Multi-Hazard Susceptibility Analysis using Multi-Criteria Decision analysis, an application of Analytical Hierarchy process: A Case Study of Ghizer District, Gilgit Baltistan

By

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DEDICATION

"Dedicated to my Family who support me in all moments of life"

And

"To teacher and friends who helped me to complete my thesis"

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
AHP	Analytical Hierarchy Process
MCDA	Multi-Criteria Decision Analysis
TWI	Topographic Wetness Index
TPI	Topographic Positional Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NDSI	Normalized Difference Snow Index
LULC	Land Use/ Land Cover
CR	Consistency Ratio
CI	Consistency Index
CA	Catchment Area
WOE	Weight Of Evidence
IV	Information Value
FAHP	Fuzzy-Analytical Hierarchy Process
FR	Frequency Ratio
RSI	Relative Significance Index
GPR	Ground Penetrating Radar

ABSTRACT

Natural hazards can be of various types such as Earthquakes, Landslide, Avalanche, Flash flooding and etc, but all in all these hazards bring long lasting destruction whenever and where ever they occur. The northern regions of Pakistan particularly the Himalayan mountain range are prone to these natural hazards. The main objective of this research is to perform susceptibility analysis on three particular natural hazards in Ghizer District namely: Landslides, Flash floods and snow avalanches and find suitable mitigation measures for each natural hazard in said region. Data of the study area was collected through satellite imagery, while the data of the triggering factors (factors responsible for natural hazards) such as lithology, precipitation and drainage density was acquired through manipulation of said satellite image and through the use of various GIS techniques. The susceptibility analysis of the mentioned natural hazards was calculated through the use of multi-criteria decision analysis techniques primarily Analytical Hierarchy Process (AHP). The AHP model to be used was operated through the extension AHP2.0 for Arc-Map. The results indicated that the potential susceptibly zones were found near fault lines and high slope zones, high drainage density and high precipitation zones, and near regions of greater snow cover respectively for landslide, Flash-Flood and Snow Avalanche respectively. The accuracy of prediction of the AHP model was determined through the use of the AUC and ROC curve method where the AUC values for Landslide, Flash-Flood and Snow Avalanche Susceptibility were 71%, 72% and 89% respectively. The accuracy of AHP model can be improved through increasing the number of true positives/ historic data. The study also suggested various mitigation factors for said natural hazards while considering the economic conditions of the area.

Chapter 1

INTRODUCTION

1.1 NATURAL HAZARDS

Climate change can contribute to natural phenomena's which are referred to as natural hazards, which are natural phenomena (caused by natural events) that have the capability or probability to disrupt or destroy the life of humans either physically through death or monetary wise trough destruction of property or lands. A natural hazard that actually does harm human life is referred to as a natural disaster. The frequency of natural hazards increased and humans are aware that natural hazards turned disaster are due to anthropogenic means. The word hazard basically means eventual harm to a place or region. These events are natural phenomena caused by natural triggers such as wildfires, volcanic eruptions, etc. Another cause for natural hazards are anthropogenic activities which are human activities such as the case of deforestation along with the creation of poor drainage systems etc. Climate Change which is the change in atmospheric conditions (outside of the norm) can also cause natural hazards such as floods. Natural hazards also play the role of a cause for another natural hazard such as the case of an earthquake-triggered landslide. Natural Hazards as a whole have further classification based on the nature of the hazardous event such as geological, hydrological, meteorological and biological hazards. Basically Geological Hazards include events such as earthquakes and landslides primarily due to tectonic plate movement. Hydrological hazards in simpler terms include floods, droughts and other water-related events. Meteorological events include events such as tornadoes and other extreme weather events. Biological hazards include pandemics such as the most recent Covid-19 pandemic, which spread worldwide. These natural hazards mentioned above can have serious effects on human life such as earthquakes and landslide, which cause the destruction of infrastructure which can also cause death. Floods can also damage infrastructure along with damaging irrigated land, destroying the livelihood of humans; droughts can have long-term impacts on the human population such as food shortages and etc. All in all, natural hazards have a significant impact on entire human population so much that it becomes very important to have a solid understanding of the nature of said hazardous events to mitigate such events.

