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SCHOOL OF ENGINEERING

DEPARTMENT OF GEOMATICS ENGINEERING

A REPORT ON

A GIS BASED EVACUATION ROUTE PLANNING IN FLOOD-SUSCEPTIBLE AREA OF HELAMBU RURAL MUNICIPALITY

SUBMITTED TO:

DEPARTMENT OF GEOMATICS ENGINEERING

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ABSTRACT

Nepal, a country with complex topography and climatic conditions, is highly susceptible to various natural disasters, particularly floods. Flooding is a common and devastating occurrence during the monsoon season, primarily due to the country's more than 6,000 rivers and rivulets. These floods pose significant risks to life, property, and infrastructure, necessitating effective early warning systems and evacuation planning to minimise fatalities and damage.

This study focuses on Helambu Rural Municipality, an area with a history of flooding, to develop a comprehensive flood susceptibility and evacuation route mapping using Geographic Information System (GIS) and Analytical Hierarchy Process (AHP). The methodology involves Multi-Criteria Decision Making (MCDM) to evaluate multiple factors that contribute to flood risk and prioritise optimal evacuation routes.

The project identifies key flood-causing factors, including topographic wetness index, slope, elevation, precipitation, land use/land cover, distance from roads and rivers, and drainage density. Using AHP, these factors are assigned weights based on their relative importance, and a flood susceptibility map is created. The map categorises the area into different susceptibility zones, enabling targeted evacuation planning.

Network analysis is employed to design the evacuation routes, focusing on the shortest path analysis, best route determination, and closest facility analysis. This approach ensures that evacuation routes are not only the shortest but also considers real-time conditions, dynamic changes in terrain, and the availability of resources such as shelters and medical facilities.

The resulting GIS-based system provides a robust tool for emergency management in Helambu, offering real-time, optimised evacuation routes tailored to the unique conditions of the area. This system enhances the efficiency of evacuation during floods, potentially saving lives and reducing the impact of such disasters on the community.

Overall, this study demonstrates the effectiveness of integrating GIS and AHP for disaster management, highlighting the importance of multi-criteria analysis in evaluating flood risks and planning evacuation routes. The methodologies and findings can be applied to other flood-prone areas in Nepal and beyond, contributing to better preparedness and resilience against natural disasters.

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
DD	Drainage Density
DRi	Distance from Rivers
DRo	Distance from Road
E	Elevation
EOCs	Emergency Operation Centers
GIS	Geographic Information System
LULC	Land Use/Land Cover
MCA	Multi-Criteria Analysis
P	Precipitation
S	Slope
SDSS	Spatial Decision Support System
TWI	Topographic Wetness Index
NDVI	Normalized Difference Vegetation Index

KEY WORDS

Analytic Hierarchy Process (AHP)

Closest Facility Analysis

Evacuation Route

Flood

Geographic information system (GIS)

Multiple-criteria decision-making

Network Analysis

Susceptibility mapping

Weighted overlay analysis

1. INTRODUCTION

1.1 Background

Flood is the overflow of water that submerges the dry land. Effects on the environment by humans increases the intensity and frequency of flooding. Overflow of water from water bodies such as rivers, lakes or ocean causes floods.

Types of flooding:

a) **Areal flooding:** The flood caused due to prolonged periods of rain is areal flooding. It occurs in flat areas like floodplains and in local depressions not connected to a stream channel.

b) **River flooding:** Floods occur in every type of river depending on the flow of water. Flash floods; rapid flooding often in small rivers can cause intense damage to human life and property.

c) **Coastal flooding:** Coastal flooding is caused when dry and low-lying land is submerged by sea water combining with high tides and large waves at sea.

d) **Urban flooding:** Flood caused by heavy rain and drainage systems, such as storm sewer (infrastructure designed to drain excess rain and ground water from paved streets).

e) **Intentional floods:** Floods are significant for various fields (agriculture, military, river-management purpose, hydraulic engineering). Eg. For agricultural purposes, floods are caused in preparing paddy fields for the growing of rice. In the military, flood is intended to impede the movement of the enemy.

1.1.1 Flood in context of Nepal

Flood is a common water induced disaster of monsoon season in Nepal. It is one of the most occurring and devastating disasters in Nepal. Several locations in Nepal are at high risk of flooding. These places require proper guidance on early warning and safe evacuation of people to emergency locations through optimal routes to minimize fatalities.

Weak geological formations, topography, active seismic conditions, concentrated monsoon rains and unscientific land utilization are some of the major reasons for flood in Nepal (DWIDP, 2013). Nepal is considered the second highest country at risk of floods in South Asia (UNDP, 2009). Between 1954 and 2018, floods in Nepal caused 7,599 deaths, affected

6.1 million people and caused economic losses of about 10.6 billion USD. On average, 100 people were killed annually (EMDAT, 2019).

Nepal lies in second highest country at risk of floods in South Asia (UNDP, 2009). Regular flooding, predominantly in the monsoon season, results in significant loss of life, property, and livelihoods (NCVST, 2009). According to Dilley et al. (2005), Nepal falls in 11th position on disaster vulnerability in the world and half of its population is under the threat of four types of disaster at a time including flood. The problem of flooding in certain plain areas in Nepal is very chronic. The majority of flood disasters' victims are poor people living in the floodplain. The expansion of urban areas and economic activities in floodplains is placing additional people and infrastructures at risk. Thus, resulting in changes in natural slope, river morphology and the drainage system, land use/land cover, the frequency in the occurrence of landslide and flood hazards, exacerbating the water induced disaster.

In Nepal, there are more than 6000 rivers and rivulets originating from the Himalayas that travel through the Hills and the Terai. So, river flooding is one of the most recurring, destructive and harmful disasters in Nepal. River flooding usually occurs from the month of June and lasts until the month of September.

Different approaches are used to develop maps of flood susceptible areas namely multi-criteria decision making (MCDM) methods, physically based hydrological models, statistical methods, and various soft computing methods. Among these various methods, MCDM is used in this project. MCDM is a process in which many criteria can be evaluated together and values can be assigned to alternatives in problems such as disasters. This method allows the best choice to be selected from more than one criterion applied at the same time for evaluating and prioritizing alternative decisions. This method is also applicable in case there exists criteria that cannot be expressed with a numerical value. Due to its simple structure, MCDM methods are widely used in flood susceptibility analysis (e.g Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Weighted Linear Combination (WLC), etc.

1.1.2 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process is a method for organizing and analyzing complex decisions, using math and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined since then. It contains 3 parts: the ultimate goal or problem we are trying to solve, all of the possible solutions, called alternatives and the criteria that we will judge the alternatives on. Pairwise comparison is done among two criteria at a time.

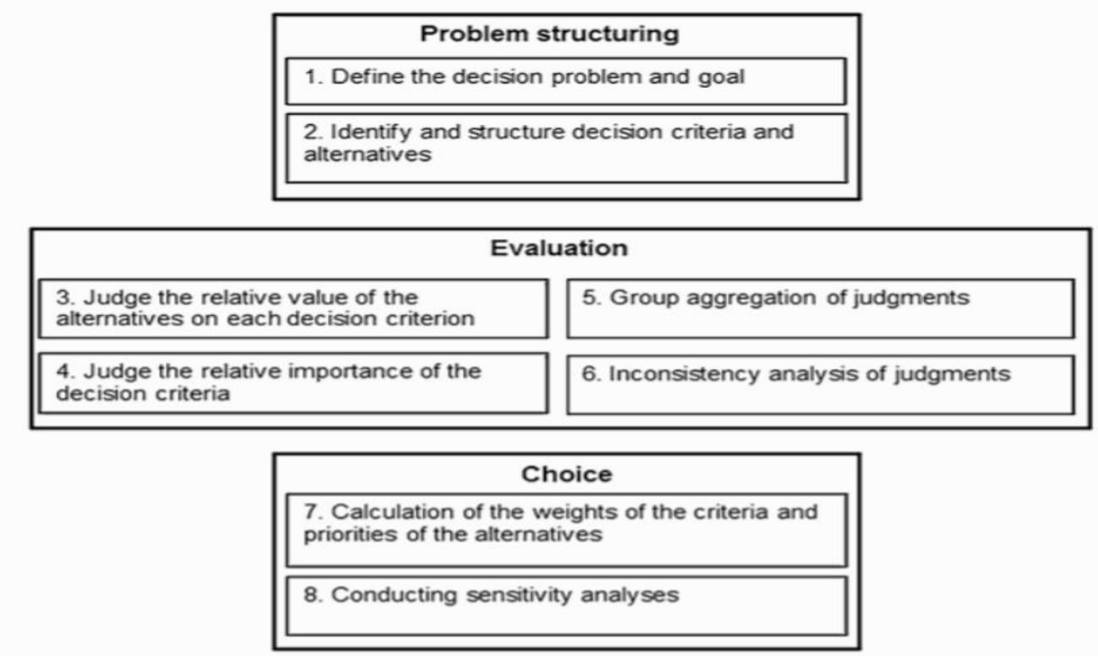

Figure 1-1 : Decision Making with AHP

AHP is most useful when finding decisions to complex problems with high stakes. It is mostly preferred as it quantifies criteria and options that are traditionally difficult to measure with numbers.

1.1.3 Network Analysis

Network analysis is the process of examining datasets from geographic or real-world networks. In order to comprehend the behavior of flows inside and around such networks, as well as locational analysis, network analysis looks at the characteristics of both natural and artificial networks. In order to simulate actual information networks, it focuses on edge-node topology. Its operation is predicated on the mathematical specializations of topology and graph theory.

Types of operation:

a. Shortest path analysis

b. Best Route

c. Closest facility
d. Allocation
e. Location-Allocation
f. OD-cost matrix
g. Network-partitioning

1.1.4 Closest Facility

Closest facility analysis in network analysis is a GIS operation that determines the nearest facilities to specified incident locations using a network dataset, such as roads. This process is essential for applications like emergency response, where quick identification of the nearest hospital or fire station can save lives. The analysis involves loading facility and incident data into a GIS software, setting travel parameters, and solving to generate optimal routes and distances.

1.2 Problem Statement

Despite advancements in technology, effective evacuation planning in flood-prone regions remains a critical challenge. Traditional evacuation route planning often lacks the precision and real-time adaptability necessary to ensure the safety of residents and minimize the impact of flooding events. This is particularly concerning as climate change exacerbates the frequency and intensity of flooding, necessitating more robust and dynamic strategies for evacuation.

Existing evacuation plans may not adequately account for evolving flood patterns, changing infrastructure, or the distribution of vulnerable populations. Furthermore, the lack of integration between GIS technologies and emergency management systems often leads to inefficient allocation of resources and delays in response efforts during flood emergencies.

Flood-prone areas lack well-defined and optimized evacuation routes, leading to confusion and delays during emergency evacuations. Current evacuation plans may not account for real-time flood conditions, dynamic changes in terrain, population density, and the availability of resources such as shelters and medical facilities. This project seeks to address these issues by developing a GIS- based system that can optimize evacuation routes tailored to the unique conditions of flood- susceptible areas.

To address these challenges, there is a pressing need for the development of a comprehensive GIS-based evacuation route planning system tailored specifically to flood-susceptible areas. Such a system would leverage spatial analysis, real-time data integration, and community engagement to optimize evacuation routes, identify safe shelter locations, and facilitate timely decision-making by emergency responders.

By harnessing the power of GIS technology, this proposed project aims to enhance the resilience of flood-prone communities by:

a) Providing accurate flood risk assessments based on spatial analysis of topographical, hydrological, and climatic data.
b) Dynamically mapping evacuation routes that account for changing flood extents, road conditions, and population distribution.

Through the implementation of this GIS-based evacuation route planning system, we seek to mitigate the impact of flooding events, reduce the loss of life and property, and enhance the overall resilience of flood-prone communities.

1.3 Objectives

The primary objective of this project is:

a) To prepare map of flood susceptible area and identify evacuation route in Helambu Rural Municipality of Sindhupalchok district, Nepal.

The secondary objectives of this project are:

a) To determine open spaces, assembly points within the study area for the flooding time.
b) To create evacuation routes based on existing data such as road.

1.4 Scope of the study

It can assist government and private sectors in disaster prevention planning and mitigation measures. It helps to reduce the number of lives affected during flooding. It warns the people to restrict development activities in the flood prone zone. It offers a promising solution to enhance safety and evacuations in Helambu Rural Municipality. It provides a tool for emergency planners and responders.

2. LITERATURE REVIEW

The utilization of GIS for flood mapping is conducted in different parts of the world. Numerous research efforts have been conducted in the past to develop new approaches for flood prediction and flood rescue using GIS. To pinpoint suitable evacuation areas and routes in flood-prone regions, it is crucial to integrate various spatial data, including topography, land use, hydrology, and transportation networks. The identification of flood triggering factors becomes a crucial component of flood hazard assessment. Using GIS for such an identification process offers a comprehensive and objective view of the risk posed by these factors, allowing for a more accurate hazard evaluation. Flood hazard mapping is vital for evacuation planning in flood-prone regions. Extensive research utilizes GIS and remote sensing to identify, analyze, and map flood-vulnerable areas and susceptible communities. This is primarily achieved by applying the identified flood triggering factors onto the topographic and hydrologic data, allowing for a visualization of potential flood zones. A common approach to evacuation planning that has been regularly explored is that of simulations using geo-spatial technology. A spatial decision support system (SDSS) was designed to assist in contingency planning. Its primary purpose was to interactively produce alternative routing for different contingencies. While important such systems are essentially after the fact models.

