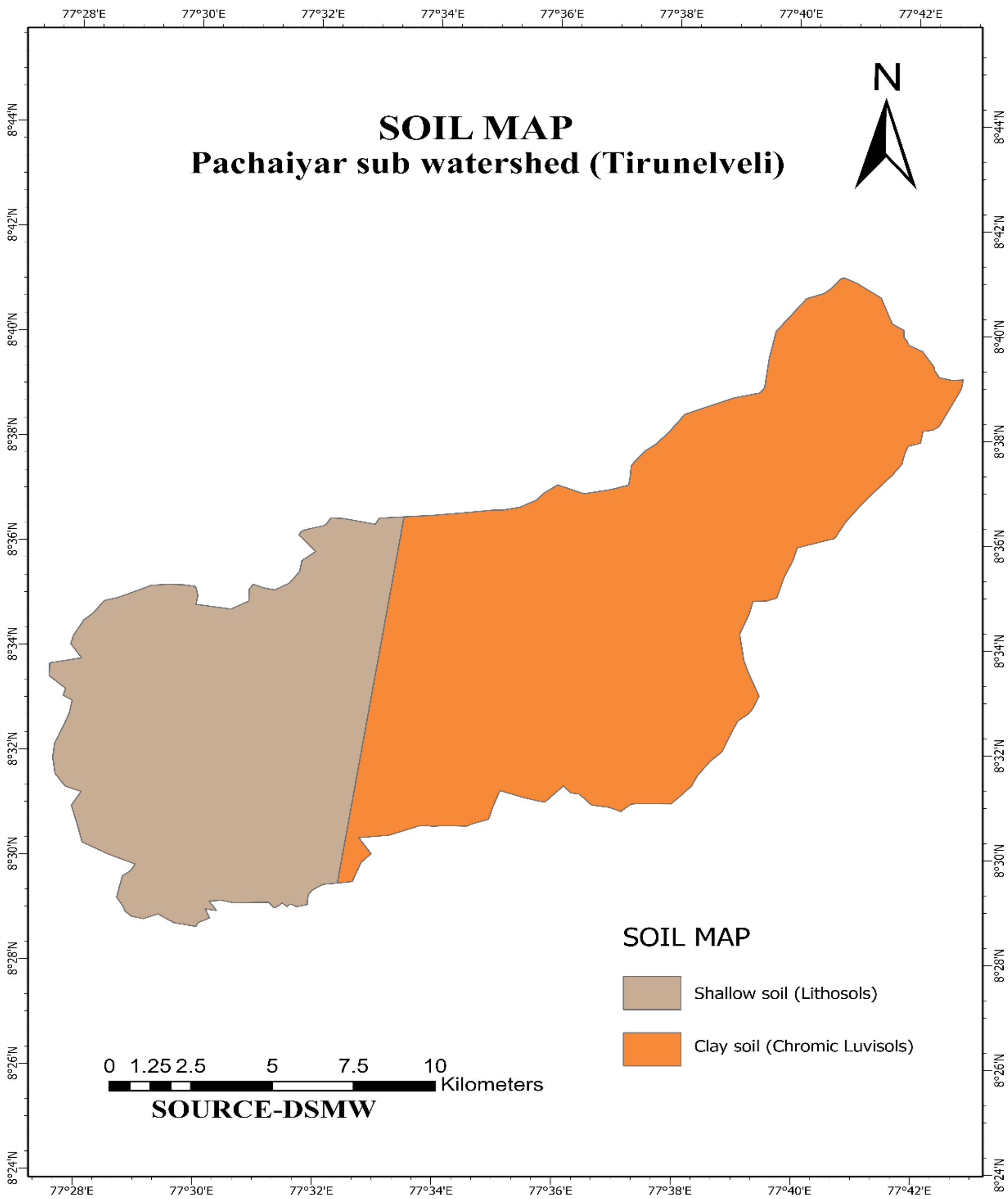


FIGURE 5.16 SOIL MAP

5.1.17 SOIL TYPE

The soil type map of the study area was created using National Bureau of Soil Survey (NBSS). It categorizes soils based on characteristics such as texture, drainage, slope, and erosion. The soil type map was shown in FIGURE 5.17.

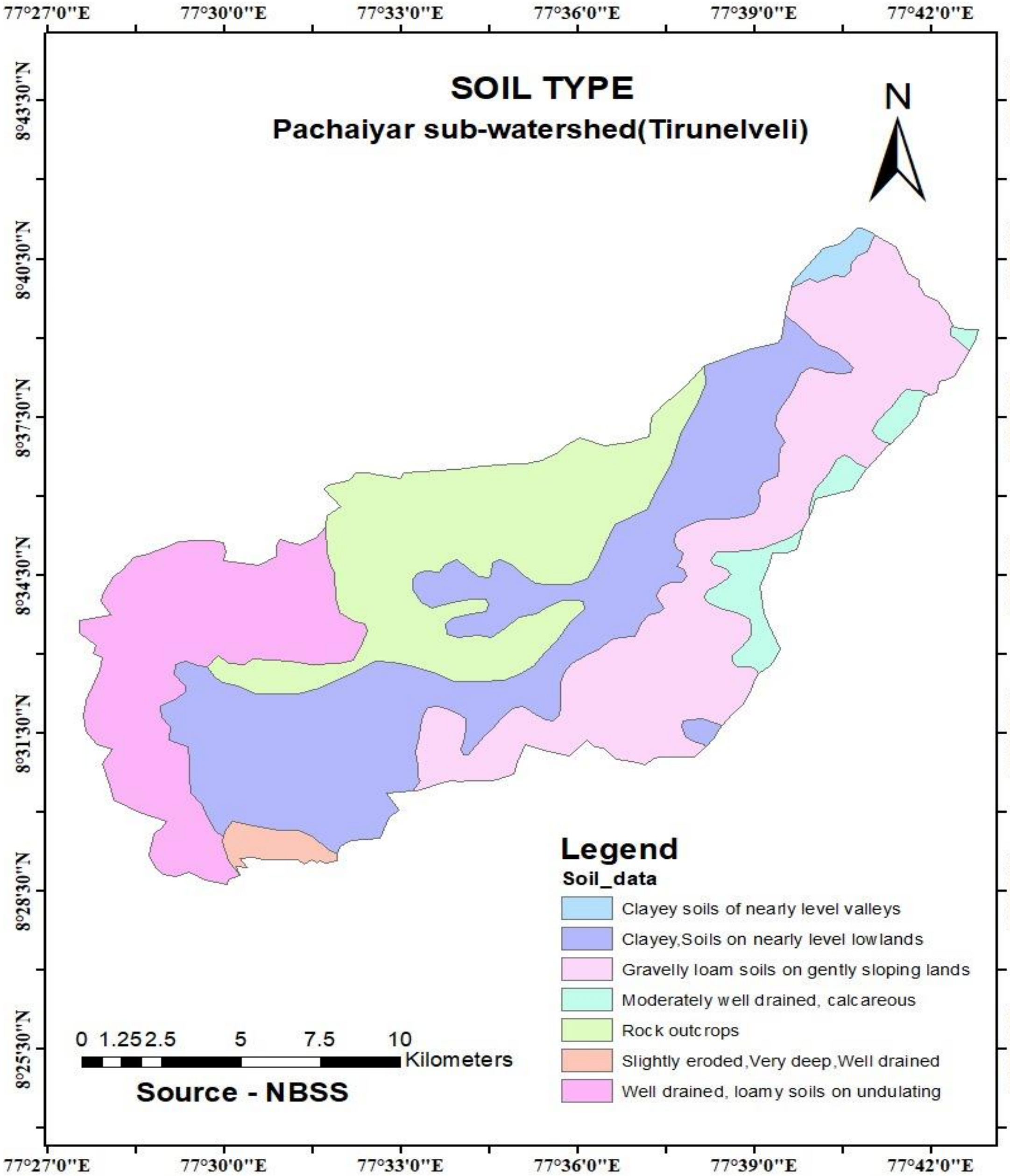


FIGURE 5.17 SOIL TYPE MAP

5.1.18 GEOMORPHOLOGY

The Geomorphology map of the study area was created using Geological Survey of India (GSI). It is highlighting landforms such as pediments, flood plains, ridges, and dissected hills. The Geomorphology map was shown in FIGURE 5.18.