1.2 BACKGROUND INFORMATION

The word natural hazard has been defined along with some of the types of natural hazards and the effect such hazards have on the human population. Natural hazards have been effecting the human population for centuries, so much so that these natural hazards were also associated with the supernatural in the early times. As time progresses, the intensity and frequency of occurrence of said natural hazards has also increased due to global warming caused primarily by climate change, which in simpler terms is propagated by increased anthropogenic activities resulting from population increase. The region of interest in this research is the district Ghizer of the Region Gilgit Baltistan of Pakistan. The region of Ghizer lies in the northern part of Pakistan having sub-polar climate (basically cold climate) and is susceptible to some natural hazards as a result of its geographic location. The natural hazards that are prevalent in this region are earthquakes, landslides, Debris Floods and flash floods along with snow avalanches. The Natural hazards for which the possible susceptible zones to be located in this research are as follows: Landslides, Flash floods and Snow avalanches. Out of the three mentioned natural hazards the natural hazard that has the most frequency of occurrence in the district Ghizer of Gilgit Baltistan is Landslide, which has a lot of triggering factors such as earthquakes, liquefaction of soil as a result of heavy rainfall and other anthropogenic activities such as deforestation. There have been a handful of landslides in this particular region such as the 2014 landslide in the village of Chalt which resulted in many deaths and damage to infrastructure. The District Ghizer is located in a rain-shadow area, which implies that the main source of precipitation is the monsoon season, which sometimes can result in Flash floods that are intense and sudden which can cause a lot of harm to the general population. Flash floods can also cause debris floods, which are prevalent in this region. The flooding event of 2010 shows the damages done to the region. As Ghizer is a Hilly region having steep slopes and is prone to heavy snowfall, this region is also prone to Snow avalanches. The snow avalanche in the village of Gupis in the year 2019 does show the effect such a hazard can have on the human population. In light of the above mentioned natural hazards it becomes important to have a comprehensive analysis of the multi-hazard susceptibility of the Ghizer district. So that the regions which are the most susceptible to the above mentioned hazards can be located so that mitigation measures can be taken in order to reduce the effect of these natural hazards on the human population of this region. Now comes the issue of finding a method for identifying said susceptible zones. In this research, the method used for finding said susceptible zones is the Multi-Criteria decision analysis (MCDA) technique. The MCDA technique or tool is a very powerful tool for decision analysis as a whole. It includes in it further methods for assisting the decision-making process (keep in mind that this method does not make the decisions it just assists the decision making process by providing results based on inputs). The basic methods in MCDA are as follows: Analytical

Hierarchy Process (AHP), Fuzzy Membership/Fuzzy Logic, Machine Learning, Artificial Neural Networks (ANN), Fuzzy-AHP process and so on. For this study the method chosen for the identification of possible susceptible zones is the Analytical Hierarchy Process (AHP) which in simpler terms, is an easy to-understand, easy to-use and systematic method for assisting decision making as it includes the consideration of multiple criteria and factors which would be explained in more detail in the methodology section. The basic objective of this research is to use the MCDA technique particularly AHP in order to assess the multi-hazard susceptibility of Ghizer District and in simpler terms assist in identifying the regions within Ghizer which are prone to the above mentioned natural hazards. After identifying said zones, basic mitigation procedures are provided to reduce the harm these natural hazards can cause to the region's general population. The discussion of the mitigation strategies to be implemented for said natural hazards would take into account the economic condition of the study area as well as the country the study area resides in, but general mitigation strategies that are being used in different part of the world would also be discussed All in all this study aims to provide valuable information to stakeholders, decision-makers and planners in this region which can help said people to contribute to the basic development of disaster risk reduction strategies.

1.3 LANDSLIDES

Landslide, also called landslip is a natural disaster specifically of the geological kinds of natural disaster. As the name implies landslide involves the sliding of mass downwards a slope due to the gravitational force exerted on it. A proper definition of landslide would be that it is the downwards movement of mass (soil, rocks, landmass etc.) because the force of gravity or other shear stresses overcome the shear strength of the material of which the slope was made of. This geological phenomenon occurs in both natural landscapes and man-made landscapes, and where ever they occur they bring with them destruction especially to human life and infrastructure (provided they occur in a man-made landscape).Slope plays a lot of importance in landslides and hence there are various types of landslides resulting from various type of slope movements such as: falls, topples, slides, spread and flows. Another factor that influences the types of landslides is the geological material such as: bedrock and debris. Hence some of the types of landslides based on Slope movement and geological material are as follows: Rock-falls (movements of boulders from a slope), Slumps (movement of rock and soil as a single unit downwards a slope) and Rock-slides (sudden movement of rocks downwards a slope). Landslides are a kind of natural disaster that can be triggered by other natural disasters such as Earthquakes (the movement of tectonic plates) but there are other triggering factors, such as heavy rainfall which can liquefy soil causing landslide. Anthropogenic activities such as deforestation and construction along slopes can also cause landslides. Various cases that show the destruction that can be caused by landslides such as the 2014 Oso Landslide which resulted in the deaths of 43 people and was caused as a result of heavy rainfall, this occurred in United states specifically Washington state. Another case is the 2017 Sierra Leone Landslide which was also caused due to heavy rainfall, and which led to the death of over 1000 people. Another case is that of the land sliding that occurred in the region of Ghizer in Gilgit Baltistan in 2016, which caused widespread damage in infrastructure. Hence in order to overcome the damage due to landslide it is important to discuss the mitigation factors of such natural hazard, the mitigation factors are discussed in the section 5.1.1.