Within crisis management, emergency management applies geo-information technologies in the crisis management process and Geographical Information Systems (GIS) have been used for over 20 years. Examples for GIS utilization in natural and man-made disasters are to support flood mapping, hurricane prediction, and environmental clean-ups after industrial accidents. In most crisis situations, GIS operators receive their orders via staff members who are asked by the decision makers to inquire about maps. The GIS specialists usually react to mapping and spatial analysis requests from decision makers, e.g. after the World Trade Center attack GIS specialists, supported by company consultants, were operating Geographic Information Systems and producing maps on demand and, after Hurricane Katrina, GIS experts from Louisiana State University provided support to evacuation and relief efforts. In larger communities, state and federal agencies GIS operations have become an integral part of Emergency Operation Centers (EOCs), but in some instances, e.g. smaller and/or rural communities, special GIS operators might not be available or are not part of the Emergency Operation Center staff. Evacuation is a process in which threatened people are transferred from the incident place to a safer place to protect their lives. It is a very complex process, besides needing to be accurate and careful; it must be done very quickly. GIS plays an important role in emergency management in general and in evacuation planning in particular. In 200, GIS was prominently used in the rescue, relief and recovery process after the World Trade Center attack. Although New York City's Emergency Operation Center and GIS infrastructure was destroyed, city officials were able to set up a backup facility and use GIS to produce maps for emergency response purposes by the evening of 9/11. (Shaker et al., 2012).In recent years, AHP has been used as an important tool in various research in Vietnam as well as in various other countries to evaluate and zone flood hazards. In Vietnam, (Tú et al., 2013) conducted flood hazard zone mapping in the Vu Gia River basin using AHP and GIS and (Phuong et al., 2015) applied the same strategy to construct a flood hazard zone map on the Huong River basin, Dung et al. (2020b) assessed the role of relative slope length in flood hazard mapping using AHP and GIS, Dung et al. (2021c) evaluated the vulnerability in 3 agricultural land in flood-prone areas based on flood hazard zone map. The research used five parameters to compute the model such as slope, soil, rainfall, land cover, and drainage density. AHP and GIS integration methodology is widely applied throughout the globe by various researchers (Fernández et al., 2010) to map the flood hazard zones in their respective study areas. AHP is widely used in the evaluation of multiple criteria and goals in problems characterized by their complexity and subjectivity. This is entirely consistent with the objective of flood research, a natural phenomenon affected by many factors. According to Saaty (2008), the application of AHP comprises the following stages: the structuring of criteria and alternatives; collecting judgments; calculating priorities; checking the consistency of judgments; and lastly, calculating the overall priorities of the alternatives.

A proper evacuation location requires several parameters, such as distance from settlements, roads, river flow, and safety from flood hazards. Previous studies conducted by Coutinho-Rogers verified that the relationship between time and distance to the evacuation site on foot is influenced by several factors such as road width, type of paving, slope conditions, and pedestrian speed up to a specific limit. In addition to the distance factor, the condition of the evacuation site must also be in good condition or proper condition by considering the minimum space required by each person. Each person (individual) requires at least 1.64 m^2 of space. The condition of the building and the area of land used for the location becomes a reference to determine a proper evacuation site by calculating the building area divided by the space requirements of each person to determine the maximum capacity and feasibility of the evacuation site conditions .

3. METHODOLOGY

3.1 Theoretical Framework

Helambu rural municipality is prone to flood and landslides due to its geographical location. The flood is mainly caused by the excess rain in Melamchi river in Helambu rural Municipality. There is no proper evacuation route during the flood. Hundreds of families are currently residing either nearby the river or in a temporary residence. The local government has no solid plan to move them to safe and permanent residence. The concept behind choosing the Helambu rural municipality is that it is highly prone to flood and there are no proper evacuation routes until now. Hundreds of houses are displaced every year and still there is no temporary shelter for the affected families.

3.2 Study Area

As part of this project, the Helambu Rural Municipality was chosen as the study location for Evacuation Route Planning in Flood-Susceptible Area. Helambu Rural Municipality is located in the Sindhupalchok District of Bagmati Province in Nepal. Geographically, it lies

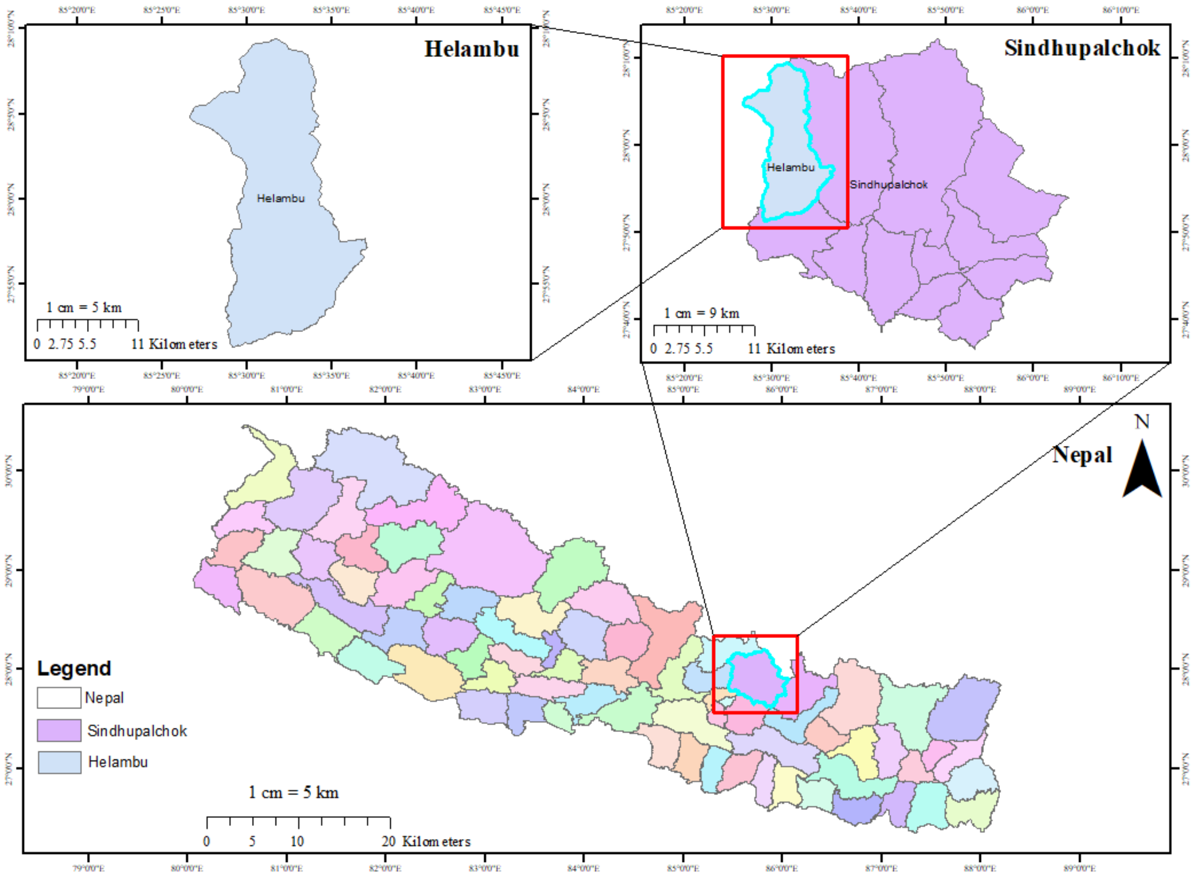

Figure 3-1 : Study Area

28° 14 '52"N and 85° 33' 20"E with an area of 287.26 square kilometers. It borders Rasuwa District to the North and Nuwakot District to the West. Helambu Rural Municipality extends from about 1000 meters above sea level to 5000 meters. Located at a distance of about 80 km from Kathmandu, the capital of Nepal, the terrain of this region is predominantly hilly and mountainous, characterized by deep gorges, steep slopes, and high peaks. It also includes parts of the Langtang National Park and is a gateway to the Langtang region. The climate varies with altitude, ranging from subtropical in the lower regions to alpine and arctic in the higher altitudes. The area experiences a monsoon season from June to September, with significant rainfall, and a dry season from October to May. Several rivers and streams flow through Helambu, including the Melamchi River, which is a major source of water and the major cause of flood for the region. According to the data obtained from the Nepal Disaster Risk Reduction Portal, there is frequent flood in Sindhupalchowk district and out of all the municipalities, Helambu is mostly affected where there are no proper evacuation routes.

3.3 Study Method

The entire process was divided into two parts. The first phase involved creating flood susceptibility maps using the AHP weighted overlay technique. The second phase focused on using network analysis to create the safest and shortest evacuation route from risk zone to safe zone.

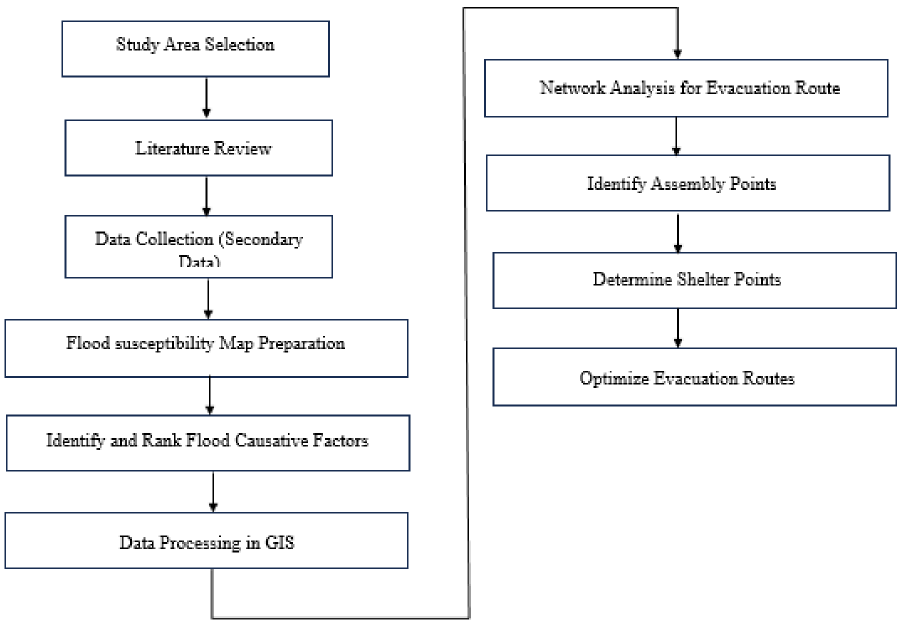

Figure 3-2 : Main Flowchart

3.3.1 Flood Susceptible Map Preparation

For the selection of flood susceptibility areas certain criteria are chosen and the data are collected from different sources. The primary and secondary data are collected from the different websites. The Multi-Criteria Decision Method (MCDM) process was performed in order to determine the flood causative factors analyzing a series of alternatives with a view to ranking them from the most preferable to the least preferable Topographic Wetness Index (TWI), Slope (S), Elevation (E), Precipitation(P), LULC, Distance from Road (DRo), Distance from Rivers (DRi), Drainage Density (DD). These parameters have been manipulated in GIS with new categorized classes into five risk levels namely very low, low, medium, high, and very high-risk zones of the flood. The importance of the physical parameters is assigned values on a scale ranging from 1 to 9 as rating scores. Next, the rating scores have been used in the calculation of the relative significance of each criterion as a pairwise matrix comparison to produce corresponding weighting factors(Seejata, n.d.) .

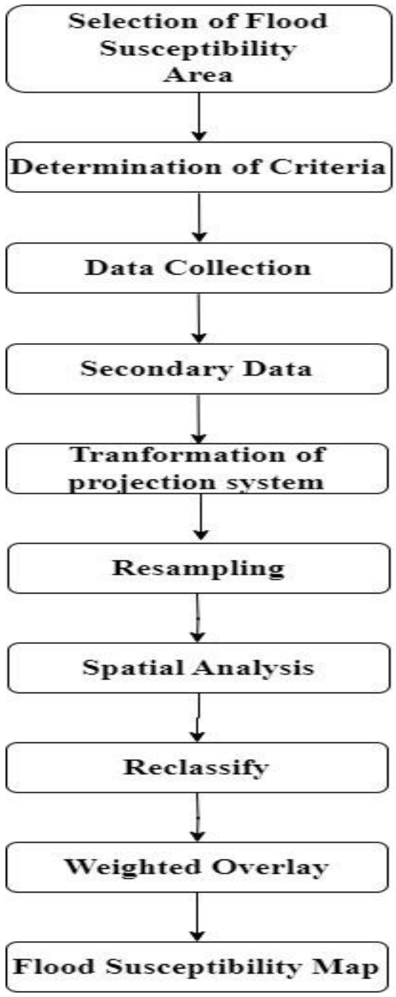

Figure 3-3 : Flood Susceptible Flowchart

3.3.2 Data and Sources

In this study, various thematic layers were created based on open-source data. Data was projected into the same projection system and unnecessary data was removed. The area of interest was kept into account. Flood susceptibility maps were created using open-source spatial data and secondary information from various sources, including local administration. For this project data of Topographic Wetness Index (TWI), Slope (S), Elevation (E), Precipitation(P), LULC, Distance from Road (DRo), Distance from Rivers (DRi), Drainage Density (DD) was taken. The data was collected through different websites. The various data sources that were used along with their sources are listed below:

S.No	Types of Data	Description	Source
1	Road networks	Road Network in Helambu	https://data.humdata.org/dataset/nepal-road-network
2	River	River Network in Helambu	https://admin.nationalgeoportal.gov.np/layers/geonode:Hydrography_Line_1_1000K
3	Rainfall	Government of Nepal, Department of Hydrology and Meteorology	https://www.dhm.gov.np/meteorology-forecast/3
4	LULC	Sentinel-2 10m	https://www.esri.com/partners/impact-observatory-a2T5x0000084pJXEAY/sentinel-2-10m-land--a2d5x000005jw9NAAQ
5	DEM	Alos Palsar 12.5m	https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/alos/

Table 1 : Source of data

3.3.3 Analytical Hierarchy Process (AHP)

AHP, which stands for Analytic Hierarchy Process, is a critical decision-making approach with applications in a variety of industries, including business, banking, education, politics, and engineering. Saaty first developed it in 1980 as a multicriteria decision-making method, drawing inspiration from Myers and Alpert's 1968 work, and it has since become one of the most widely used approaches in this field . The AHP is extremely adaptable, allowing for the consideration of both quantitative and qualitative factors in decision-making while taking into account the priorities of the user or group implementing the model(Waseem et al., 2023).