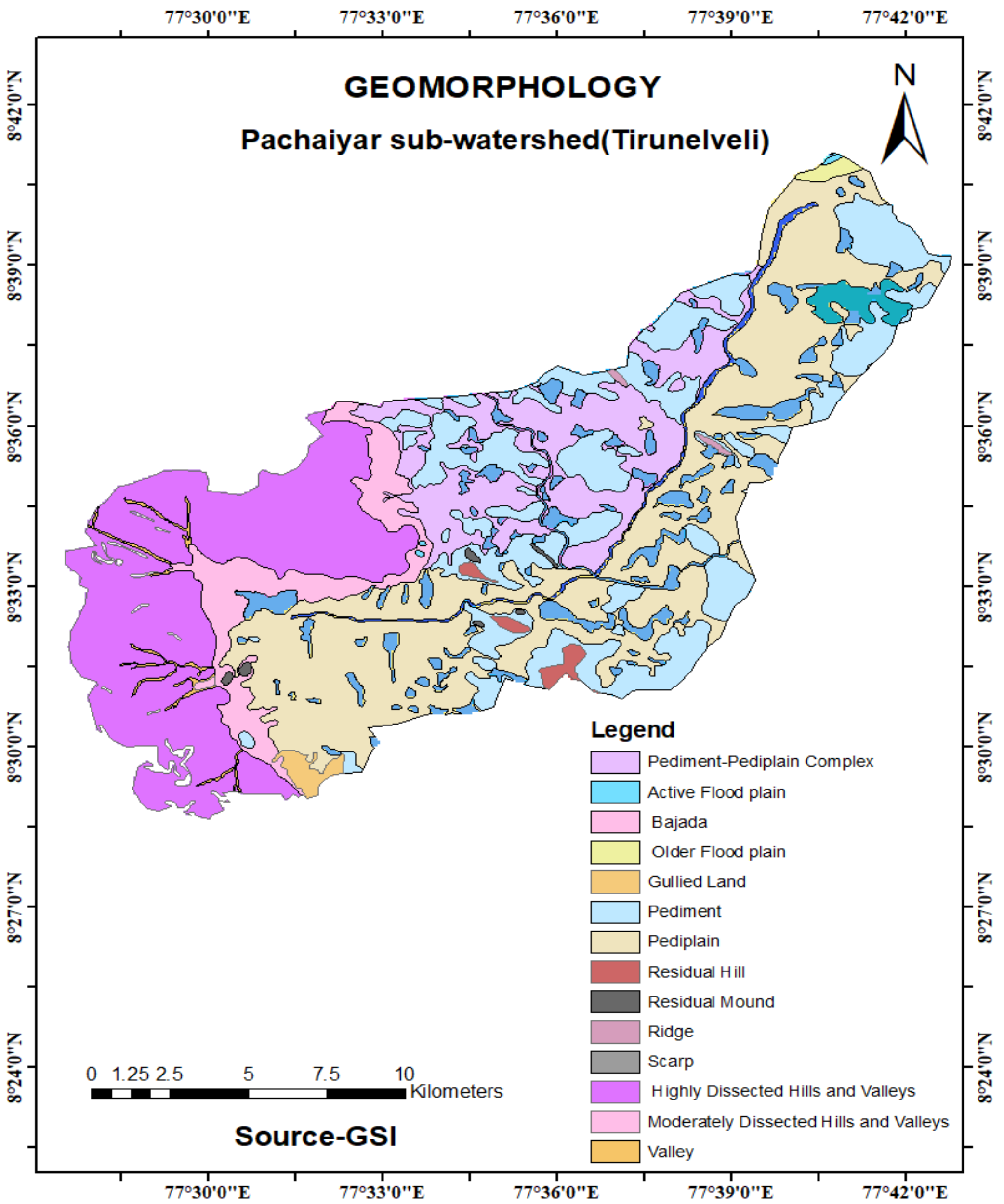


FIGURE 5.18 GEOMORPHOLOGY MAP

5.2 ANALYTIC HIERARCHY PROCESS (AHP)

INTENSITY OF IMPORTANCE ON AN ABSOLUTE SCALE	DEFINITION	INTERPRETATION
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance of one over the other	Experience and judgement strongly Favor one activity over another
5	Essential or strong importance	Experience and judgement strongly Favor one activity over another
7	Very strong Importance	An activity is strongly favoured and its dominants demonstrated in practice
9	Extreme importance	The evidence is favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgements	When compromise is needed

TABLE 5.1 SAATY'S TABLE OF PREFRENCE

5.2.1 PAIR-WISE COMPARISON MATRIX TO CALCULATE SCALE WEIGHT

- ✓ In the Analytical Hierarchy Process (AHP), the Pair-Wise Comparison Matrix is used to determine the relative importance of various criteria or alternatives by comparing them in pairs.

- ✓ Each pair of elements is assigned a numerical value on a scale typically ranging from 1 to 9, where 1 indicates equal importance and values like 3, 5, 7, and 9 represent varying degrees of preference (Saaty, 1980).

- ✓ The comparisons are reciprocal, meaning that if Criterion A is more important than Criterion B with a score of 3, the matrix will reflect a score of 1/3 for the comparison of B to A (Saaty, 2008).

- ✓ Once the comparisons are made, scale weights are calculated by normalizing the matrix and determining the principal eigenvector, which provides the proportional importance of each criterion or alternative (Chien et al., 2002).

- ✓ These weights are then used to rank and evaluate alternatives, converting subjective judgments into quantifiable values for decision-making.

- ✓ The Pair-Wise Comparison Matrix is a crucial tool in AHP, enabling a systematic and consistent approach to decision-making by organizing expert opinions and generating reliable, quantifiable outcomes.

5.2.2 PAIR-WISE COMPARISON MATRIX

Factors	Rainfall	Drainage Density	LU/LC	Slope	Geomorphology	Lithology	Lineament Density	Relief(basinal)	SPI	TWI	Roughness
Rainfall	1	4	3	3	3	2	3	3	4	3	3
Drainage Density	1/4	1	2	3	2	1	1	3	3	2	3
LU/LC	1/3	1	1	2	2	1	2	3	4	2	2
Slope	1/3	1/3	1/2	1	2	1	1	3	3	1	3
Geomorphology	1/3	1/2	1/2	1/2	1	1	1	2	2	2	2
Lithology	1/2	1	1	1	1	1	2	3	3	3	3
Lineament Density	1/3	1	1/2	1	1	1/2	1	2	2	2	2
Relief(basinal)	1/3	0	1/3	1/3	1/2	1/3	1	1	3	1	2
SPI	1/4	1/3	1/4	1/3	1/2	1/3	1/2	1/3	1	1	2
TWI	1/3	1/2	1/2	1	1/2	1/3	1/2	1	1	1	2
Roughness	1/3	1/3	1/2	1/3	1/2	1/3	1/2	1/2	1/2	1/2	1
Sum	4.33	9.83	10.08	13.50	14.00	8.83	13.00	21.83	26.50	18.50	25.00

TABLE 5.2 PAIR-WISE COMPARISON MATRIX

5.2.3 NORMALIZED PAIR-WISE COMPARISON MATRIX

- ✓ The Normalized Pair-Wise Comparison Matrix is a crucial step in the Analytical Hierarchy Process (AHP). To normalize the matrix, the values in each column are divided by the sum of that column.

- ✓ This ensures that each column of the matrix sums to 1, making the comparisons proportional and consistent across the different criteria or alternatives (Saaty, 1980).

- ✓ After normalization, the scale weights are derived by calculating the average of each row in the normalized matrix.

- ✓ These normalized values represent the relative importance of each criterion or alternative within the decision hierarchy.

- ✓ This process effectively converts subjective pairwise judgments into a consistent, quantifiable measure of importance that can be used for further evaluation and ranking.

- ✓ The use of a normalized pair-wise comparison matrix ensures that all criteria are proportionally weighted in the decision-making process, enhancing the accuracy and consistency of the AHP method.

5.2.4 NORMALIZED PAIR-WISE COMPARISON MATRIX

Factors	Rainfall	Drainage Density	LU/LC	Slope	Geomorphology	Lithology	Lineament Density	Relief(basinal)	SPI	TWI	Roughness	Sum	Criteria Weights	Criteria weig
Rainfall	0.2308	0.4068	0.2975	0.2222	0.2143	0.2264	0.2308	0.1374	0.1509	0.1622	0.1200	2.3993	0.2181	22
Drainage Density	0.0577	0.1017	0.1983	0.2222	0.1429	0.1132	0.0769	0.1374	0.1132	0.1081	0.1200	1.3917	0.1265	13
LU/LC	0.0769	0.0508	0.0992	0.1481	0.1429	0.1132	0.1538	0.1374	0.1509	0.1081	0.0800	1.2615	0.1147	11
Slope	0.0769	0.0339	0.0496	0.0741	0.1429	0.1132	0.0769	0.1374	0.1132	0.0541	0.1200	0.9921	0.0902	9
Geomorphology	0.0769	0.0508	0.0496	0.0370	0.0714	0.1132	0.0769	0.0916	0.0755	0.1081	0.0800	0.8311	0.0756	8
Lithology	0.1154	0.1017	0.0992	0.0741	0.0714	0.1132	0.1538	0.1374	0.1132	0.1622	0.1200	1.2616	0.1147	11
Lineament Density	0.0769	0.1017	0.0496	0.0741	0.0714	0.0566	0.0769	0.0916	0.0755	0.1081	0.0800	0.8624	0.0784	8
Relief(basinal)	0.0769	0.0339	0.0331	0.0247	0.0357	0.0377	0.0385	0.0458	0.1132	0.0541	0.0800	0.5735	0.0521	5
SPI	0.0577	0.0339	0.0248	0.0247	0.0357	0.0377	0.0385	0.0153	0.0377	0.0541	0.0800	0.4400	0.0400	4
TWI	0.0769	0.0508	0.0496	0.0741	0.0357	0.0377	0.0385	0.0458	0.0377	0.0541	0.0800	0.5809	0.0528	5
Roughness	0.0769	0.0339	0.0496	0.0247	0.0357	0.0377	0.0385	0.0229	0.0189	0.0270	0.0400	0.4058	0.0369	4
												11	1	100

TABLE 5.3 NORMALIZED PAIR-WISE COMPARISON MATRIX

5.2.5 CALCULATING CONSISTENCY

- ✓ The maximum values of the thematic layer and classes are determined using the highest eigenvalues to guarantee consistency in the decision-making process.

- ✓ The normalized weight plus the total weight of the parameters in the matrix are added up to determine this.

Equation 1:

$$\boxed{\lambda_{max} = \sum_{i=1}^{n} \mathrm{TW_i} * \mathrm{NW_i}}$$

- ✓ Thematic layers can be evaluated based on their largest Eigenvalue (λ max), total weight (TWi), and normalized weight (NWi).

- ✓ Saaty (1980) defines the consistency index as a measure of the degree of variation in consistency and computes it using the following formula (Eq.).