1.4 FLASH FLOOD

Flood in specific terminology is a natural disaster that is caused by an increase in sea-level which can cause water from the oceans to start encompassing the land. Flash flood on the other hand is a type of flooding event which as the name implies is a rapid and fast flooding event. Flash Flood in simpler terminology is a natural disaster that occurs as a result of rapid and intense influx of water into an area which causes sudden flooding to occur. The basic difference between a Flood and Flash Flood is that Flash floods can occur in hours while floods occur over a more extended period. In fact this short period of flash floods is the reason why they are dangerous in the first place. The Primary cause of Flashfloods is heavy rainfall and poor drainage systems, which lead to a sudden influx of water in a region. Other causes of Flash floods can be dam failure, snow melting and congested urbanization. Ironically heavy amount of rainfall of flooding events can also cause liquefaction resulting in landslides. Flash Floods can cause a lot of harm to the infrastructure and can lead to loss of a lot of lives, such as the Chennai floods in 2015 which were caused by heavy rainfall and led to a loss of at least 280 lives or more. Monsson season in Pakistan can lead to an excess of rainfall which has caused flash floods to occur in various regions of Pakistan. The Monsson season is typically between June and September in Pakistan. There are cases of Flooding events in Pakistan, such as the flash flooding event of Baluchistan in the region of Naseerabad and Jhal Magsi in the year 2013. Along with the case of flooding event in the shigar valley of Gilgit Baltistan in the year of 2019 which caused wild spread damages, the geographical position of Gilgit Baltistan makes it uniquely susceptible to flooding events generally due to poor infrastructure, poor drainage networks along with heavy amount of rainfall. Hence it becomes important to understand said natural hazard in the region of Gilgit-Baltistan in order to create mitigation procedures to reduce the damages by said hazards, which is discussed in detail in the section 5.1.2.

1.5 SNOW AVALANCHE

Snow Avalanche is a natural disaster that is included in the avalanche type disasters, landslides are another example of avalanche type disasters. In simpler terminology a Snow Avalanche is the movement of a mass of snow (mainly) and other material downwards a slope (mountainside). As the snow accumulated on the mountainside breaks away from slope due to gravitational forces exerted on it or other means, it picks up speed as it moves further downwards the slope which produces a cloud or river of snow (of sorts) that takes with it anything that comes in its way. A properly developed (large) snow avalanche can have a weight equal to approximately a million tons and can travel faster than 320 kilometers per hour. There are many causes for snow avalanche however, some of them are as follows: Steep slopes (the greater the steepness the greater the chances of avalanche), Snow Layer Unitability (Causes the snow to escape layers and result in avalanche), Anthropogenic Activities (such as skiing) and Extreme weather conditions (such as heavy snowfall). There are cases of damages done due to snow avalanches in Pakistan specifically in the northern regions of Pakistan such as the case of snow avalanche of Gyari in the year 2012 which struck a military camp in siachin glacier which caused loos of human life and the camp as a whole.