The AHP converts the comparison matrix into a priority vector and calculates a consistency ratio by assigning an arbitrary index value. The highest level in the hierarchy represents the decision's final state, followed by its criteria, and finally the least preferred options at the lowest level. Decisions can be made at the bottom of the hierarchy. To ensure consistent pairwise comparisons, the total number of criteria as well as each discrete criterion must be accurately defined. Similar criteria should be grouped together to allow for a meaningful interpretation. AHP can be used with a variety of criteria, and after the hierarchy is established, it compares the five criteria to determine their relative importance. An AHP pairwise comparison matrix was used to calculate the relative weights of the relevant components. As the criteria are prioritized, their relative weights are determined. There is a relative importance scale that ranges from 1 to 9, with 9 representing the most significant component.

The pairwise comparison matrix indicated in the following equation (Eq. 1) theoretically revealed the weighting coefficients of the stated flood risk components in the AHP approach.

$$\boldsymbol{A} = [\boldsymbol{a_{ij}}] \begin{pmatrix} 1 & \boldsymbol{a_{ij}} \ldots & \boldsymbol{a_{1n}} \\ {}^{1}/\boldsymbol{a_{ij}} & 1 & \boldsymbol{a_{2n}} \\ {}^{1}/\boldsymbol{a_{1n}} & {}^{1}/\boldsymbol{a_{2n}} & 1 \end{pmatrix}$$

Equation 1 : AHP Matrix

Cat		Priority	Rank
1	Elevation	10.4%	4
2	Slope	7.8%	6
3	Precipitation	16.2%	2
4	Distance From River	21.6%	1
5	Drainage Density	16.1%	3
6	Topographic Wetness Index	10.2%	5
7	Land Use Land Cover	7.0%	7
8	Ndvi	6.2%	8
9	Distance from road	4.5%	9

	1	2	3	4	5	6	7	8	9
1	1	2.00	0.33	0.33	1.00	1.00	2.00	2.00	3.00
2	0.50	1	0.50	0.33	0.33	2.00	1.00	2.00	1.00
3	3.00	2.00	1	0.50	1.00	1.00	3.00	3.00	5.00
4	3.00	3.00	2.00	1	1.00	3.00	3.00	3.00	5.00
5	1.00	3.00	1.00	1.00	1	3.00	2.00	4.00	1.00
6	1.00	0.50	1.00	0.33	0.33	1	1.00	1.00	8.00
7	0.50	1.00	0.33	0.33	0.50	1.00	1	1.00	3.00
8	0.50	0.50	0.33	0.33	0.25	1.00	1.00	1	3.00
9	0.33	1.00	0.20	0.20	1.00	0.12	0.33	0.33	1

Table 2 : AHP Calculation

The scale of Relative Importance in the Analytic Hierarchy Process (AHP) is utilized to allocate weights or priorities to various criteria or factors, considering their respective significance or preference, to support decision-making processes. The decision matrix in AHP is a tool to compare alternatives based on criteria and determine their relative importance. The pairwise assessment matrix 9×9 with diagonal elements equal to 1. Members of parliament must first prioritize their major criteria by evaluating them in pairs for relative importance, resulting in a pairwise comparison matrix .These are the pair wise comparison matrix and the resulting matrix.

3.3.4 Flood Susceptibility Evaluation and Flood Conditioning Factors

Nine different parameters based on literature review and their relevance to flood susceptibility: Topographic Wetness Index (TWI), slope, elevation, precipitation, land use/land cover, distance from a road, distance from rivers, drainage density, and Normalized Difference Vegetation Index (NDVI). In addition, all these factors were categorized into five different classes on a scale of 1 to 5 where 1 refers to very low flood risk while 5 refers to very high flood risk. The Susceptibility class ranges and ratings ,weight are shown in table 3.

Flood Causative Criterion	Unit	Class	Susceptibility Class Ranges and Ratings	Susceptibility Class Ratings	Weight(%)
Elevation	meter	881-1831	Very High	5	10.4
		1831-2617	High	4	
		2617-3507	Moderate	3	
		3507-4430	Low	2	
		4430-5783	Very Low	1	
Slope	%	0-6.27	Very High	5	7.8
		6.27-10.58	High	4	
		10.58-16.07	Moderate	3	
		16.07-26.27	Low	2	
		26.27	Very Low	1	
Drainage Density	m/km	0-0.580	Very Low	1	16.1
		0.580-1.851	Low	2	
		1.851-3.261	Moderate	3	
		3.261-4.698	High	4	
		4.698-7.0481	Very High	5	
Land Use Land Cover	Level	Water	Very High	5	7
		Trees	High	4	
		Built Up	Moderate	3	
		Rangeland	Low	2	
		Crops	Very Low	1	
Normalized Difference Vegetation Index	Level	-0.1222-0.0665	Very High	5	6.2
		0.0665-0.1554	High	4	
		0.1554-0.2748	Moderate	3	
		0.2748-0.3832	Low	2	
		0.3832-0.5859	Very Low	1	
Precipitation	mm/year	319.180-319.362	Very Low	1	16.2

		319.362-319.548	Low	2	
		319.548-319.737	Moderate	3	
		319.737-319.912	High	4	
		319.912-320.091	Very High	5	
Distance From River	meter	0-354.80	Very High	5	10.4
		354.80-743.94	High	4	
		743.99-1167.42	Moderate	3	
		1167.42-1728.2	Low	2	
		51728.252-2918.572	Very Low	1	
Distance From Road	m	0-1471.812	Very High	5	4.5
		1471.812-4074.014	High	4	
		4074.014-6672.216	Moderate	3	
		6672.216-9076.177	Low	2	
		9076.177-12510.40	Very Low	1	
Topographic Wetness Index	Level	0.663-4.198	Very Low	1	10.2
		4.198-5.649	Low	2	
		5.649-7.552	Moderate	3	
		7.552-11.088	High	4	
		11.088-23.779	Very High	5	

Table 3 : Susceptibility Class Ranges and Rating

a. **Slope:** Slope has a significant impact on flood formation and distribution. It is an indicator describing the sensitivity of the region to flooding. The higher the slope, the higher the runoff velocity in those areas, which makes the area that has a lower slope accumulate a large volume of water making it highly susceptible to flood.

b. **Elevation/ DEM:** The elevation is the height above or below certain reference points such as sea level, benchmarks, etc. Topographical data like slope, SPI, aspect, TWI, etc., can be derived from DEM. Elevation can be derived from DEM as well as from height data in DEM. The data are effective factors both in the establishment of the hydrological model and in the strength and development of floods and their impact on land cover. elevation has an inverse relation with the flood as lower elevation is highly prone to flood and vice-versa.

c. **Topographic Wetness Index:** It represents the specific location of surface saturation and spatial distribution of soil water and quantifies the effect of local topography on runoff generation. When the saturation level increases, the level of groundwater rises, creating a condition for flooding. So, a higher TWI increases the chance of the area being flooded. The TWI in this area is computed from DEM using Equation (1) and spatial analyst tools in ArcGIS Software.

$$\text{TWI} = \ln\left(\frac{\alpha}{\tan\beta}\right).$$

Equation 2 : Topographic Wetness Index

where α is the specific catchment area

β is the local slope.

d. **Precipitation:** It is one of the major causes of river flooding when there is excess of water in the river. The intensity and duration of the precipitation, as well as the amount of precipitation, are also effective for the development of the flood and flood duration, its area of influence, and possible damages to occur in the region. Higher precipitation causes higher runoff in the region, which makes it highly susceptible to flood.

e. **Land use/ Land cover:** Land use refers to the use of the basin, such as settlement, industry, and agriculture, which are shaped by socio economic activities. Land cover expresses the physical and biological conditions (forests, arid areas, water bodies, etc.) that make up the nature of the basin. LULC data cover the environmental impacts of anthropogenic activities and the full distribution of natural cover (Waleed & Sajjad 2022).

f. **Distance from River:** The spread of the flood in the basin is related to the distance of the location to the drainage system (Elkhrachy *et al.,* 2015). While less flooding occurs in areas far from the drainage system, it occurs more in closer areas (Samanta *et al.,* 2018). In this respect, drainage network density is one of the important parameters for flood sensitivity analysis. The river network was obtained from OpenStreetMap. Distance from each river was found using the Euclidean function in the ArcGIS environment.

g. River Network Density/ Drainage density: Drainage density demonstrates the nature of the ground and its geotechnical features. It refers to the ratio of the total drainage channel to the area of the basin. When the drainage density of an area is high, the water accumulation in this area is high which makes it more susceptible to flood.

h. Distance from Road: The data for the road network for Nepal was extracted from OSM. Then, the data required for our study area was clipped. The euclidean distance was then calculated. Euclidean Distance tool from the Spatial Analyst toolbox is used to calculate the straight-line distance from each cell to the nearest source.

i. Normalized Difference Vegetation Index: It quantifies the vegetation characteristics in an area by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) as in Equation (2). The value ranges from −1 to +1 and the value near +1 represents vegetation which acts as a defense to flood.

$$\text{NDVI} = \frac{(NIR - R)}{(NIR + R)}$$

Equation 3 : Normalized Difference Vegetation Index

where NIR = Near Infra-Red values

R = Visible (red) values.

3.3.5 Network Analysis

Network analysis is a tool and operation in GIS that analyzes the datasets of geographic networks or real-world networks. Network analysis inspects the properties of natural and man-made networks to comprehend the way of behavior of flows within and around such networks and locational analysis. It centers on the edge-node topology to address real-life networks of information. Its function is based on the mathematical sub disciplines of graph theory and topology.

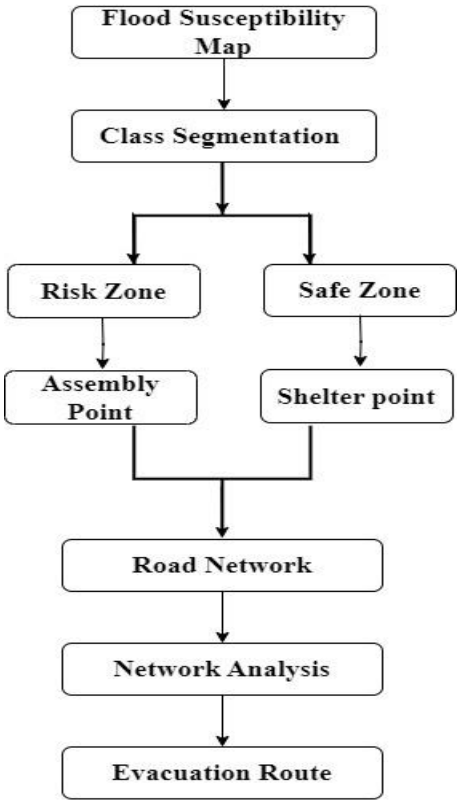

Figure 3-4 : Network Analysis flowchart

Criteria for Assembly Point:

a. It can be any road junction which is safe for immediate gathering.
b. It must be viable at the safest range from the buildings.

Criteria for Open Space:

a. Land must be governmental such as schools ground, public parks, etc.
b. Space must be risk-free from flood, landslide, etc.
c. Space must be close to the settlements.
d. Space must have facilities of water supply, electricity, etc.

3.3.6 Evacuation Route Planning

The prime objective of the project is to safely evacuate residents of Helambu Rural Municipality during the time of flood emergency. The evacuation route planning involves three spatial data i.e. assembly point, evacuation route, shelter point.

3.3.7 Determination of Assembly Points:

The assembly point should be in the shortest distance where people can gather before evacuating to the shelter point. Assembly points were determined on the basis of the location having higher population density; the higher population density was considered to be the location with a greater number of buildings whose data was extracted from Open Street Map (OSM).

3.3.8 Determination of Shelter Points:

Shelter point refers to any safe space that people can reside in after evacuation from the assembly point. Any public buildings are assigned as the emergency shelter point. Government offices, schools, colleges, sports centers, etc. were identified and digitized to obtain location of these places and a safe zone was declared.

3.3.9 Evacuation Route:

The route is chosen such that a person in an emergency reaches the assembly point by the shortest route possible. Road network datasets were downloaded from OSM and used for the analysis. It ensured that the road network was connected to one another.

To perform network analysis in a GIS program, we followed these basic steps. This section outlines the general procedure for analyzing and solving network problems:

a. Organizing the Network Analysis Settings

In any GIS system, like ArcGIS, we need to enable the Network Analysis extension. We also need to display the Network Analysis toolbar before you can perform any analysis.

b. Creating the Network Analysis Layer

Layers contain an in-memory class where inputs, properties, and results can be stored. In the case of performing network analysis, the layer has to be connected to a network dataset. This layer had to be created and added to the dataset before the analysis can was performed. In ArcMap, a network dataset was first added so that when an analysis layer is created, Network Analyst could bind the analysis layer to the network dataset. The six kinds of network analysis layers in ArcGIS include: route analysis layer, closest facility analysis layer, service area analysis layer, OD cost matrix analysis layer, vehicle routing problem analysis layer, and location-allocation analysis layer.

c. Inputting Network Analysis Features and Records

This step had us add features, or objects, to our dataset input. Network analysis objects are features and records used as input and output during network analysis. These objects can include barriers, routes, facilities, or other man-made structures that will influence the end analysis. When you add these objects, setting the properties for the network analysis layer will further define the function of the input.

d. Performing the Analysis

After we had finished the other steps of the procedure and created your layer, it was time to perform the network analysis. This was done by clicking the Solve button on the Network

Analysis toolbar that we set up earlier in the process. The results were then displayed on the map and double-clicked the network analysis objects in the Network Analysis.