5.2.6 CONSISTENCY TABLE

C.W	0.2181	0.1265	0.1147	0.0902	0.0756	0.1147	0.0784	0.0521	0.0400	0.0528	0.0369			
Factors	Rainfall	Drainage Density	LU/LC	Slope	Geomorphology	Lithology	Lineament Density	Relief(basinal)	SPI	TWI	Roughness	Weighted sum value	Criteria Weight	WSV/CW
Rainfall	0.2181	0.5061	0.3440	0.2706	0.2267	0.2294	0.2352	0.1564	0.1600	0.1584	0.1107	2.6156	0.2181	11.99
Drainage Density	0.0545	0.1265	0.2294	0.2706	0.1511	0.1147	0.0784	0.1564	0.1200	0.1056	0.1107	1.5179	0.1265	12.00
LU/LC	0.0727	0.0633	0.1147	0.1804	0.1511	0.1147	0.1568	0.1564	0.1600	0.1056	0.0738	1.3495	0.1147	11.77
Slope	0.0727	0.0422	0.0573	0.0902	0.1511	0.1147	0.0784	0.1564	0.1200	0.0528	0.1107	1.0465	0.0902	11.60
Geomorphology	0.0727	0.0633	0.0573	0.0451	0.0756	0.1147	0.0784	0.1043	0.0800	0.1056	0.0738	0.8707	0.0756	11.52
Lithology	0.1091	0.1265	0.1147	0.0902	0.0756	0.1147	0.1568	0.1564	0.1200	0.1584	0.1107	1.3330	0.1147	11.62
Lineament Density	0.0727	0.1265	0.0573	0.0902	0.0756	0.0573	0.0784	0.1043	0.0800	0.1056	0.0738	0.9218	0.0784	11.76
Relief(basinal)	0.0727	0.0422	0.0382	0.0301	0.0378	0.0382	0.0392	0.0521	0.1200	0.0528	0.0738	0.5971	0.0521	11.45
SPI	0.0545	0.0422	0.0287	0.0301	0.0378	0.0382	0.0392	0.0174	0.0400	0.0528	0.0738	0.4546	0.0400	11.36
TWI	0.0727	0.0633	0.0573	0.0902	0.0378	0.0382	0.0392	0.0521	0.0400	0.0528	0.0738	0.6174	0.0528	11.69
Roughness	0.0727	0.0422	0.0573	0.0301	0.0378	0.0382	0.0392	0.0261	0.0200	0.0264	0.0369	0.4269	0.0369	11.57
													L.max=	11.67

TABLE 5.4 CONSISTENCY TABLE

5.2.7 RANDOM CONSISTENCY INDEX (RCI)

Equation 2:

$$CI = \frac{\lambda max - n}{n - 1}$$

The consistency index (CI) is calculated using the largest Eigenvalue (max) of the thematic layers. By comparing with the Random consistency index (RI) given in the Table below, he proposed to use the consistency index.

5.2.8 RANDOM CONSISTENCY INDEX (Saaty's 1980*)*

number of items

Random index

1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59
16	1.605
17	1.61
18	1.615
19	1.62
20	1.625

n= number of parameters;

RI = random consistency index

since the number of parameters considered here is 11 the RI value is 1.51.

TABLE 5.5 SAATY'S TABLE

Equation 3:

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

CI= λmax – n /n-1   CI = 0.65 / 10   CI=0.065 (0.07)

5.2.9 CONSISTENCY CHECKING

The Consistency Ratio (CR) compares the Consistency Index (CI) to the Random Consistency Index (RI). It is calculated using the following formula:

Equation 4:

$$CR = \frac{CI}{RI}$$

According to Saaty (1980), when evaluating the consistency of a judgment using the consistency ratio (CR), the value of CR should be equal to or less than 0.1. If the CR value is greater than 0.1, the judgment needs to be revised. The consistency index (CI) and random consistency index (RI) are also used in this evaluation.

CR=0.07/ 1.51

CR= 0.04, which is less than 0.1 hence consistency is proved.

5.2.10 PARAMETERS RECLASSIFICATION

- ✓ Weights have been given to a number of metrics in order to comprehend the elements that influence the likelihood of floods in a certain area.

- ✓ A scale of 1 to 5 has been used to assign these weights, where 5 denotes a significant impact and 1 denotes a low impact.

- ✓ Each parameter's impact on the region's risk of flash floods has been taken into consideration while determining the weights.

- ✓ Overall, we may better understand how particular elements contribute to the incidence of flash floods in a location by giving these aspects weights.

- ✓ This information can then be utilized to create suitable plans to stop or lessen the likelihood of flash floods in the region.

5.2.11 FEATURE WEIGHTS FOR EACH FEATURE CLASS

S NO	PARAMETER	FEATURE CLASS	ASSIGNED WEIGHT(AW)	GEOMETRIC MEAN(G)	NORMALIZED WEIGHT (N=AW*G)
1	RAINFALL	568 - 582	1	0.22	0.22
		583 - 596	2		0.44
		597 - 610	3		0.66
		611 - 625	4		0.88
		626 - 639	5		1.1
		640 - 653	5		1.1
2	DRAINAGE DENSITY	0 – 171.6(Very low)	5	0.13	0.65
		171.7 – 343.1(Low)	4		0.52
		343.2 – 514.7(Medium)	3		0.39
		514.8 – 686.3(High)	2		0.26
		686.4 – 857.8(Very high)	1		0.13
3	LANDUSE AND LAND COVER	Waterbody	5	0.11	0.55
		Land with scrub	5		
		Barenland	5		0.55
		Built-up Area	4		0.44
		Cropland	3		0.33
		Rangeland	3		0.33
		Agricultural land	3	0.11	0.33
		Vegetation	2		
		Tropical Evergreen Forest	2		0.22
4	SLOPE	0 – 1.3(Nearly level)	5	0.99	4.95
		1.4–3.4(Very gently sloping)	4		3.96
		3.5 – 5.7(Gently sloping)	3		2.97
		5.8–7.1(Moderately sloping)	2		1.98
		7.2 – 15(Strongly sloping)	2		1.98
		16 – 36(Steep sloping)	1		0.99
		37–70(Very steep sloping)	1		0.99

5	**GEOMORPHOLOGY**	Active flood plain	5	0.08	0.4
		Older flood plain	4		0.32
		Active Quarry	3		0.24
		Pediplain	3		0.24
		Gullied Land	3		0.24
		Valleys	3		0.24
		Bajada	2		0.16
		Pediment	2		0.16
		Residual Mount	2		0.16
		Residual Hill	1		0.08
		Ridge	1		0.08
		Highly dissected hills and valleys	1		0.08
		Moderately dissected hills and valleys	1		0.08
6	**LITHOLOGY**	Garnet-biotite gneiss	5	0.11	0.55
		Garnet-sillimanite-graphite gneiss	4		0.44
		Hornblende-biotite gneiss	3		0.33
		Calc-granulite and limestone	2		0.22
		Quarzite	1		0.11
7	**LINEAMENT DENSITY**	Very low	5	0.08	0.4
		Low	4		0.32
		Moderate	3		0.24
		High	2		0.16
		Very High	1		0.08

8	**RELIEF(BASINAL)**	39-200(Very low relief)	5	0.05	0.25
		210-410(Low relief)	4		0.2
		420-670(Moderate relief)	3		0.15
		680-1000(High relief)	2		0.1
		1100-1600(Very high relief)	1		0.05
9	**STREAM POWER INDEX(SPI)**	0-0.012(Very high)	1	0.04	0.04
		0.013-0.05(High)	2		0.08
		0.051-0.11(Moderate)	3		0.12
		0.12-0.19(Low)	4		0.16
		0.2-0.43(Very low)	5		0.2
10	**TOPOGRAPHIC WETNESS INDEX(TWI)**	(-9.2)-(-5.9)	1	0.05	0.05
		(-5.8)-(-4.3)	2		0.1
		(-4.2)-(-2.8)	3		0.15
		(-2.7)-(-0.8)	4		0.2
		(-0.79)-(7.2)	5		0.25
11	**ROUGHNESS (TRI)**	0.11-0.3(Very low)	5	0.04	0.2
		0.31-0.43(Low)	4		0.16
		0.44-0.54(Moderate)	3		0.12
		0.55-0.68(High)	2		0.08
		0.69-0.89(Very high)	1		0.04

TABLE 5.6 FEATURE WEIGHTS FOR EACH FEATURE CLASS

5.2.12 FLOOD PRONE ZONATION

- ✓ The Final Flood Prone Zonation map for the study area was meticulously prepared through a series of comprehensive analytical steps to ensure accuracy and reliability.

- ✓ The process began with the generation of various thematic layers, each representing critical flood-inducing parameters such as terrain, hydrology, and land features.

- ✓ These parameters were analyzed using the Analytical Hierarchy Process (AHP) to assign appropriate weightages based on their relative contributions to flood vulnerability.

- ✓ Following this, the thematic layers were reclassified using the Reclassify tool in the ArcToolbox, ensuring a consistent representation of flood susceptibility across the study area.

- ✓ Once reclassified, these layers were integrated using the Weighted Sum tool, a method that combines weighted contributions from all parameters to produce the final flood prone zonation map.

- ✓ To facilitate area calculations, the reclassified raster layers were converted into vector format through vectorization within the ArcGIS environment.

5.2.13 FLOOD PRONE ZONATION MAP

The flood prone Zonation map for the study area was shown in the FIGURE 5.19.