Chapter 2

LITERATURE REVIEW

Along with the progression in research methodology and technology (specifically the progress in the utilization of Satellite Imagery) the understanding of Climate change and its causes and effects has increased over the years, Hence the understanding of Natural Disasters events in general has also increased. But this understanding of Natural Disaster event is limited by the region of the said event and the technology being used in that region. Prediction of natural hazard susceptible zone is a multi-layerd complex proplem which requires a suitable model to be solved, in this study the model being used is the AHP model which is a sub-category of the MCDA techniques which handle such complex problems as it influences the decision making process of solving said problems. The performance of any business or solution to any complex problem greatly depends upon the decision making ability of the people working in said business and solving said problem as the most important attribute of the human species which causes individuals to be engaged with each other through out their life is decision making (Shahsavarani, Azad, & Abadi, 2015). A study which was carried out to generate a landslide susceptibility map in order to facilitate the creation of landslide susceptible zones through AHP for the region of Gilgit-Baltistan, which showed the possible zones for the said region, this study explained the possible triggering factors of landslide and how they affect the study area. The resulting Susceptibility map showed that the northern and eastern part of Ghizer district are highly susceptible to landslides. The Area under the curve method was used to determine accuracy (Rahim, Ali, & Aslam, 2018). Another study utilized earthquake information along with a landslide database that was created through ASTER satellite images in order to use multi-criteria approach to create landslide susceptibility zones as a result of earthquakes for the 2005 Kashmir earthquake, the outcome was that areas with steep slopes, high reliefs and poor soil condition have the greatest susceptibility to landslides (Kamp, Growley, Khattak, & Owen, 2008). Other studies have also used MCDA (Multi-Criteria Decision analysis) in order to generate susceptibility zones for landslides as a result of earthquakes and the outcome was the identification of 148 earthquake-triggered landslides in Cephalonia and that the importance of lithology and slope exceeded that of distance from faults and seismic intensity as factors triggering landslides (Mavroulis et al., 2022). In flash flood susceptibility analysis it becomes essential to identify urban prone flash flood susceptible regions in order to mitigate a plan around such natural disasters, a study was performed in order to zone these flash flood susceptible regions through the use of Multi-Criteria decision technique, and through the use of MCDA it was found out that areas with steep slopes, high drainage density and proximity to streams had the greatest susceptibility to flash floods (Choudhury, Basak, Biswas, & Das, 2022). While another study was carried in order to observe the most ideal method for the creation of flash flood susceptible zones through comparison of research papers and already performed projects (Saleh, Yuzir, & Abustan, 2020) this study showed that although Analytical Hierarchy Process (A.H.P) is the most used method for determining flash flood susceptibility the most accurate results are produced through Machine Learning algorithms. Primarily like other studies various studies were carried out for avalanche susceptibility and most of these studies used MCDA (Multi-Criteria Decision analysis) in order to produce the susceptible zones. Such as the following study used to create avalanche-susceptible zones for Serbia, where the key factors for evaluation susceptibility were topography and snowfall intensity (Durlević et al., 2022). While another study was also performed to find avalanche susceptibility through the use of Analytical Hierarchy process, where it was found that slope inclination and angle along with intensity of snowfall plays a very important role in determining snow avalanche susceptibility (Kumar, Srivastava, & Snehmani, 2017). The MCDA approach has also been used in order to determine the susceptibility of a region as a whole, as in a particular study the AHP technique was used to determine the snow avalanche susceptibility of Gilgit Baltistan as a whole and it was determined that topography, slope angles, vegetation and snow fall intensity along with anthropogenic activities (such as construction and deforestation) are the main triggering factors of snow avalanche in these regions, the highly susceptible regions were Chitral, Sakardu, Ghizer and Ganche (Sardar, Raziq, Rashid, & Saddiq, 2019). Another study used the MCDA method particularly AHP to determine the snow avalanche susceptibility for the district of shigar, slope, topography land use/land cover were determined to be triggering factors. AUC (area under the curve) method was used to determine the model's accuracy and the data was acquired from STRM DEM (Ali, 2019). As discussed previously some natural disasters serve as the cause of other natural disasters, in such cases it becomes important to generate a multi-hazard susceptibility model in order to count for all the possible natural disasters. Such as the study that aims to use MCDA to determine the susceptible regions of Kathmandu Nepal, this region of Nepal is susceptible to a lot of natural disasters in this study the disasters under discussion were earthquakes, landslides and floods. It was discovered through the use of MCDA that the southern and western parts of the region were highly susceptible (Khatakho et al., 2021). Another study used AHP along with the Frequency ratio (FR) technique in order to determine the susceptibility for the following hazards: Landslides and floods for the northwest Himalayas, through the use of MCDA and FR it was determined that the northwestern and southern parts are to most suitable regions for economic development in contrast the eastern and western regions are located in very too highly susceptible regions. Landslide were determined to be the most occurring natural disaster in this region (Rehman et al., 2022). Another study used MCDA or in simpler terms AHP to determine the susceptibility for the following natural hazards: Landslide, Volcanic activity, costal erosion and earthquakes. The region of interest in this study was south Aegean Volcanic Arc Islands. It was determined that the eastern part of said region was prone to seismicity while the central and southern parts were prone to volcanic activity and that mountainous areas were prone to landslides while areas within low-lying coastlines were prone to costal erosion (Krassakis et al., 2023).The AHP method is preferred in the cases of determining natural hazard susceptibility because of its simplicity but it is not the only way to determine susceptibility, there are other methods within MCDA such as Machine learning and Artificial Neural Network along with hybrid techniques which are in simpler terms a combination of both such as Fuzzy AHP (combination of fuzzy logic and Analytical Hierarchy Process). Such as the following study used a combination of fuzzy logic and AHP, referred to as FAHP in this particular literature, to generate a model for the prediction of flood susceptibility for the region of Guelmim of morocco. The reason why FAHP was used was because of this methods effective dealing with uncertainty and biasness, this algorithm also integrates the criteria (multiple and sub) within the assessment process. The results determined that slope and land use were this case’s most important triggering factors (Talha, Maanan, Atika, & Rhinane, 2019). Statistical models have also been used in order to determine the natural hazard susceptibility of a region such as the study conducted for the region of Swat of the province KPK of Pakistan, the study utilized models such as the Weight of Evidence (WOE), Frequency Ration (FR) and Information Value (IV) (Islam et al., 2022). Another study was conducted for the region of Italian Dolomites, which used terrain features such as slope along with historical data of snow avalanches to find susceptible zones through statistical techniques (Ghinoi & Chung, 2005). A study was conducted for the north eastern turkey tourism region namely Uzungol. Three different models were used to determine the snow avalanche susceptibility, models were FR, AHP, and FAHP the prediction accuracy of said models were determined through the use of area under the curve method where it was determined that for the case of Uzungol FR technique had the greater prediction accuracy as compared to the FAHP and the AHP technique (Varol, 2022). Another study was conducted to determine multi-hazard susceptibility for the region of Derwent Valley mills (heritage site according to UNESCO) used AHP to determine susceptibility, although the weights in this case were calculated through the use of RSI in order to decrease the biasness involved (Guerriero et al., 2022). In order to improve the accuracy of the prediction through AHP a study was conducted to modify the AHP model in terms of the GPR prediction accuracy, the AHP model was improved through the addition of a new measure of weights along with the integration of principle maximum membership which is derived from fuzzy logic (Zheng, Li, Liu, Huang, & Tang, 2020). Another study was conducted in order to represent the importance of using the AHP method in solving complex problems with multiple alternatives, the AHP model in this study was explained in three levels in order to show its importance. (Canco, Kruja, & Iancu, 2021)