3.3.10 Software Used

For a GIS-based evacuation route planning project in Helambu Rural Municipality, Sindhupalchok, Nepal. The software used for project are listed below in table 4.

S.No	**Software**	**Description**
1	ArcGIS	A comprehensive GIS platform with tools for spatial analysis, network analysis, data visualization, and map creation.
2	Microsoft package	MS-Word, Excel, Power-Point were also used to interpret our result among all.

Table 4 : Software Used

4. RESULTS

4.1 Flood Susceptibility Mapping

The nine factors that were taken into consideration and categorized into five classes depending upon their range of values. Weightage value of each parameter was computed. The distance from river and precipitation were of high importance as these two parameters are majorly responsible for flooding in Helambu.

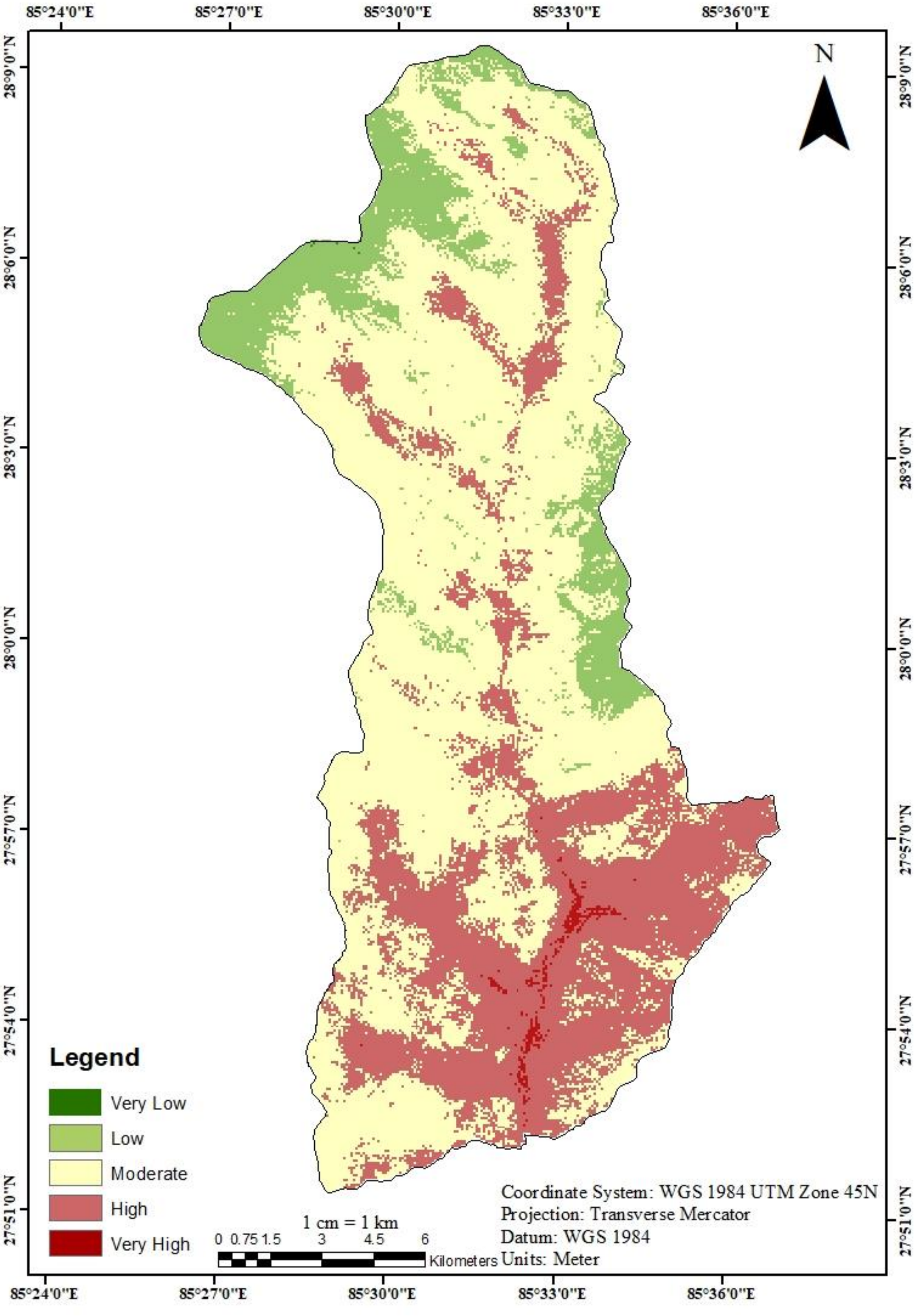

Figure 4-1 : Flood Susceptible Map

The figure above shows the flood susceptibility map that was generated. The area coverage and percentage are shown in the table 5:

S.No	Flood Susceptibility	Area (km^2)	Area (%)
1	Very Low	0.029318	0.010
2	Low	32.42568	11.28
3	Medium	169.4872	58.55
4	High	82.23692	28.31
5	Very High	1.617375	1.85
	Total	**285.7964**	**100**

Table 5 : Flood Susceptibility Area

4.2 GIS Layer Map Preparation

a. Elevation:

A point or object's elevation is its height with respect to a fixed reference point, usually sea level.

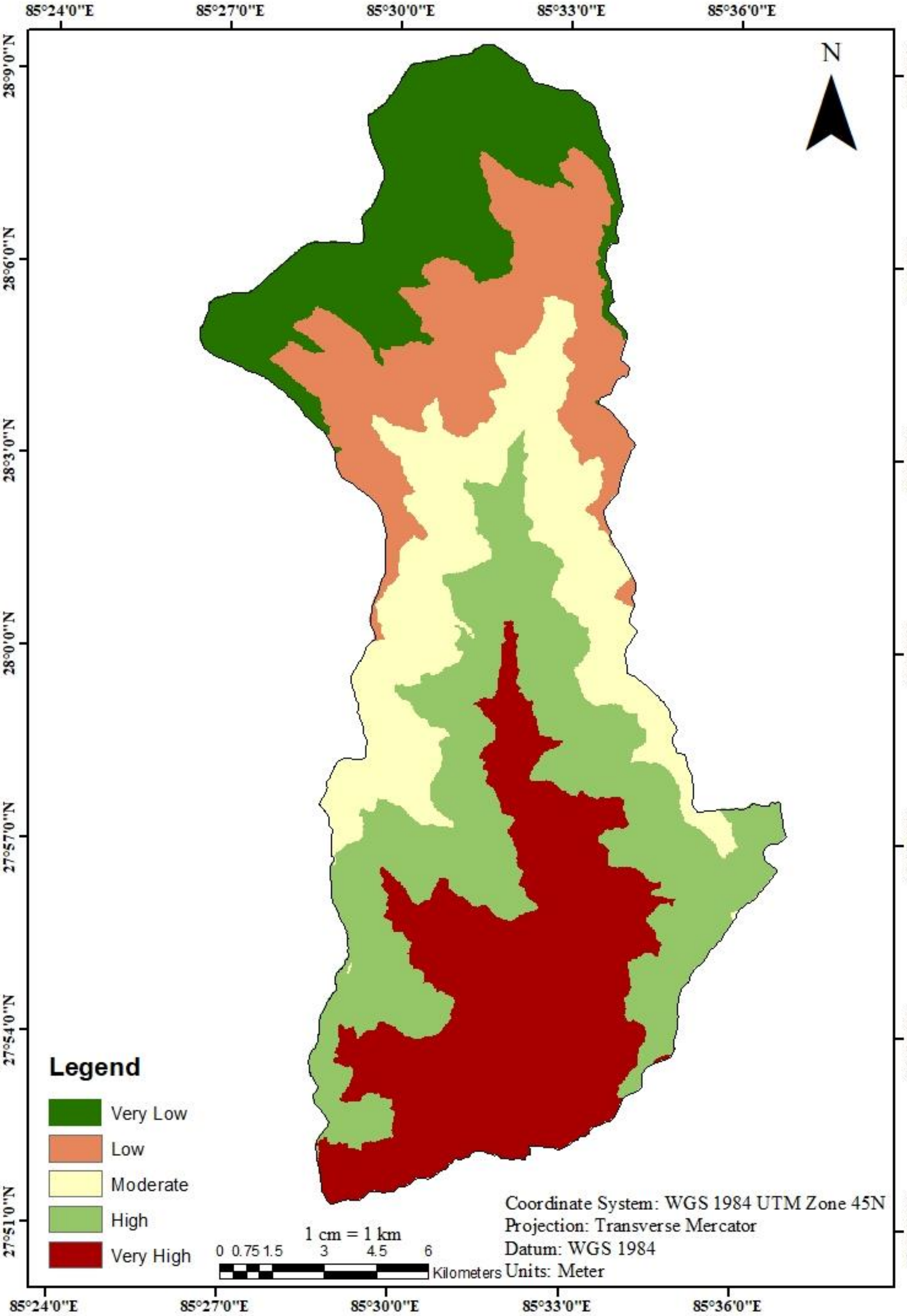

Figure 4-2 : Elevation Map

b. Slope

Slope in ArcGIS is calculated by examining the rate at which elevation changes over a surface. Slope was calculated from the dem using the Slope Tool in the Spatial Analyst toolbox. Slope shows the steep the terrain is. Low-sloped areas (low lands) are more likely to flood due to the accumulation of large volumes of water, resulting in severe floods.

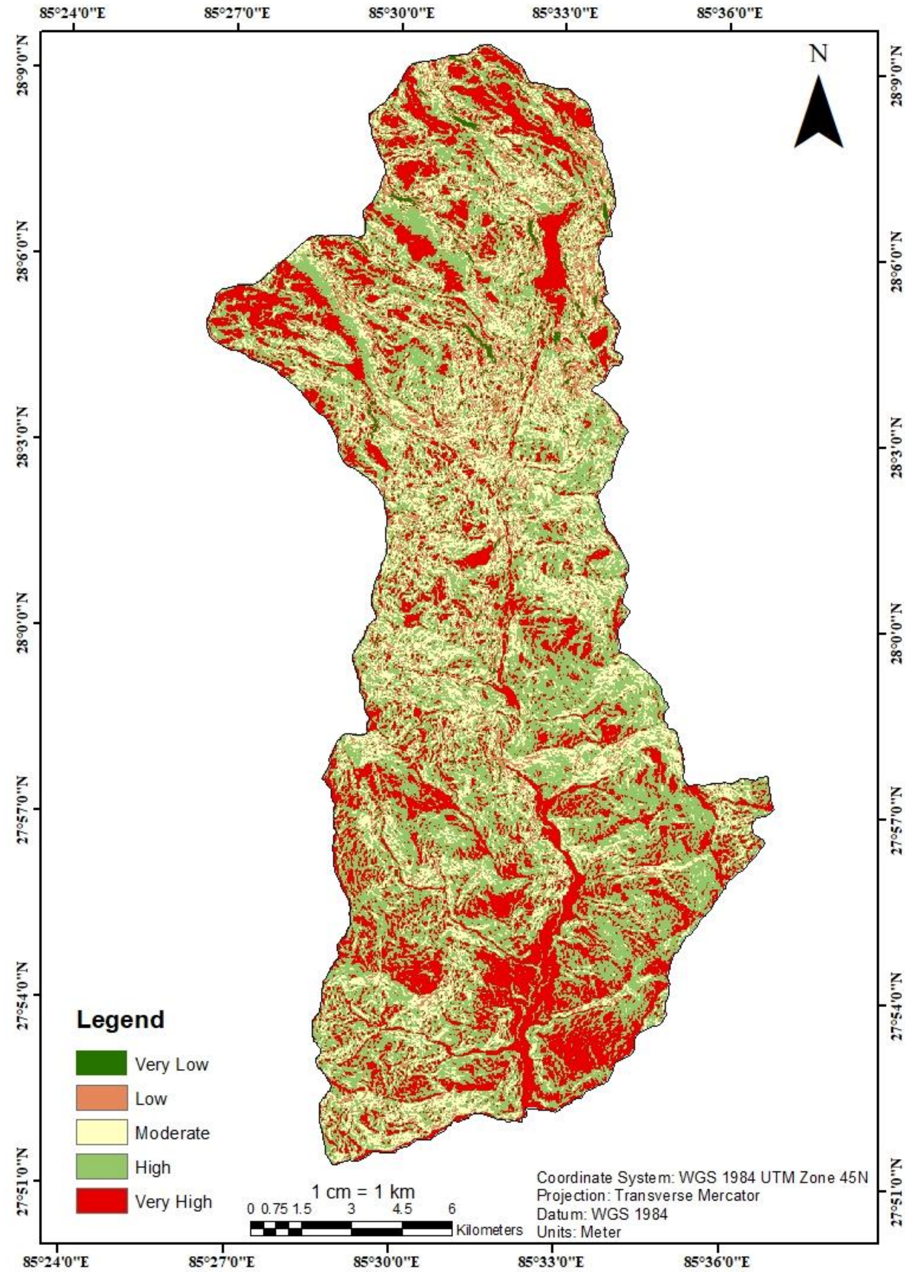

Figure 4-3 : Slope Map Map

c. Topographic Wetness Index

In hydrology and environmental research, the Topographic Wetness Index (TWI) is a commonly used metric to evaluate the impact of topography on the distribution and quantity of moisture in a landscape. To determine how water collects in a specific region, impacting soil moisture, plant patterns, and the chance of saturation, it combines the local slope and the upstream contributing area. Higher the topographic wetness index higher is the flood risk and lower the wetness index lower is the flood risk.