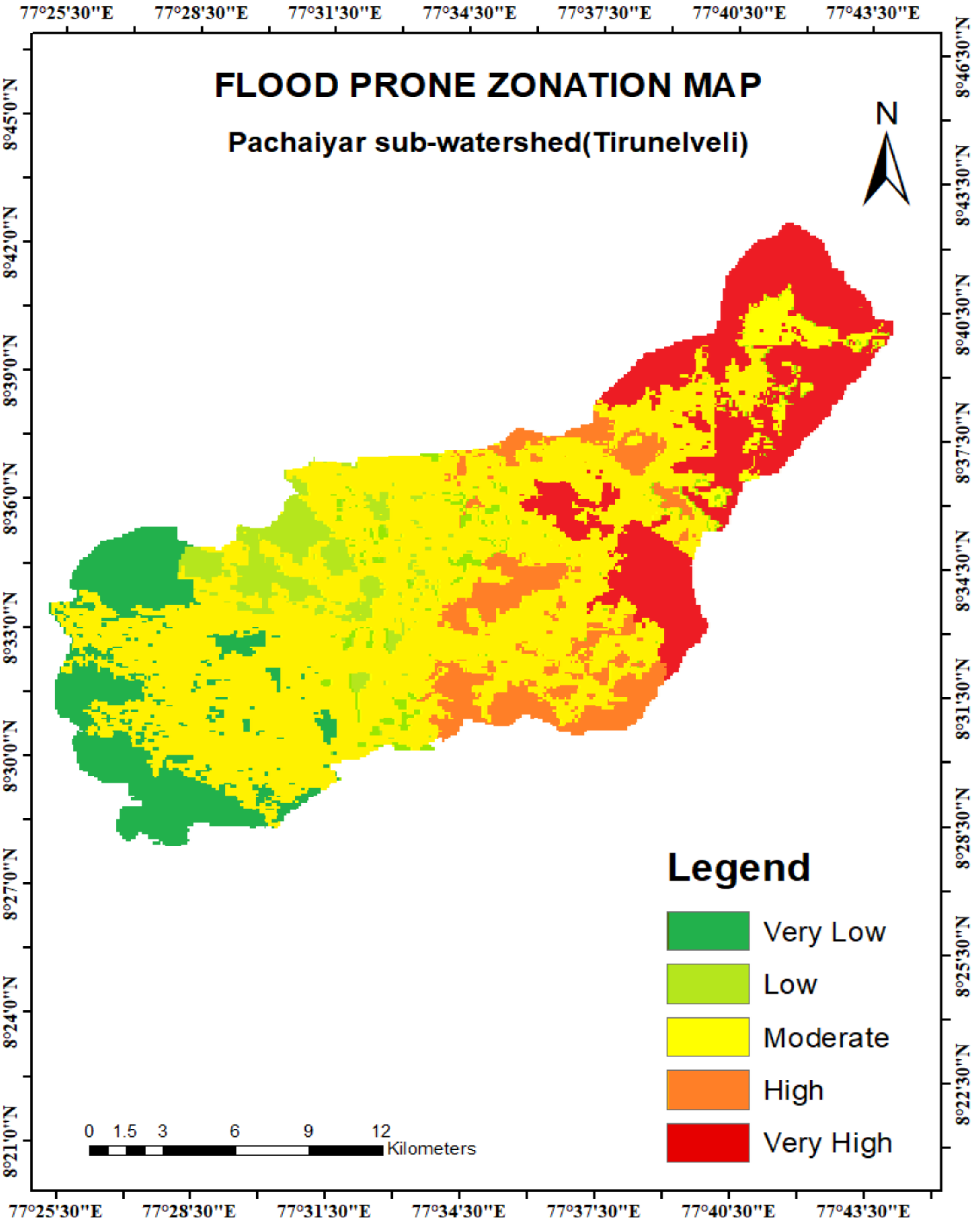


FIGURE 5.19 FLOOD PRONE ZONATION MAP

5.2.14 AREA OF THE FLOOD PRONE ZONES

ZONES	AREA(Sq.Km) TOTAL-288.66	PERCENTAGE (%)
Very Low	50.30	17.43
Low	30.87	10.69
Moderate	95.60	33.13
High	35.57	12.32
Very High	76.32	26.43

TABLE 5.7 AREA OF THE FLOOD PRONE ZONES

- ✓ The analysis revealed a striking spatial distribution of flood vulnerability across the study area.
- ✓ Very high flood vulnerability zones, marked in red, covering an extensive area of 76.32 sq. km, which constitutes 26.43% of the total study area. High vulnerability zones, depicted in orange, span 35.57 sq. km, while moderate vulnerability zones cover an area of 95.60 sq. km.
- ✓ Low and very low vulnerability zones, occupy 30.87 sq.km and 50.30 sq.km, respectively, highlighting a gradation of flood risk across the landscape.
- ✓ These findings underscore the substantial proportion of Pachaiyar sub-watershed that is at significant risk of severe flooding events.

5.3 RUSLE MODEL

EQUATION OF RUSLE

$$\boxed{A = R*K*LS*C*P}$$

Where,

A = average annual soil loss per unit area (kg ha^{-1} yr^{-1}),

R = rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}),

K = soil erodibility factor (Kg ha h MaJ^{-1} mm^{-1}),

L = slope length factor, (Dimensionless)

S = slope steepness factor, (Dimensionless)

C = cover and management factor, (Dimensionless) and

P = support and conservation practices factor. (Dimensionless)

5.3.1 R FACTOR

The highest value of R-factor noted in the study area is 672.467 MJ mm ha^{-1} h^{-1} yr^{-1} and lowest is 585.492 MJ mm ha^{-1} h^{-1} yr^{-1}

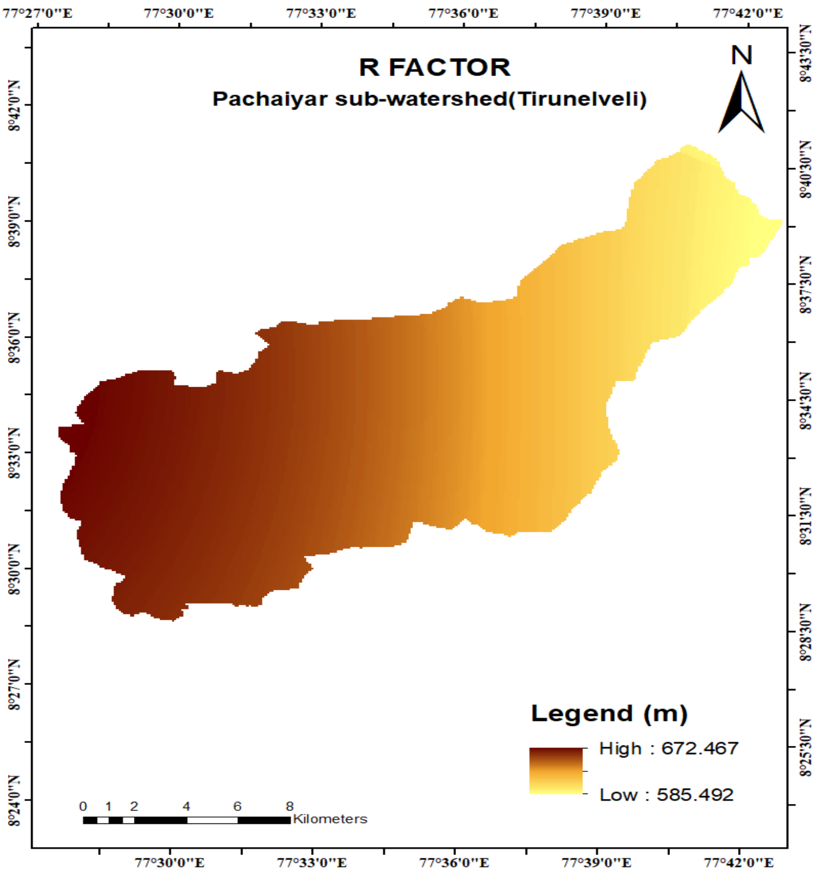


FIGURE 5.20 R FACTOR MAP

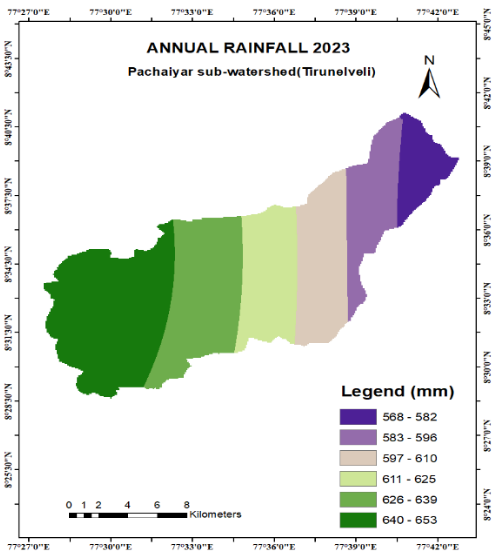


FIGURE 5.20.1 RAINFALL MAP

5.3.2 K FACTOR

The K values for different soil textures is ranging from maximum of 0.16 (Kg ha h MJ^{-1} mm^{-1}) to minimum of 0.5(Kg ha h MJ^{-1} mm^{-1}).