Chapter 3

MATERIALS AND METHODS

3.1 STUDY AREA

The study area for this research is the district Ghizer in Gilgit-Baltistan. In its entirety GB is a highly populated mountain region in the north of Pakistan.As GB is a mountainous region it spreads geologically over three mountain systems; Himalaya, Karakorum and the Hindukush ("Home :: Gilgit Baltistan," online.). The District Ghizer is located geographically in a region bounded on the north by Upper Chitral district of KPK Pakistan along with the Wakhan district of Afghanistan's Badakhshan Province, on the eastern side Ghizer district is bounded by Hunza, Nagar and Gilgit district. In other terms it is geographically located on 35.77° to 36.33° North latitude and 72.71° to73.58° East longitude. Ghizer district has an elevation of about 1,481 meters above sea level as it is a region having a lot of mountains, glaciers, Lakes and recreational land. The highest peak in Ghizer is Koyo Zom (6,871m). As a result of its geographical location the climate of Ghizer is such that the summers are mild with temperature remaining about 27°C on average, while the winters are cold and severe with temperature dropping to about approximately -10°C, in simpler terms it has a dry and cold Climate. The major source of precipitation in this region is the monsoon season. This region is prone to many natural hazards such as landslides, flash floods and snow avalanche but the frequency of landslides is greater due to its geographic position, such as the case of flash floods that occurred in Damaas village in Ghizer that has effected the livelihood of the locals their ("PAMIR TIMES," online 2015.).