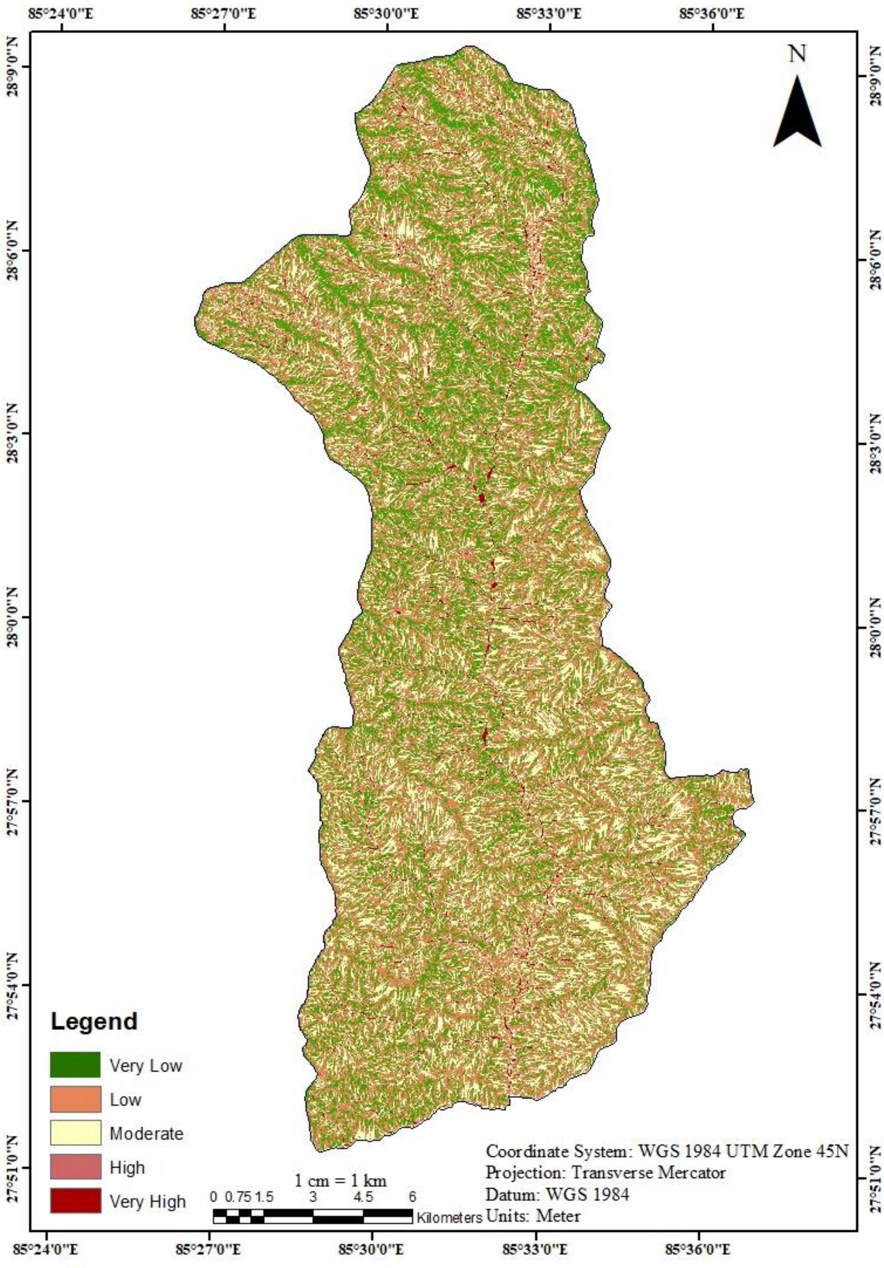

Figure 4-4 : Topographic Wetness Index Map

d. Drainage Density

The total length of the channels per unit area is the drainage density. The effectiveness of water transportation over the landscape is correlated with drainage density. Flood risk increases with increasing drainage density and decreases with decreasing drainage density.

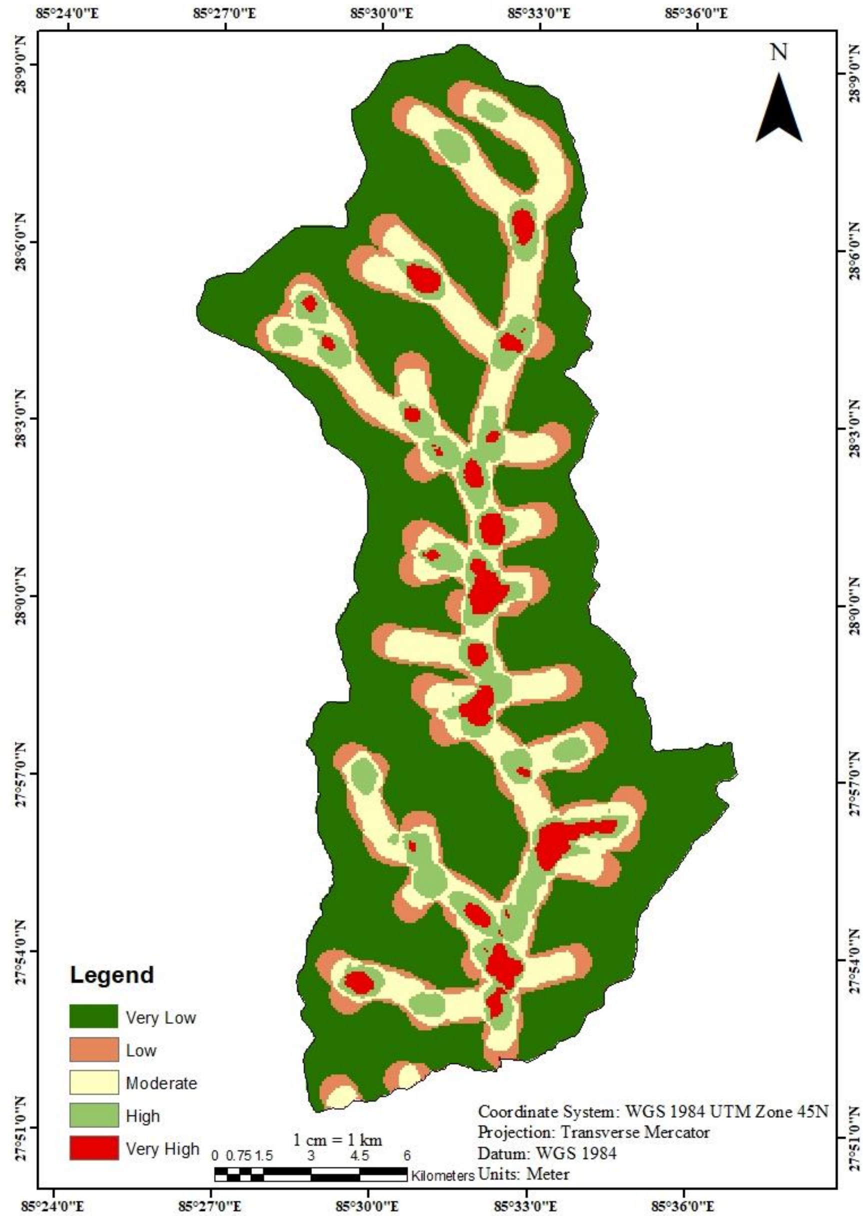

Figure 4-5 : Drainage Density Map

e. Land Use Land Cover

Land cover is typically defined as ground surface coverage such as woods, farms, villages, urban infrastructures, water, grass, barren soils, rocks, snow, or other. Supervised Classification was done on sentinel 2 imagery on GIS software. Five classes were defined for the classification namely waterbodies, tress, rangeland, built-up areas and crops.

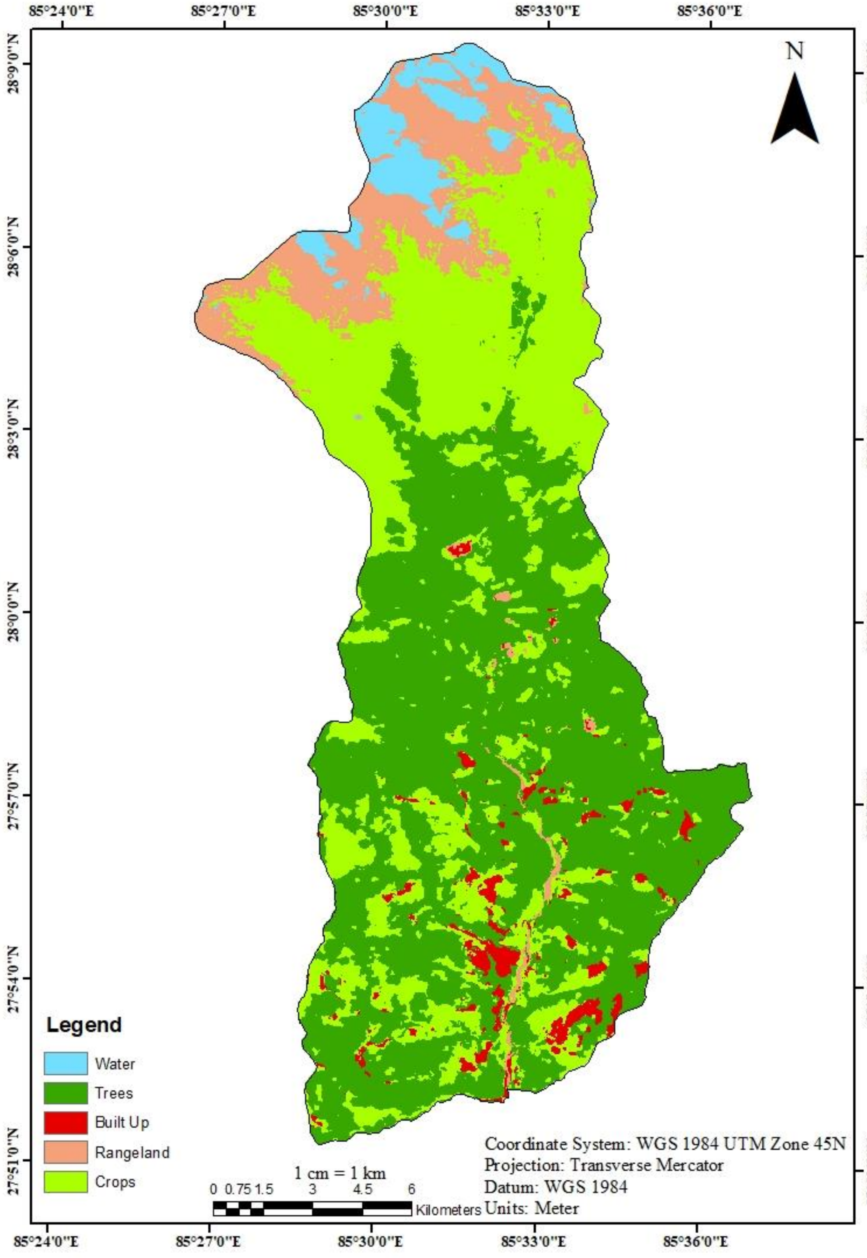

Figure 4-6 : Land Use Land Cover Map

f. Normalized Difference Vegetation Index

By measuring the difference between red light, which plant absorbs, and near-infrared, which vegetation strongly reflects, the NDVI measures vegetation. Higher greenness levels suggest a lesser danger of flooding, whereas lower NDVI values indicate a higher risk of flooding. The NDVI value measures the vegetation's greenness.