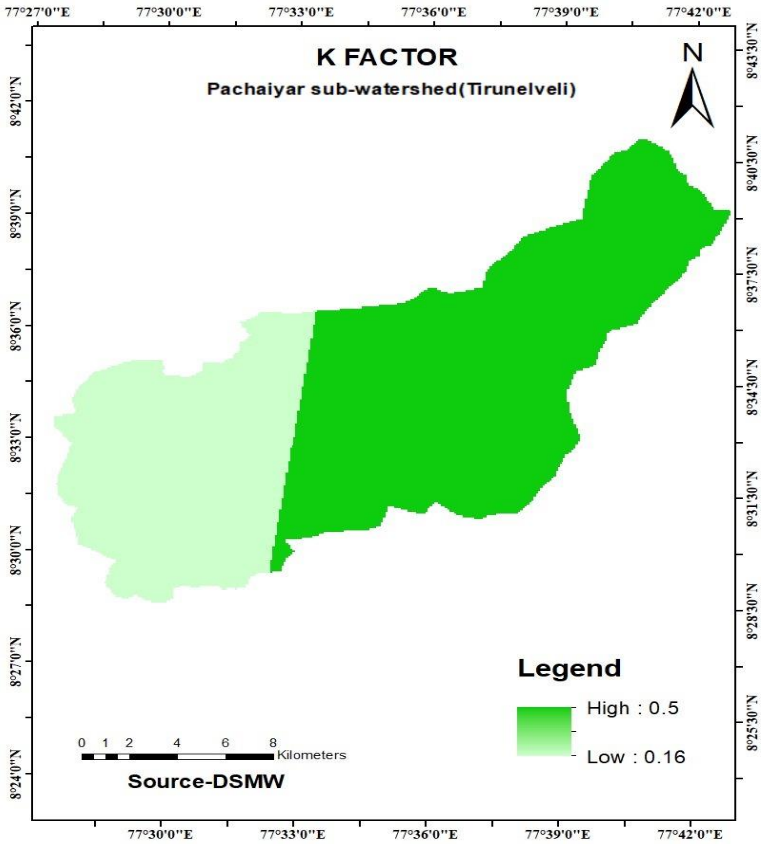


FIGURE 5.21 K FACTOR MAP

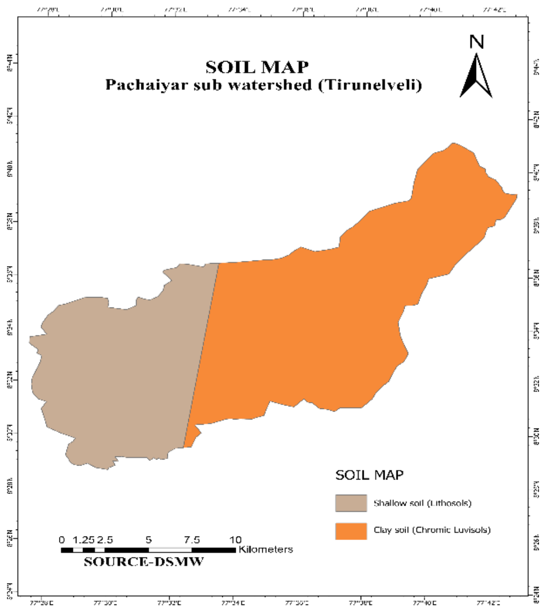


FIGURE 5.21.1 SOIL MAP

5.3.3 LS FACTOR

LS is the Slope Length and Slope Steepness factor.

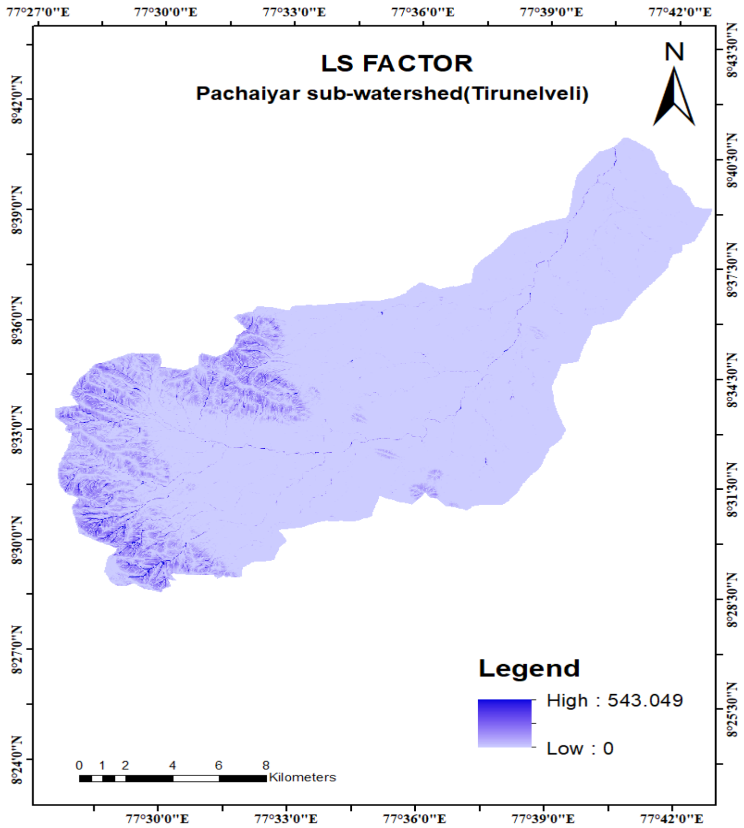
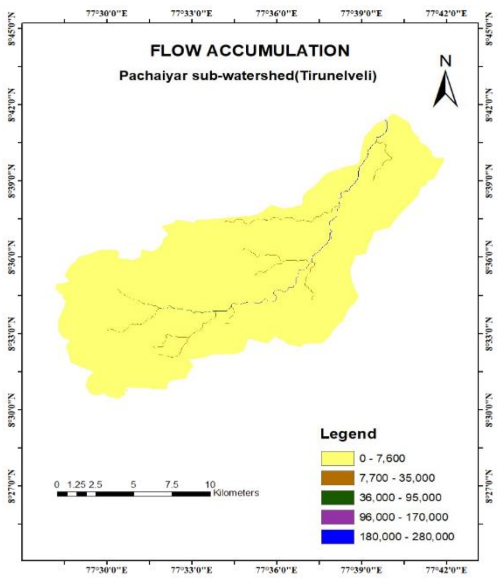


FIGURE 5.22 LS FACTOR MAP



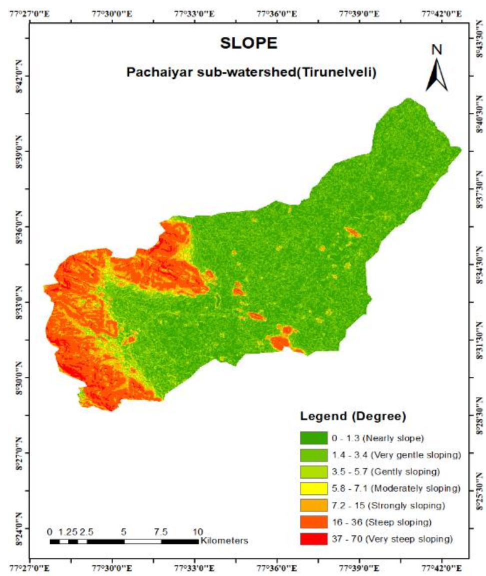


FIG 5.22.1 FLOW ACC MAP

FIG 5.22.2 SLOPE MAP

5.3.4 C FACTOR

The cover management factor is the ratio of soil loss from an area with specified cover and management to that of an area in tilled continuous fallow.

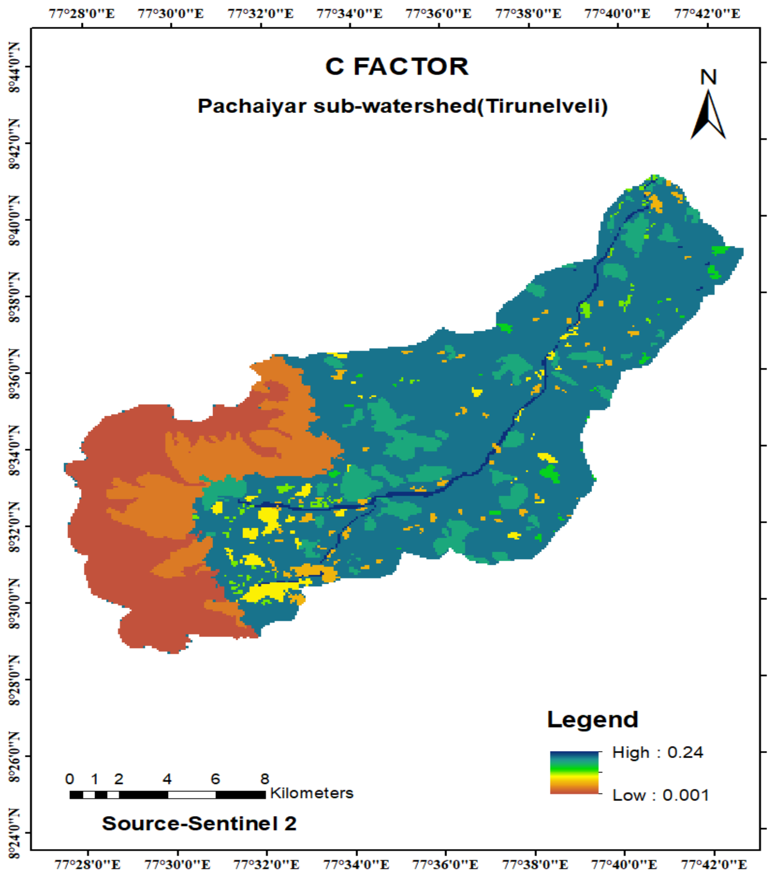


FIGURE 5.23 C FACTOR MAP

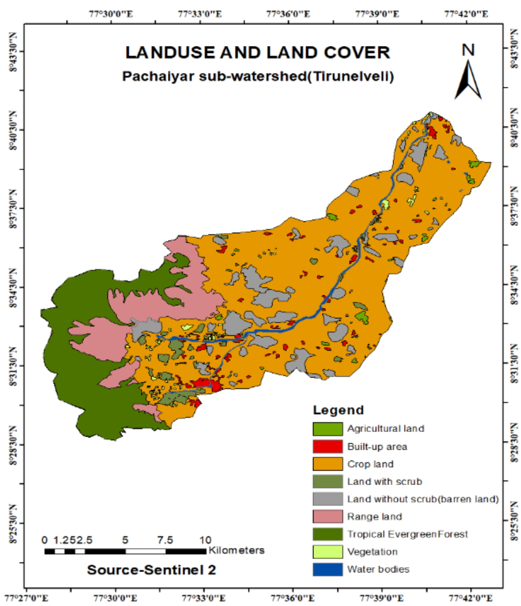


FIGURE 5.23.1 LULC MAP

5.3.5 P FACTOR

The Conservation Practices factor reflects the effects of practices that will reduce the amount of erosion.