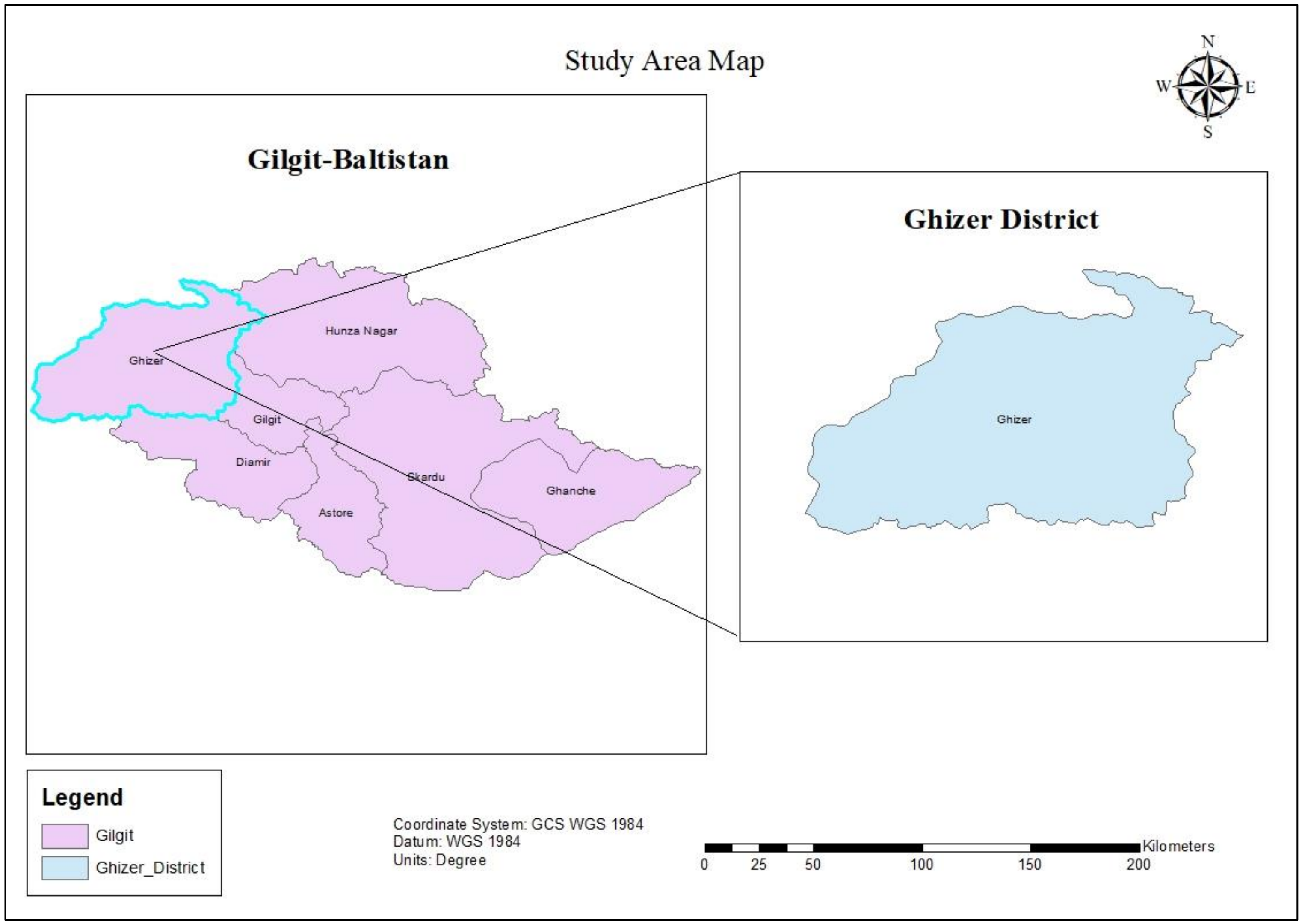


Figure 3.1: The Map of the study area, district Ghizer of Gilgit Baltistan

3.2 MATERIALS

The materials used in this study are regarding the acquisition of data necessary for research along with the software and hardware used in this study. The hardware used in this study in simpler terms was a desktop computer (provided in the lab) along with a personal laptop (for working purposes). Field data for the creation of historical inventory of occurred natural hazard was acquired in the means of location (acquired through GPS and expert opinions of locals of the region of Ghizer district). While the data to be used in the AHP analysis was acquired through the use of Internet from specific websites. This data was manipulated to gain results through the use of software such as ARC-MAP, QGIS and ENVI

3.3 DATA ACQUISITION

3.3.1 Data and its acquisition

In simpler terminology for the AHP analysis to work regarding the natural hazard we need the triggering factors of said natural hazards (especially those that are relevant to the geographic position of study area). In fact these triggering factors play the role of Criteria which are supposed to be assigned weights in order for the AHP model to be executed. As there are three natural hazards that are being discussed and each have their own triggering factors, so data would consist of these triggering factors and it becomes necessary to understand these triggering factors before acquiring them. After understanding how these triggering factors affect natural hazards, the next step is to acquire the data that represents these triggering factors. Before going through the datasets of the triggering factors, it is necessary to represent the data collected regarding the study area such as the satellite imagery and DEM which is represented in table 3.1.

Table 3.1. List of data used in the study.

Dataset	Specification	Source
Landsat 8	Spatial Resolution 30m & 2-10m	USGS
DEM	Resolution:1 Arc	Earth explorer
Tectonic Map	Scanned map	GSP
Vector Data	Road and stream network	Open Street Map

3.3.1.1 Landslide Susceptibility Triggering Factors

Landslides as natural hazards for the study area have already been explained in the introduction portion of this research. In this section, the triggering factor of said natural hazard and their source will be represented in tabular form in the appendix.