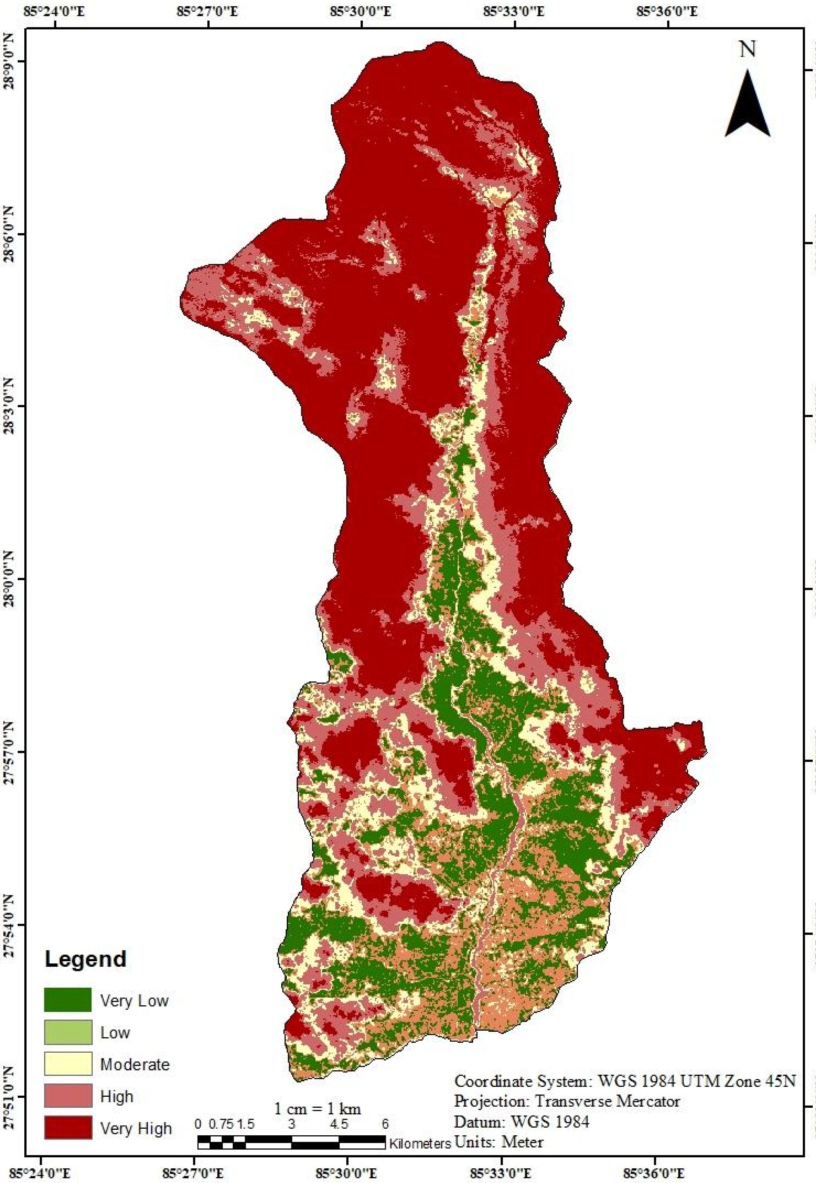

Figure 4-7 : Normalized Difference Vegetation Index Map

g. Precipitation

Precipitation is any liquid or frozen water that forms in the atmosphere and falls back to the Earth. Annual rainfall data from 2013 to 2023 of two rainfall stations “Sarmathan” and “Tarke Jhyang” were used to create the precipitation map of the study area. Higher the precipitation, higher the risk of flood and vice versa.

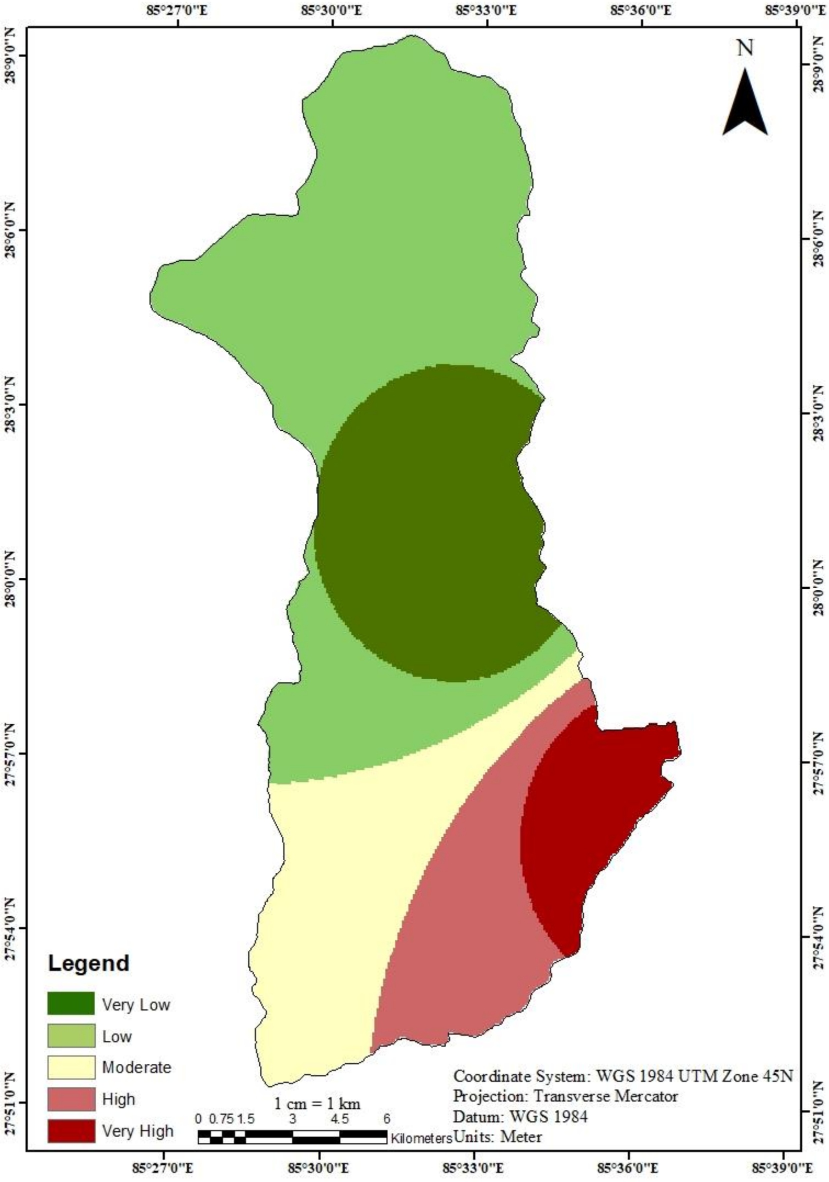

Figure 4-8 : Precipitaion Map

h. Distance from River

The Euclidean Distance function in the Arc Toolbox of GIS software was used to compute the distance between each pixel and the river. Area close to rivers are more likely to flood, whereas areas farther away from rivers are less likely to flood.

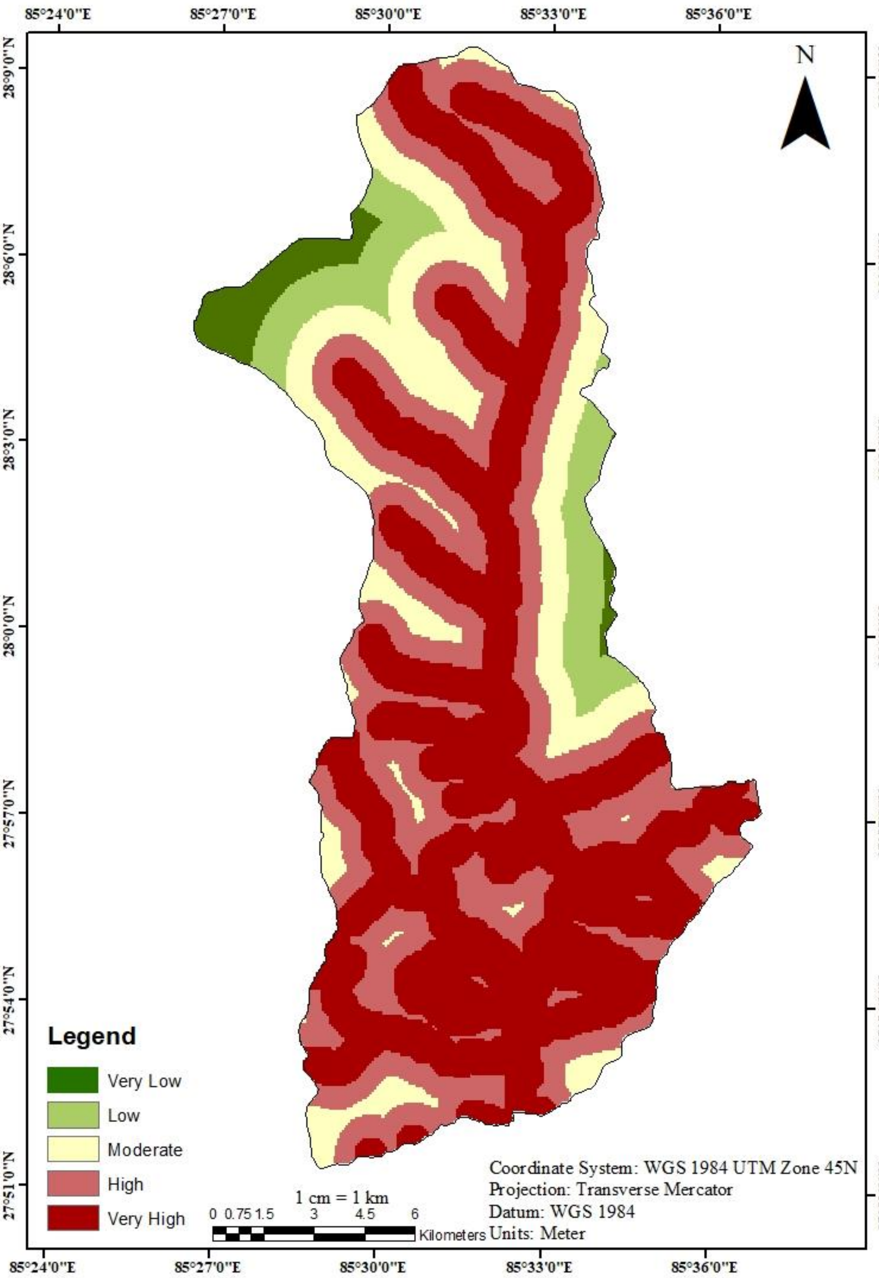

Figure 4-9 : Distance From River Map

i. Distance from Road

The Euclidean Distance function in the Arc Toolbox of GIS software was used to compute the distance between each pixel and the road. The distance from the road contributes to the flooding. Area close to roads are more likely to flood, whereas areas farther away from roads are less likely to flood.

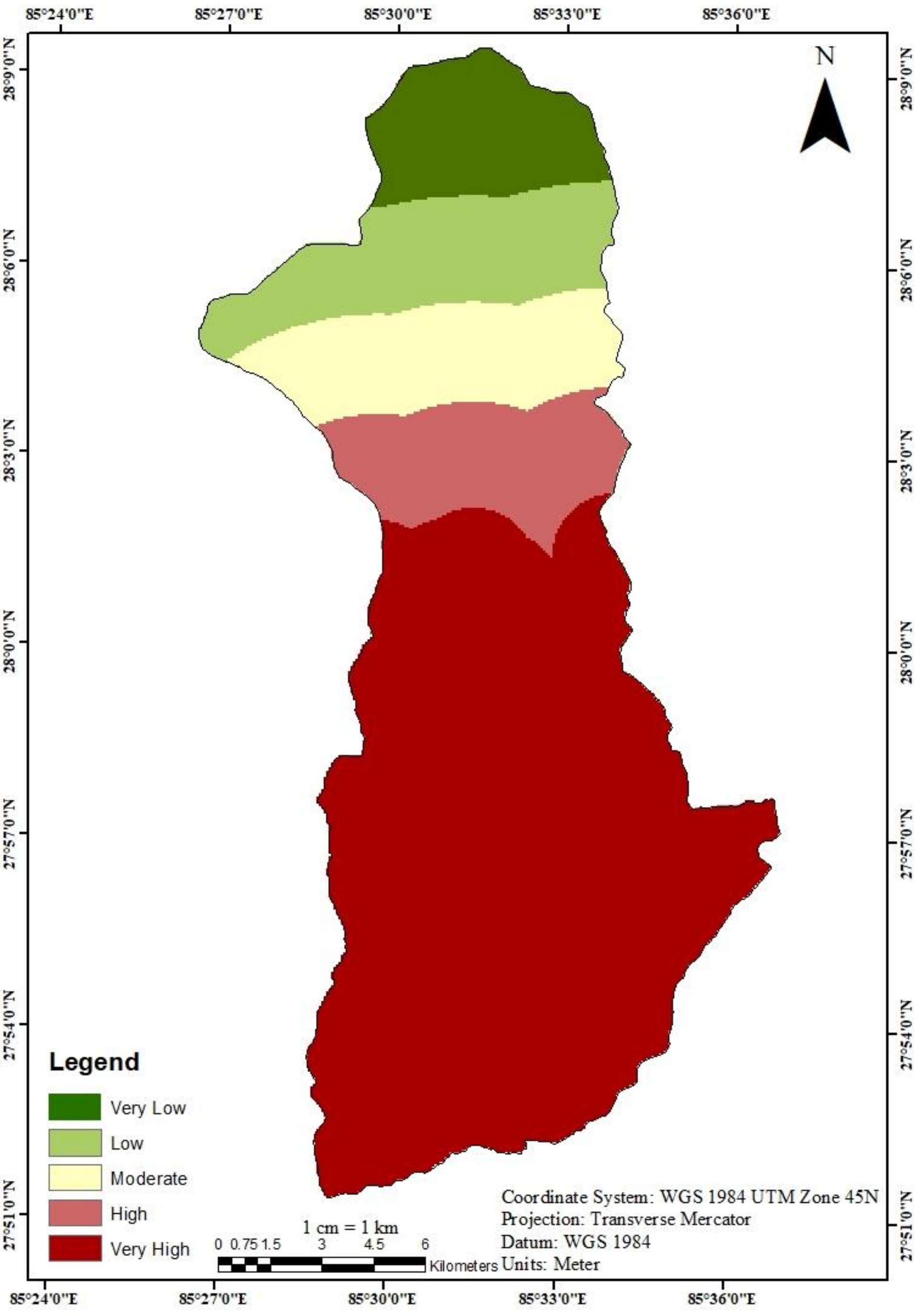

Figure 4-10 : Distance From Road Map

4.3 Evacuation Route Modelling

The above flood susceptibility map was further classified into two zones mainly risk zone and safe zone. Risk zone consist of high and very high risked zone and safe zone consist moderate, low and very low risked zone of flood susceptibility classes.