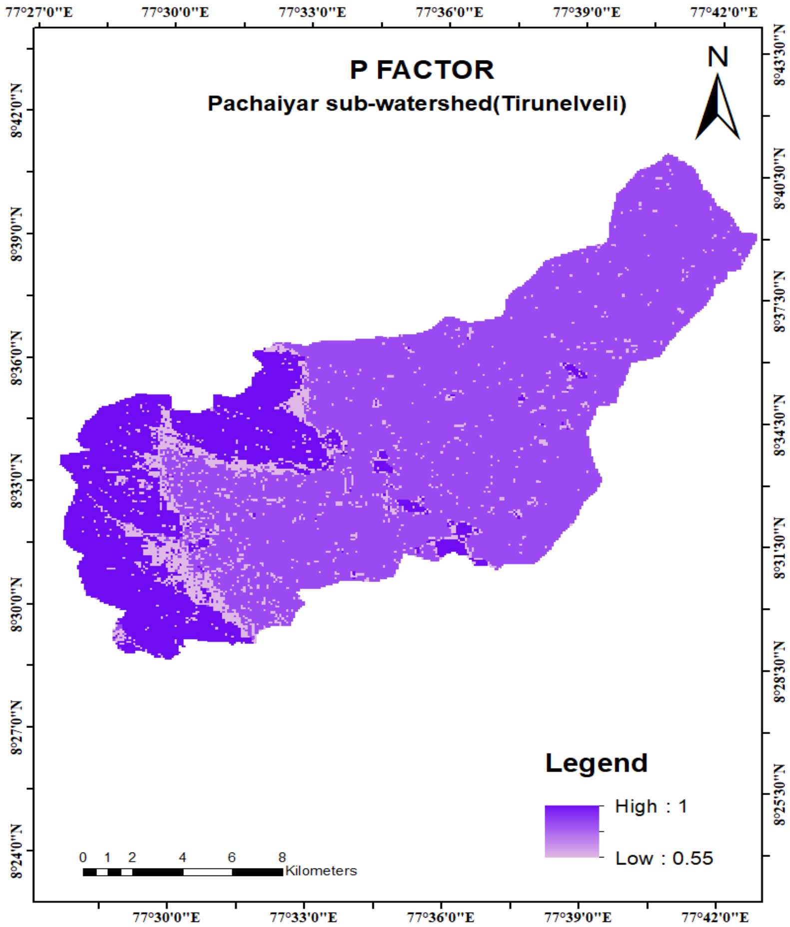


FIGURE 5.24 P FACTOR MAP

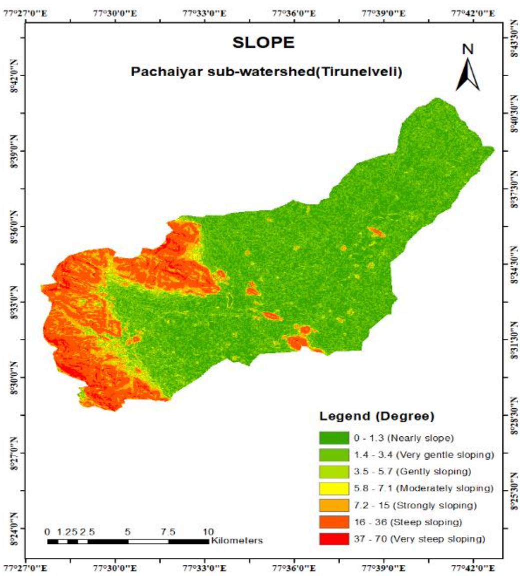


FIGURE 5.24.1 SLOPE MAP

5.3.6 MAPPING OF ANNUAL SOIL LOSS

The annual soil loss is identified by multiplying the all five factors of RUSLE together.

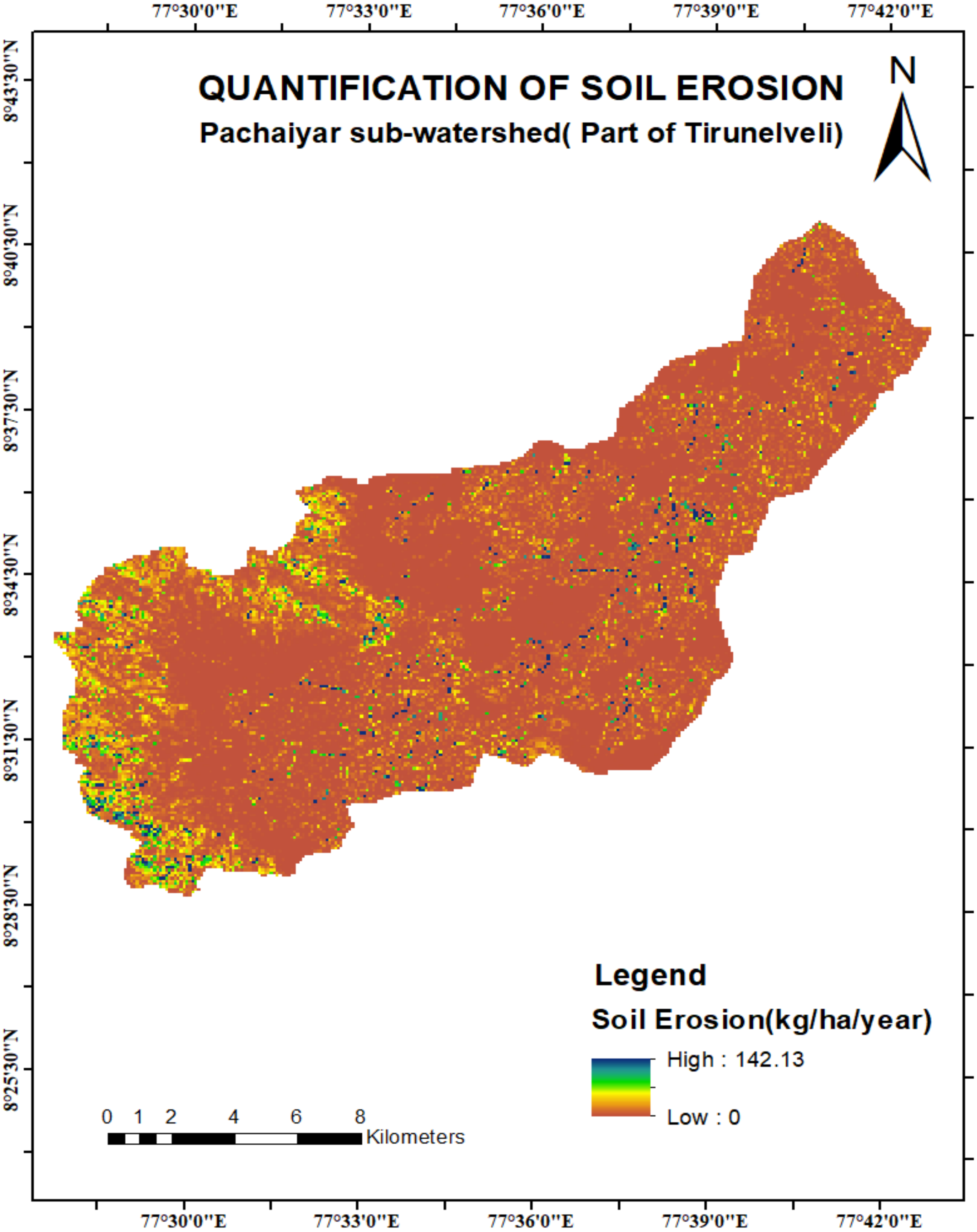


FIGURE 5.25 SOIL LOSS MAP

From the output it is noticed that the soil loss that happened in the year 2023 in the study area includes an amount of **142.13 Kg/ha/yr.**