3.3.1.1.1 Criteria: Slope

Slope, as the name implies is the steepness which is measured in the units of ° degree. In other words, it is the measurement of the degree of inclination of a surface. It is calculated as a ration of vertical to horizontal distance with a range of 0°-90°.There are literatures representing a consensus among researchers regarding the use of Slope as a parameter in determining landslide susceptibility. A study of the literature determined that most researchers in 1500 studies used slope as an input parameter (Çellek, 2020.). Slope data was acquired from the DEM of the satellite image (which can be downloaded online from the USGS website. After Acquiring the DEM the next step is to use the slope calculation tool in the spatial analyst toolset to generate the slope. After acquiring the slope data the next step would be to classify that data in respect to the classes that would be made for the susceptibility analysis. This would be explained further.

3.3.1.1.2 Criteria: Aspect

Aspect is the orientation of slope, measured clockwise in degrees from 0° to 360°, where 0° is north-facing, 90° is east-facing, 180° is south-facing, and 270° is west-facing. In simpler terminology, it is the measure of the direction of a slope. Aspect in itself affects other factors, such as moisture accumulation and wind triggering hence it effects landslide susceptibility. The Aspect data can also be acquired from the satellite imagery's DEM through the use of the aspect calculation tool in the spatial analyst toolset in Arc-Map.

Which once acquired, is also classified in accordance with the susceptibility analysis classes.

3.3.1.1.3 Criteria: Distance to Road Buffer

This data set contains road networks of an area, around which a buffer would be created. The road network data was acquired through Open street Maps through the use of Bbbike website, which is a website that allows the extraction from Planet.osm in various formats, including shapefile ("BBBike Extracts OpenStreetMap (OSM)," online.). The buffers were created by using distance calculation tools in Arc-Map similar to that used in the calculation for stream buffers. These buffers would represent the distance to and from the road networks, representing the proximity to the road network.

3.3.1.1.4 Criteria: Distance to Stream Buffer

This dataset contains streams or water ways of an area, around which a buffer would be created. The Stream network data was acquired from open street map through the use of Bbbike website, while the buffer around it was created through the use of distance calculation tools in Arc-Map the Euclidian Distance calculation tool to be precise. These bufferes would represent the distance to and from the stream networks representing the proximity to said stream network.

3.3.1.1.5 Criteria: Distance to Fault Line Buffer

This dataset would contain the fault line data of the study area on which a buffer would be created. An area that is close to an active fault line is more prone to landslide. The buffer would represent the approximate distances to and from the fault lines representing the proximity to said fault lines. The fault line data was acquired from digitizing topographic maps and scanned tectonic maps. The buffer was created through the Euclidean distance tool from the spatial analyst toolset.

3.3.1.1.6 Criteria: Land Use/ Land Cover

This is an abbreviation for Land use/ Land Cover which as the name implies is the representation of the ways the natural bodies have been used on land such as wood and other materials for construction and the natural bodies present on the land respectively. In simpler terms Land Cover corresponds to the natural bodies such as water bodies, vegetation etc. that cover the land while Land use refers to the anthropogenic activities on the land. Although other factors influence landslide susceptibility such as Slope and Aspect these factors are static, while LULC is a dynamic variable/factor that is related to anthropogenic activities, a study assessed the impact of LULC change on landslide susceptibility based on three scenarios: existing, Proposed and simulated LULC patterns, which showed that with the changes in LULC, the landslide susceptibility would change (Rabby, Li, Abedin, & Sabrina, 2022). There are multiple ways of acquiring this data set as it can be downloaded online form USGS at 2-10m spatial resolution or it can be acquired through the use of supervised classification tools present in Arc-Map or Eras Imagine for this study supervised classification method was used to acquire said data which was classified accordingly into 9 classes which are as follows: Water, Trees, Flooded Vegetation, Crops, Built Area, Bare Ground, Snow/Ice cover, Range land.

3.3.1.1.7 Criteria: Lithology

Lithology in simpler terms is the Science of rock, more appropriately it is the understanding of the material composition and classification of rocks along with how the occur in nature. Hence, it influences how rocks are formed in nature and how susceptible they are to erosion by the atmosphere around them. As Slope is a factor that influences landslides, slope itself is composed of materials that in fact influence the topography of the slope hence, lithology influences landslide susceptibility. In fact, a research/ study was conducted in order to find the correlation between landslide susceptibility and lithology; it was concluded that rock formations and structure greatly influence landslide susceptibility (Trisnawati, Najib, Hidayatillah, & Najib, 2022). The data was acquired online from USGS lithology data set in certmapper, this website provided the updated global lithology map in the form of a shapefile from which the area of interest was extracted.