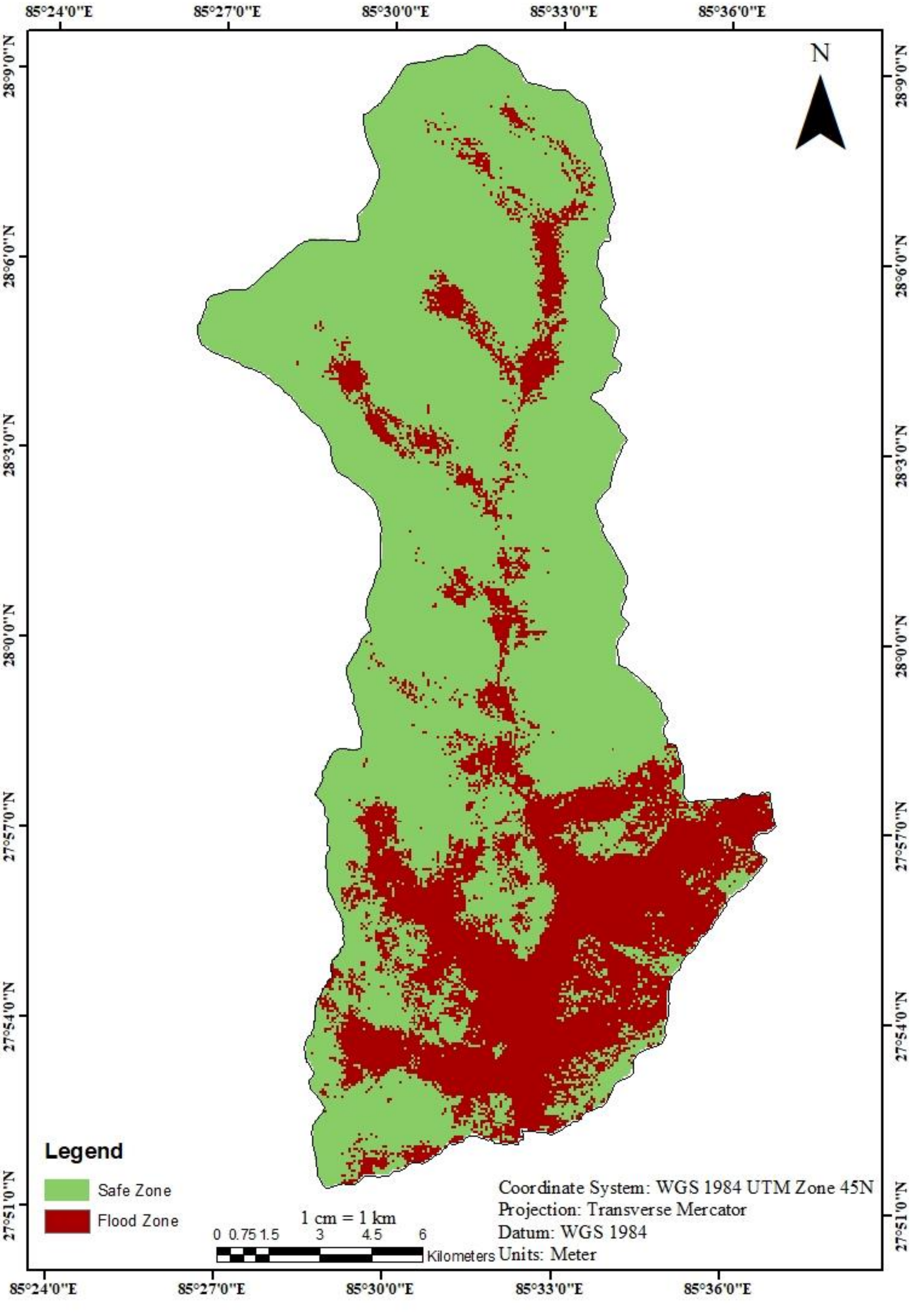

Figure 4-11 : Safe And Risk Zone Map

Assembly Points

The total number of assembly points are 57 .

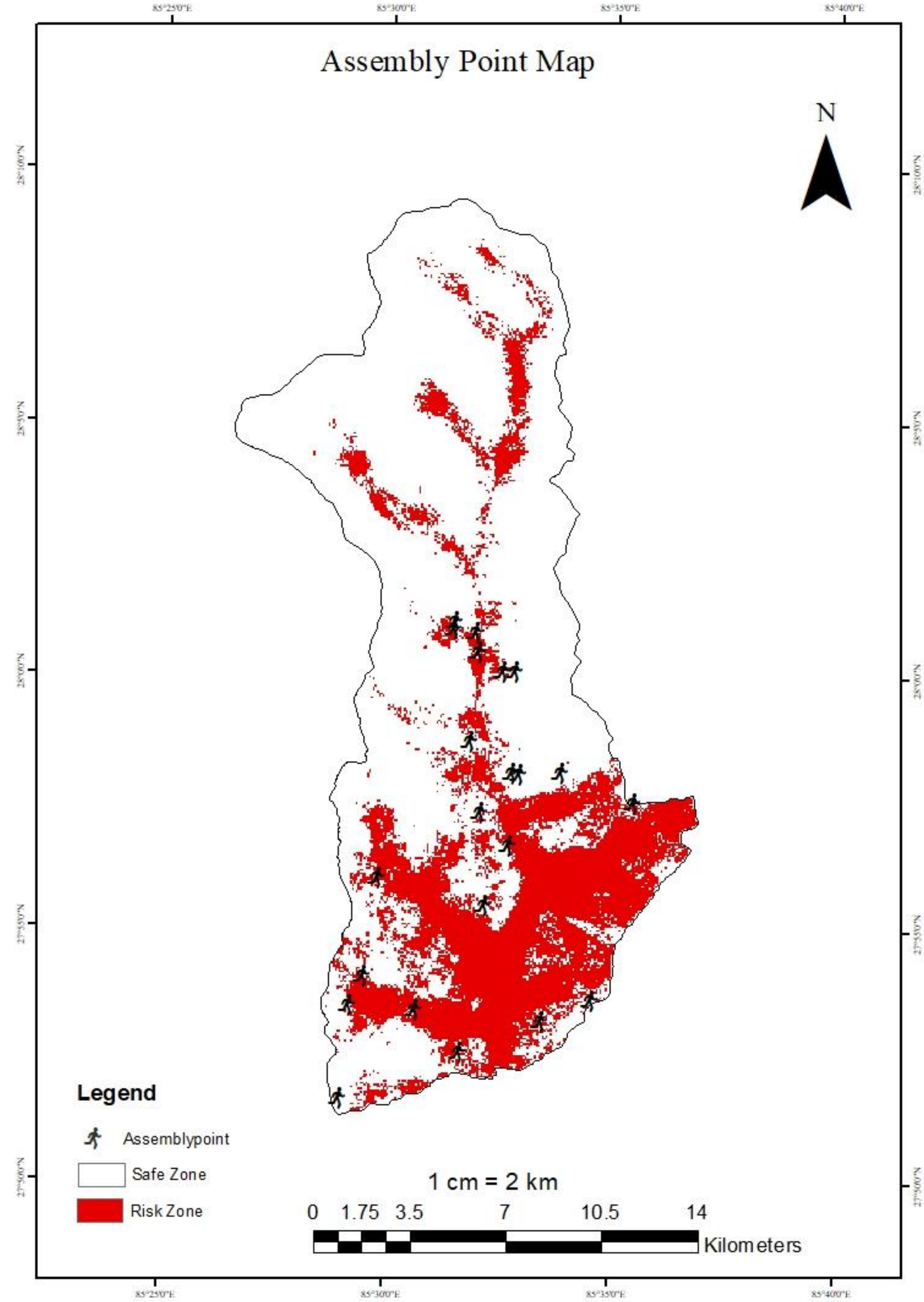

Figure 4-13 : Assembly Point Selection Map

Shelter Point

The total number of shelter point are 22.

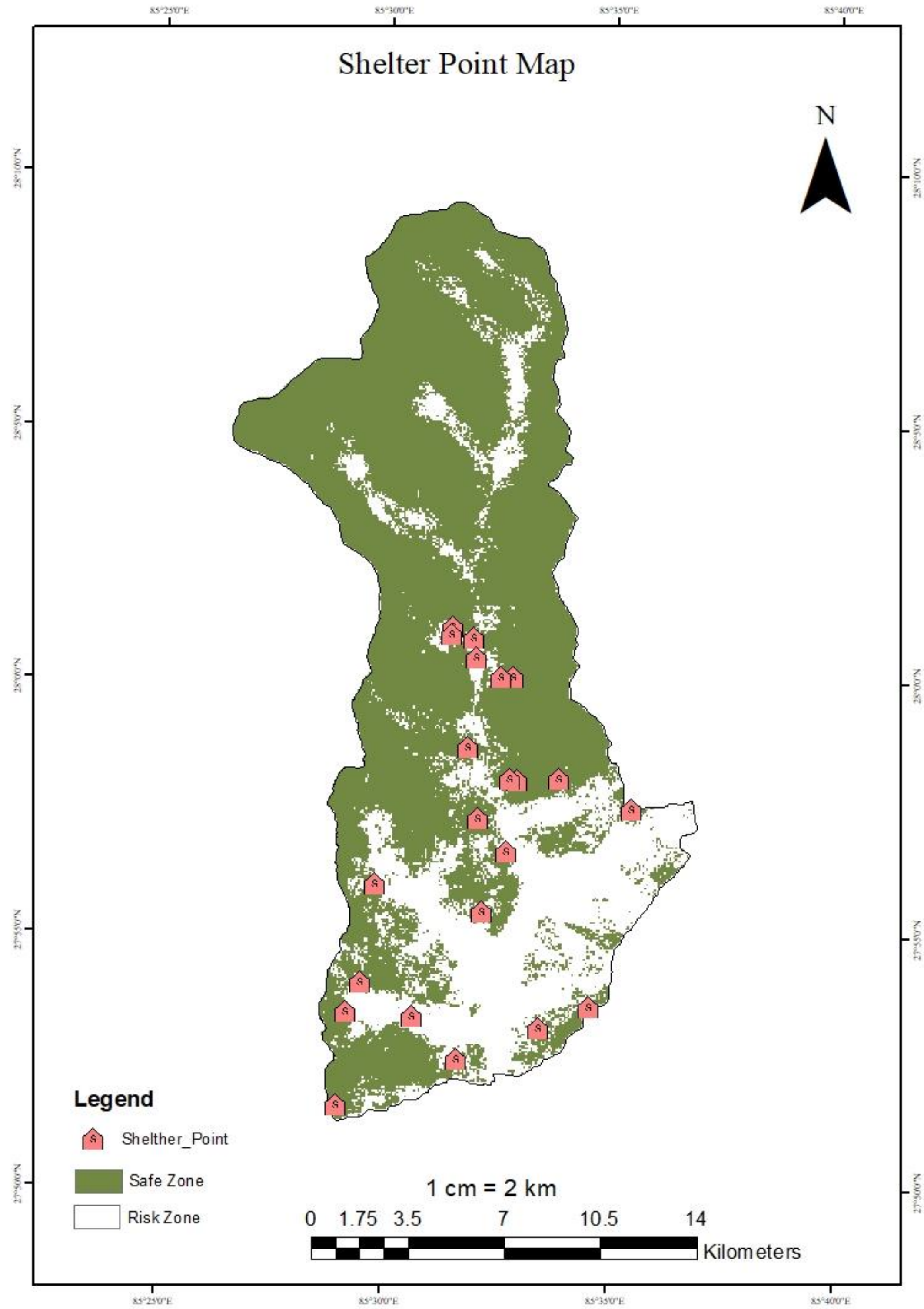

Figure 4-15 : Shelter Point Selection Map

Evacuation Route

The evacuation route was found using Network Analysis function in GIS. The closet facility tool was mainly used for the selection of the route. In case of this study, the safest route couldn't be verified because of no on field investigation so the evacuation route to the open space is considered as the route.