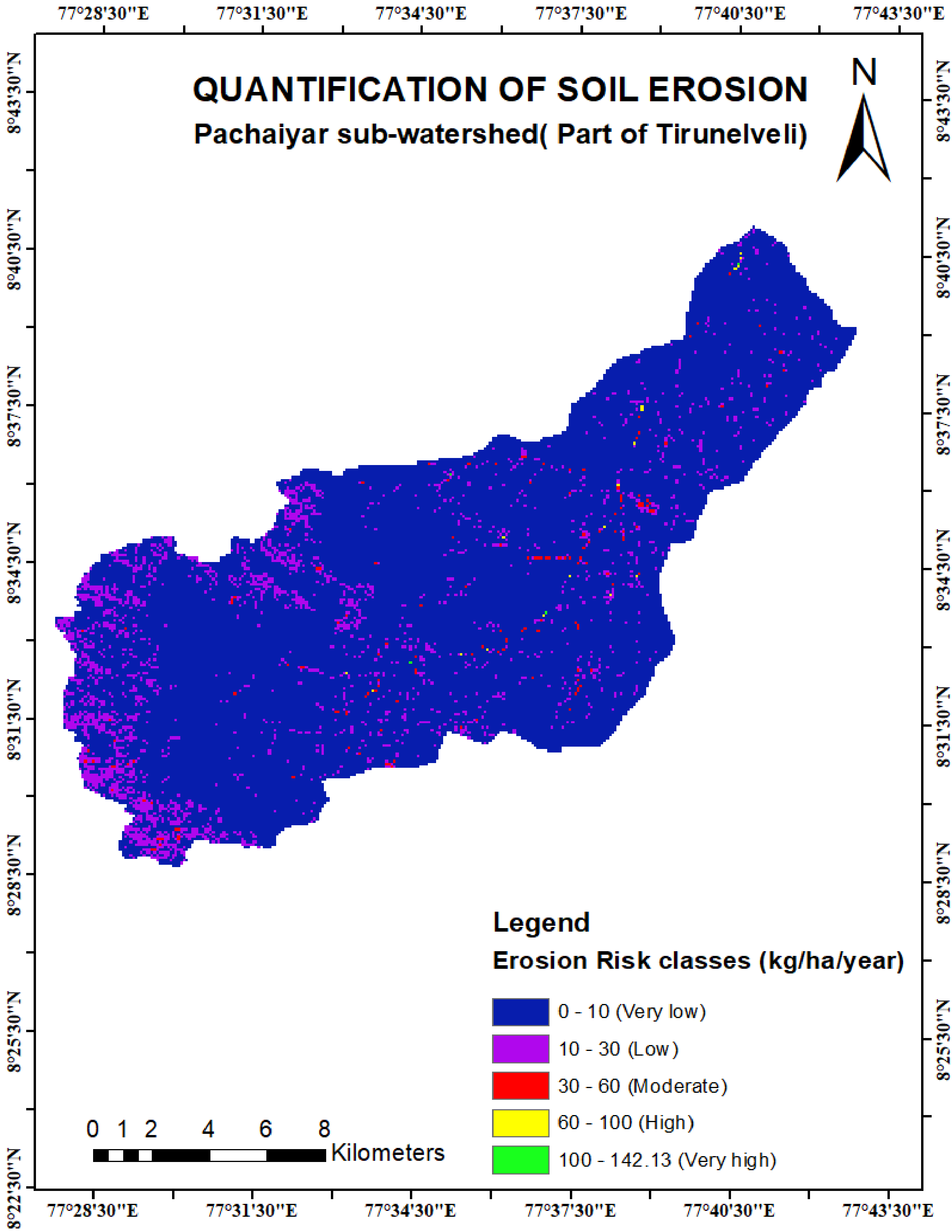


FIGURE 5.26 CLASSIFICATION OF SOIL LOSS MAP

5.3.7 SHOWING SOIL EROSION IN DIFFERENT CLASSES WITH AREA AND PERCENTAGE

SOIL EROSION CLASS	RANGE (Kg/ha/year)	AREA(SQ.KM) Total area-288.66	PERCENTAGE (%)	PRIORITY CLASS
Very Low	0 – 10.213	260.96	90.4	5
Low	10.213 – 30.509	20.83	7.21	4
Moderate	30.509 – 60.567	3.43	1.18	3
High	60.567 – 100.208	2.35	0.84	2
Very High	100.208 – 142.132	1.09	0.37	1

TABLE 5.8 AREAS OF SOIL EROSION RISK CLASS

- ✓ The analysis revealed a striking spatial distribution of soil erosion across the study area.
- ✓ Very high erosion risk class covers about 0.37%.
- ✓ High erosion risk class covers about 0.84%.
- ✓ Moderate erosion risk class covers about 1.18%.
- ✓ Low erosion risk class covers about 7.21%.
- ✓ Very low erosion risk class covers about 90.4%.