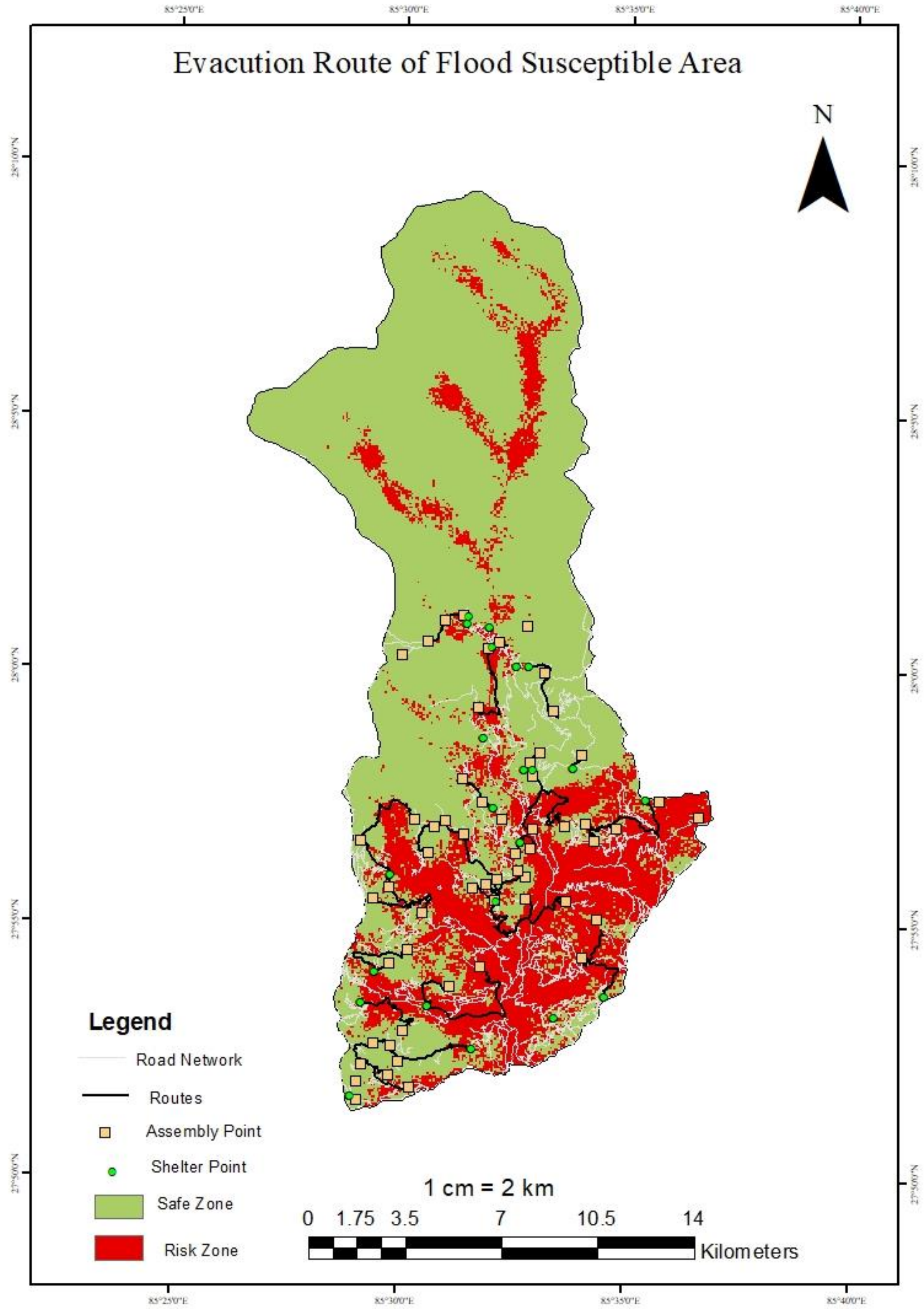

Figure 4-17 : Evacuation Map

5. DISCUSSION

This project proposes an efficient way to evaluate flood- susceptible areas and evacuation routes to move people from emergency points to a safe zone. MCDA approach along with AHP is used to find and evaluate the effect of nine different factors causing flooding. Shelter points were also suggested on the basis of study, analysis using different tools in ArcGIS and data extracted from OSM. After finding the susceptible areas that can potentially be inundated at the time of the flood, route to the safe spot was also computed. The flood susceptibility map obtained through the MCDA-AHP technique showed that half of the area of Helambu Municipality (1.85% of the total area) is susceptible to flood.

One of the major issues in finding the susceptibility using the MCDA approach is the number of floods conditioning factors and choosing the most suitable factors for the area. Nine factors were used in this study, which was similar to other studies by Nsangou et al. (Sci. African 2022) and Khosravi et al. (Nat. Hazards 2016, 83, 947–987) which used ten factors. Similarly, Dahri et al. (Environ. Earth Sci. 2017), Seejata et al. (Remote Sens. 2019), and Ouma et al. (J. Geogr. Inf. Syst. 2015) used six factors, Vojtek et al. (Water 2019) used seven factors, Hammami et al. (Arab. J. Geosci. 2019) used eight factors, Negese et al. (Appl. Water Sci.) used 11 factors, which shows that the number of factors can be variable, but should be selected such that the overall weightage is not dominated by the individual factor. The factors should also be selected such that they best fit with the geomorphologic and geologic conditions of the area.

6. CONCLUSION AND RECOMMENDATION

a. Conclusion

This project demonstrates an efficient approach to evaluate flood-susceptible areas and develop evacuation routes in Helambu Rural Municipality using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) methods, specifically the Analytical Hierarchy Process (AHP). The study successfully identified and evaluated the impact of nine flood-causing factors, leading to the creation of a detailed flood susceptibility map. The map indicated that approximately 1.85% of Helambu Municipality is highly susceptible to flooding.

The methodology incorporated various factors such as elevation, slope, topographic wetness index, drainage density, land use/land cover, normalised difference vegetation index, precipitation, distance from rivers, and distance from roads. These factors were selected to best fit the geomorphologic and geologic conditions of the area, ensuring the accuracy and reliability of the flood susceptibility assessment.

b. Recommendations:

Field Verification: Conduct on-site investigations to validate the proposed evacuation routes and ensure their practicality and safety during actual flood events.

Continuous Monitoring: Implement a system for continuous monitoring of flood-prone areas using real-time data. This can enhance early warning systems and improve the responsiveness of evacuation plans.

Community Training: Organise regular training programs for the local community to raise awareness about flood risks and educate them on the use of evacuation routes and assembly points.

Consideration of Evacuees Speed and Age: The population density of the area can be taken into account in order to estimate the walking speed of the evacuee during flood.

Infrastructure Development: Invest in flood-resistant infrastructure and improve existing facilities in high-risk areas to mitigate the impact of floods and facilitate smoother evacuations.

Policy Implementation: Advocate for the integration of flood susceptibility maps and evacuation plans into local government policies and urban planning to ensure long-term sustainability and disaster preparedness.

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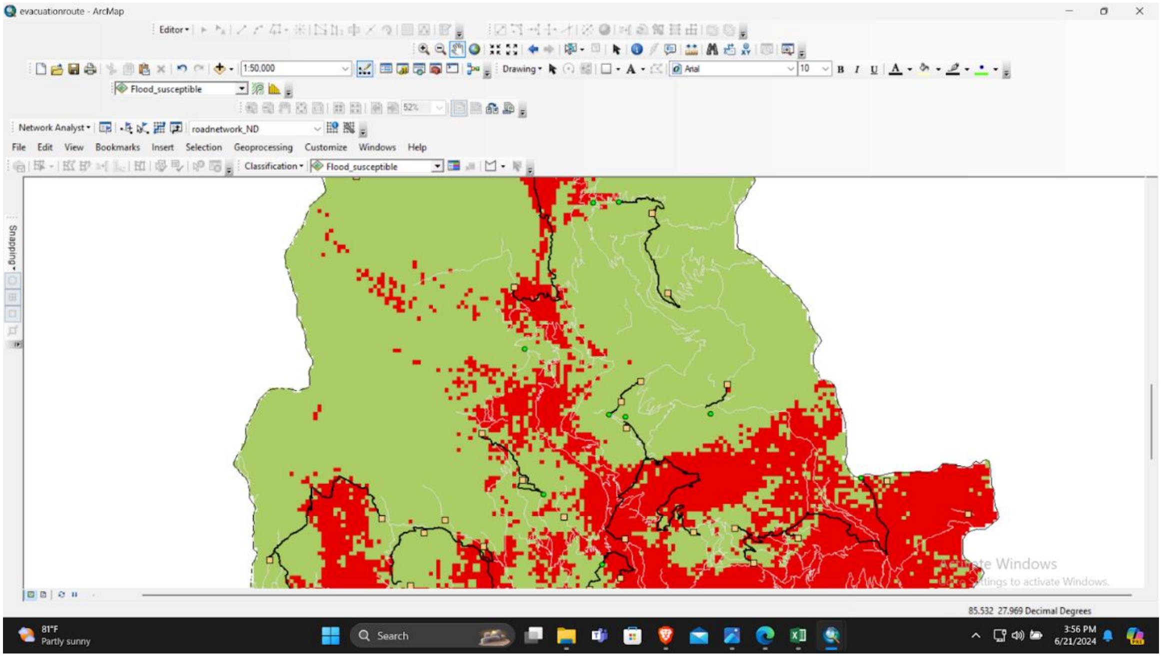
8. ANNEX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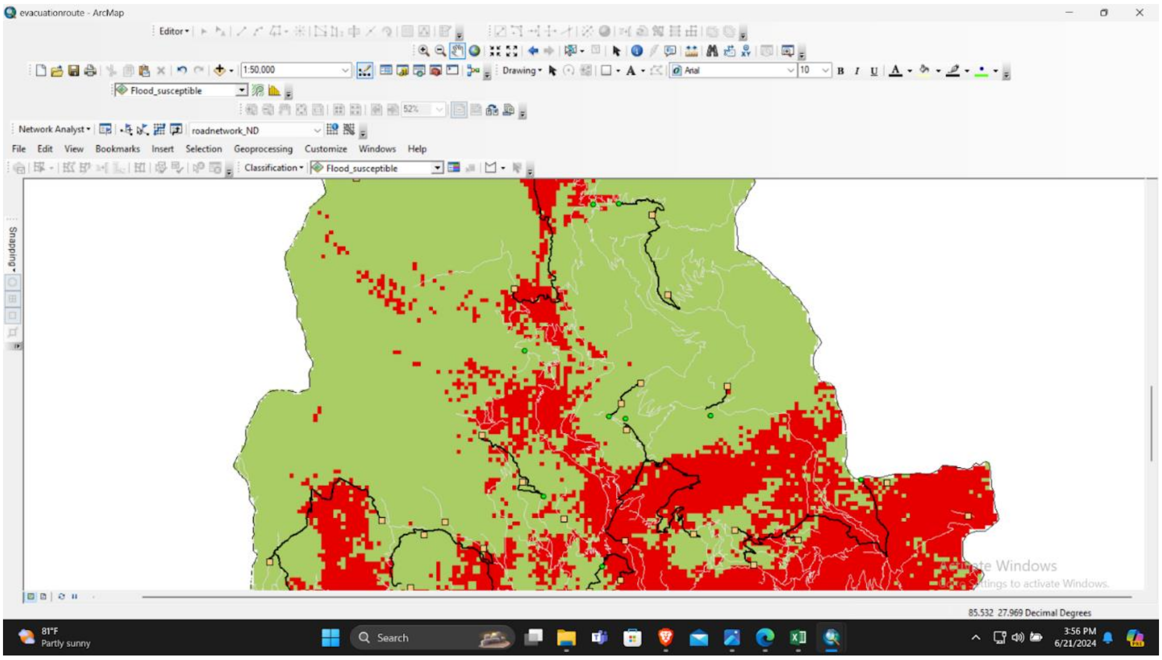
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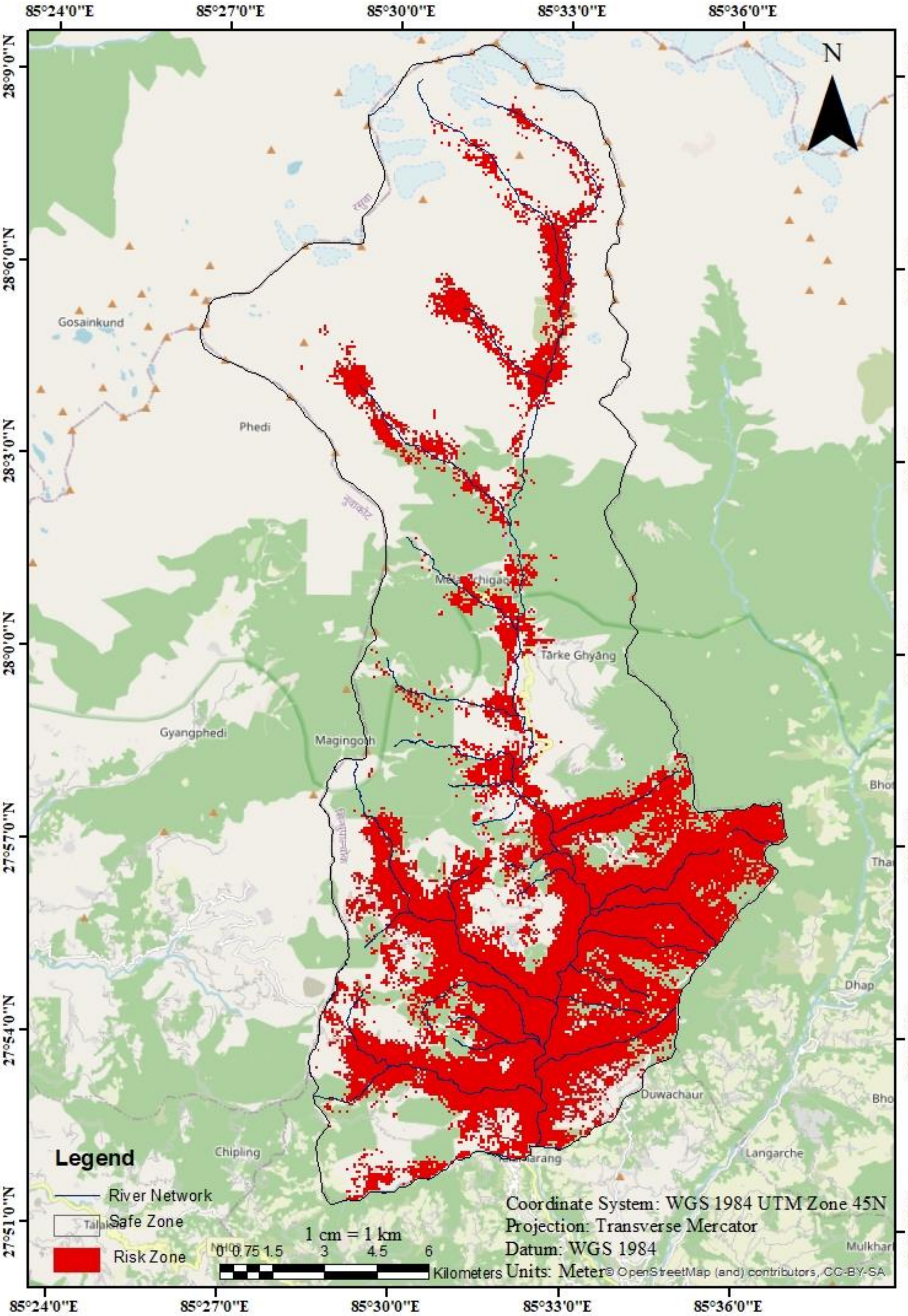
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Coordinate System: WGS 1984 UTM Zone 45N
Projection: Transverse Mercator
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Units: Meter
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