PIECHART FOR FLOOD PRONE ZONES IN PERCENTAGE

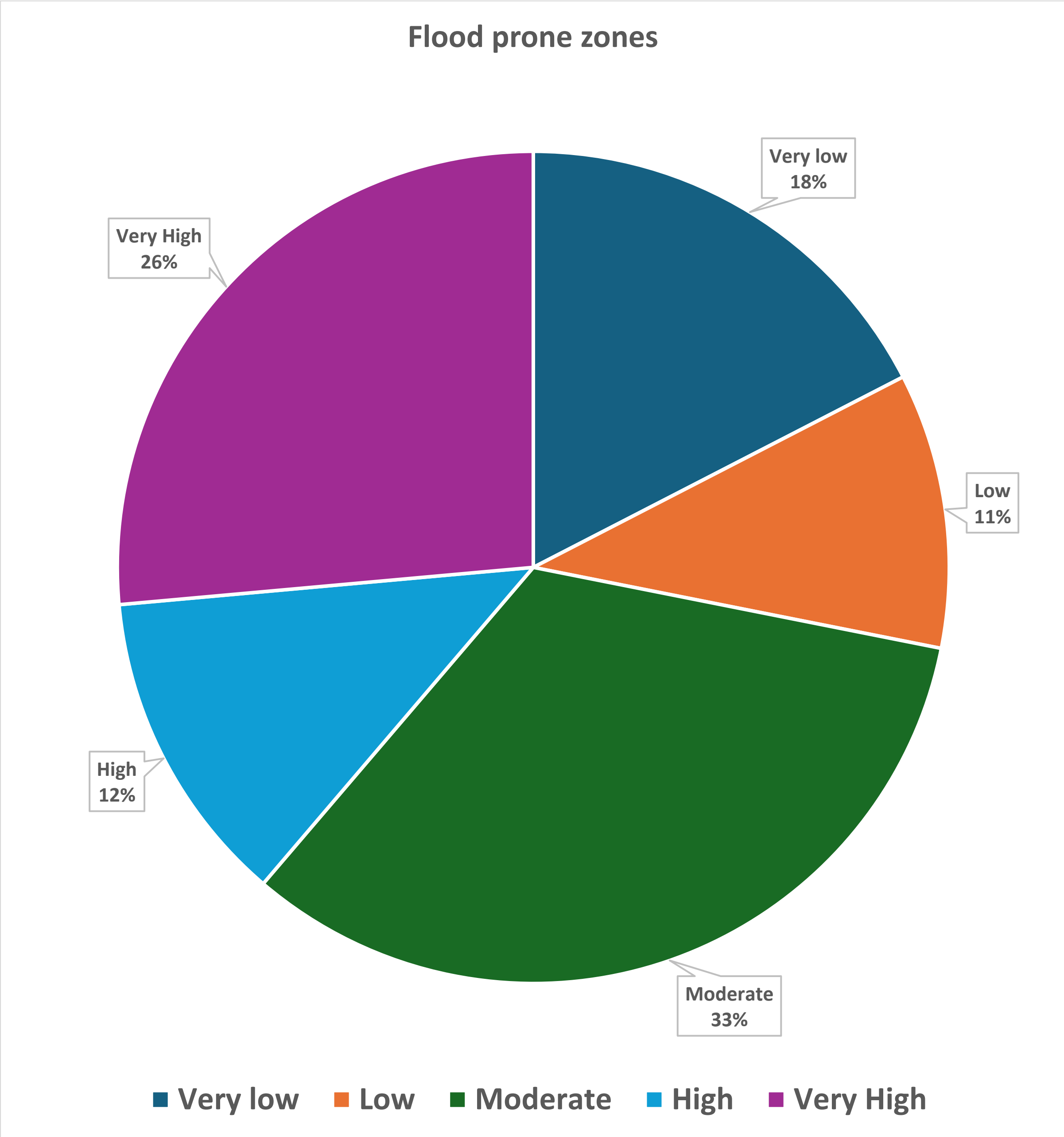


FIGURE 5.27 PIECHART FOR FLOOD PRONE ZONES

PIECHART FOR SOIL EROSION RISK CLASS IN PERCENTAGE

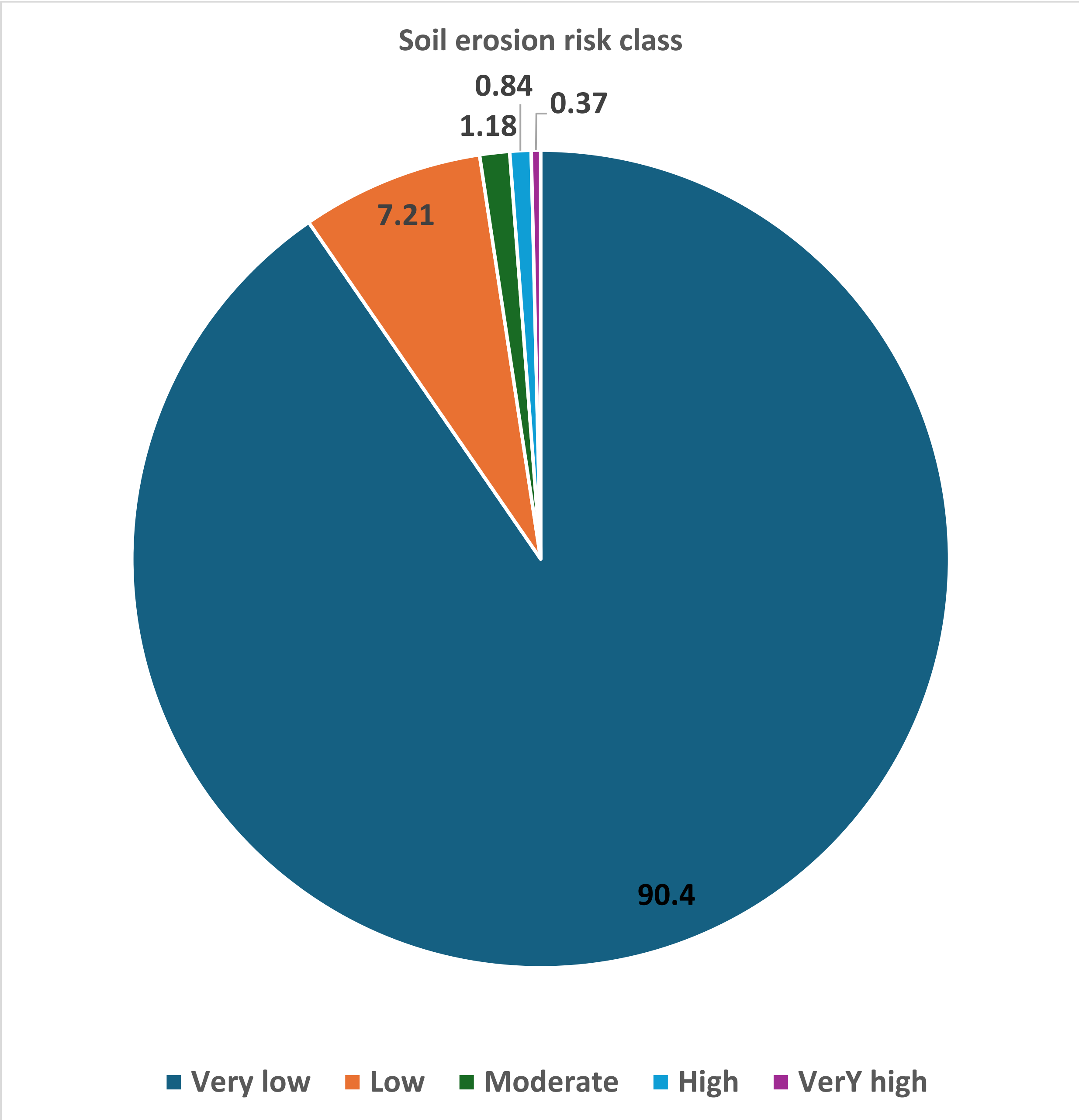


FIGURE 5.28 PIECHART FOR SOIL EROSION RISK CLASS

5.4 MITIGATION PLAN

5.4.1 Flood Mitigation Plan for Pachaiyar Sub-Watershed (Thamirabarani River Basin)

FIGURE 5.29 FLOOD

Strengthen Stormwater and Watershed Management

- ✓ Implement micro-watershed planning to divide the area into smaller manageable units.
- ✓ Establish stormwater retention basins and vegetated swales in urban and peri-urban zones to reduce surface runoff.
- ✓ Introduce GIS-based flood modeling to simulate scenarios and plan mitigation measures effectively.

Expand Groundwater Recharge Structures

- ✓ Construct and rehabilitate recharge wells and percolation tanks along traditional drainage lines (odais).
- ✓ Promote contour trenching and stone bunding in upland agricultural areas to slow down runoff and increase infiltration.
- ✓ Develop check dams with sediment traps on key tributaries feeding into the Thamirabarani to manage both floods and siltation.

Restore and Integrate Traditional Water Systems

- ✓ Revive ancient eri (tank) systems and temple ponds not just for storage but as flood buffers.
- ✓ Reconnect disconnected tanks to natural flood pathways to store excess rainfall during peak monsoon.
- ✓ Incorporate traditional Kudimaramathu (community water management) practices for tank maintenance and flood preparation.

Upgrade Urban and Rural Drainage Infrastructure

- ✓ Desilt and deepen channels regularly, particularly in flood-prone low-lying villages.
- ✓ Use culvert upgrades with larger diameters and debris screens to handle flash floods.
- ✓ Establish green corridors along drainage channels to prevent encroachment and improve flow during heavy rains.

Conserve and Restore Natural Wetlands

- ✓ Map and protect wetlands in the lower reaches of the Pachaiyar sub-watershed, which act as natural flood buffers.
- ✓ Encourage paddy field bund strengthening as seasonal flood control structures.
- ✓ Promote riparian buffer zones along streams to reduce erosion and slow floodwaters.

Early Warning and Monitoring Systems

- ✓ Set up community rain gauge networks with real-time data sharing via mobile alerts.
- ✓ Train local youth groups in flood monitoring and first-response actions.
- ✓ Use automated river level sensors at critical points along the Pachaiyar and its tributaries.

Policy and Capacity Building

- ✓ Enforce land-use regulations preventing construction in flood plains.
- ✓ Organize capacity building workshops for Panchayat leaders and farmers on flood resilience.
- ✓ Introduce incentives for farmers adopting flood-resilient cropping practices (e.g., short-duration paddy, flood-tolerant varieties).

5.4.2 Soil Erosion Mitigation plan for Pachaiyar Sub-watershed (Thamirabarani River Basin)

FIGURE 5.30 SOIL EROSION

To mitigate soil erosion in the Pachaiyar sub-watershed, an integrated watershed management approach is recommended. Key strategies include:

- ✓ Implement contour bunding, contour farming, and graded bunds to reduce surface runoff and enhance soil moisture conservation.

- ✓ Establish vegetative buffer strips along stream banks and slopes using native grasses like Vetiver and Cymbopogon, which are effective in the Thamirabarani region.

- ✓ Construct series of check dams, percolation ponds, and nala bunds across drainage lines to slow down water flow and encourage groundwater recharge.

- ✓ Promote agroforestry systems by integrating native tree species such as Albizia amara (Indian Siris) , Ailanthus excelsa (Indian tree of heaven) , and Pongamia pinnata (Indian beach tree) with crops to improve soil stability and livelihood.

- ✓ Enhance soil cover with leguminous cover crops (e.g., Stylosanthes, Desmodium) to improve soil fertility while reducing erosion risks.

- ✓ Capture and store surface runoff using farm ponds and recharge structures to support irrigation and reduce erosive water velocities.

- ✓ Promote mixed cropping and intercropping systems to reduce erosion and improve crop resilience in rainfed areas.

- ✓ Adopt conservation tillage and minimize soil disturbance during land preparation.

- ✓ Alternate cropping patterns to include soil-restorative crops like pulses and green manure crops to improve soil structure and health.

- ✓ Plant windbreaks and shelterbelts using species such as Casuarina equisetifolia (Pine) along field borders to reduce wind erosion.

- ✓ Minimize chemical fertilizer and pesticide use to improve soil biodiversity, reduce greenhouse gas emissions, and enhance long-term soil health.

- ✓ Restore degraded hill areas by planting deep-rooted native species and adopting assisted natural regeneration (ANR) techniques.

- ✓ Implement community-based watershed committees to monitor, maintain, and manage soil and water conservation structures.

- ✓ Promote awareness and capacity building among local farmers on sustainable land management practices tailored to the Pachaiyar landscape.

5.5 CONCLUSION

In this chapter, the results and discussions on the Flood prone areas and soil eroded areas for Pachaiyar sub-watershed, Tirunelveli have been discussed.

CHAPTER 6
CONCLUSIONS

6.1 CONCLUSION

The present study on the Identification of Climate Change Impacts in the Pachaiyar Sub-Watershed Using Geospatial Technology has demonstrated the significant role that advanced spatial analysis tools play in understanding environmental changes at the watershed level. By applying the Revised Universal Soil Loss Equation (RUSLE) model, the research has successfully quantified soil erosion patterns, highlighting critical zones that are highly susceptible to degradation. Additionally, the integration of the Analytical Hierarchy Process (AHP) facilitated an effective flood prone zones assessment, enabling the identification of areas most vulnerable to flooding events within the sub-watershed.

The overall results for flood prone zones shows that the most affected zone is the Moderate flood-prone zone, covering 95.60 sq.km, which accounts for the largest share at 33.13% of the total area. This is followed by the Very High flood-prone zone, which spans 76.32 sq.km, making up 26.43% of the area, indicating significant vulnerability. The Very Low zone covers 50.30 sq.km (17.43%), suggesting relatively safer areas but still requiring monitoring. High flood-prone areas comprise 35.57 sq.km or 12.32%, while Low zones cover 30.87 sq.km (10.69%). Overall, a substantial portion of the land (over 70%) falls under moderate to very high flood risk, underscoring the urgent need for flood management strategies, early warning systems, and sustainable land use planning in these zones.

The result for the soil erosion analysis for a total area of 288.66 sq.km reveals that the vast majority of land, 260.96 sq.km or 90.4%, falls under the Very Low erosion class (0–10.213 Kg/ha/year). This indicates minimal soil degradation across most of the region. The Low erosion class (10.213–30.509 Kg/ha/year) covers 20.83 sq.km, comprising 7.21% of the area. Meanwhile, Moderate erosion (30.509–60.567 Kg/ha/year) affects 3.43 sq.km or 1.18%, and High erosion (60.567–100.208 Kg/ha/year) is present in 2.35 sq.km (0.84%). The most critical zone, Very High erosion (100.208–142.132 Kg/ha/year), represents the smallest portion with only 1.09 sq.km, amounting to 0.37% of the total area. Priority-wise, areas under Very High and High erosion fall into Priority Classes 1 and 2, respectively, signalling an urgent need for soil conservation and erosion control measures.

A comprehensive comparison of the flood-prone zonation map and the soil erosion classification map of the study area reveals a strong spatial relationship between flood risk and soil erosion intensity across different zones. The very low-risk zones, located predominantly in the western part of the watershed, show both minimal flood vulnerability and very low soil erosion rates. Similarly, the low-risk zones, which lie adjacent to these areas, exhibit slightly higher but still manageable levels of both flooding and erosion. The moderate zones, mainly situated in the central region, reflect an intermediate state in both maps, experiencing noticeable but not extreme levels of floodwater accumulation and soil loss. The high-risk zones, demonstrate a significant overlap in both flood and erosion hazards. Finally, the very high-risk zones, are the most critical areas, facing both intense flooding and severe soil erosion.

Overall, this study provides a mitigation measures to counteract the escalating impacts of climate change.

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