3.3.1.2 Flashflood Susceptibility Triggering Factors

The natural hazard referred to as Flash floods have already been explained in the introduction portion of this study. In this section the factors that influence flash flood susceptibility would be discussed, these factors would be used as criteria in the AHP analysis model. The description of these factors and the sources from which the data regarding these factors was acquired from would be represented in tabular form in the appendix. Note: Some of the triggering factors are similar such as Slope, Aspect, LULC and Distance to stream so they would not be discussed in the appendix table.

3.3.1.2.1 Criteria: Curvature

As the name implies Curvature represents the physical structure of a surface in simpler terminology it is the degree of bending of a surface or a representation of the curvature of said surface. The curvature can be concave or convex depending upon the surface, in fact once the curvature is calculated the shape can be concluded through examination of the curvature value. The curvature itself is calculated by calculating the second derivative of the surface. Curvature influences processes such as surface runoff and channelization while explaining the drainage basin's physical characteristic. Hence it influences the Flash Flood Susceptibility. Curvature can be acquired from the DEM of the satellite Image through the use of curvature calculation tools from spatial analyst tool set.

3.3.1.2.2 Criteria: Normalized Difference Water Index

NDWI is an abbreviation for Normalized Difference Water Index, an indices for delineating water bodies. It also monitors changes in water bodies by monitoring the increase or decrease in water bodies. It is used to detect the presence of water bodies such as lakes and rivers, which have chances of accumulating run off, causing flash floods. A study was conducted regarding the importance of assessing the damages of floods using NDWI (Memon, Muhammad, Rahman, & Haq, 2015). As NDWI is an index it can be calculated through the use of Band Mathematics through the use of Raster Calculator in Arc-Map the formula for the calculation of NDWI is as follows:

$$\text{NDWI} = \frac{\text{GREEN} - \text{NIR}}{\text{GREEN} + \text{NIR}} - - - - - - - - \text{Equation3.1}$$

The GREEN and NIR values are that of the band respectively for the case of Landsat 8 Band 3 is Green and Band 5 is the NIR

3.3.1.2.3 Criteria: Normalized Difference Vegetation Index

Abbreviation for Normalized Difference Vegetation index, as the name implies this index represents the vegetation quality of an area its range of values is from -1 till +1. A value of +1 indicates dense vegetation while a value of -1 indicates water bodies, on the other hand a value of 0 indicates urbanization or barren land. NDVI is one of the most used factor in determining flash flood Susceptibility. Dense vegetation represents preventing of floods and no vegetation propagates flooding (Algorithms, Askar, Peyma, Yousef, & Prodanova, 2022). NDVI can be calculated similarly as NDWI since both are index (ratios), the formula for the calculation of NDVI is as follows:

$$\text{NDVI} = \frac{\text{NIR}-\text{R}}{\text{NIR}+\text{R}}$$ ---------------------------Equation 3.2

Where NIR is Band #5 and R is Band # 4 in Landsat 8.

3.3.1.2.4 Criteria: Annual Precipitation

Precipitation refers to the downwards motion of water or snow from the clouds. In the case of flash flood it refers to water as rain (in simpler terms). Annual Precipitation is the precipitation that falls Annually/yearly over a region which is measured in millimeters or inches. High intensity Precipitation events can trigger flash flooding events The Precipitation data was acquired through the Climate Research data (available online) in the form of a Net-Cdf file which was converted into a Raster through the use of Arc-Map conversion toolset and then was converted into Points from where IDW method was used to determine the precipitation. The resolution of which was 325 * 325 meters. The units of measurement are millimeters per year as this is a yearly averaged data for 2021-2022.

3.3.1.2.5 Criteria: Drainage Density

Drainage density is referred to as the calculated length of channel per unit watershed area hence it is measured in the unit km/km^2. In simpler terms it is the length of all the water bodies in a drainage basin divided by the total area of that drainage basin. Drainage basin greatly influences flood flows. A study was carried out to address the relationship between drainage density and flood frequency through a numerical simulation. It was observed that a minimum for flood statistics implies a minimum in flood flow hence drainage density greatly influences flood flow (Pallard, Castellarin, & Montanari, 2009). Hence, this implies that an area with higher drainage density means greater streams or rivers leading to greater chances for flash floods. The Drainage Density data can be acquired through the DEM of the Satellite Imagery, through various manipulations and calculations of said DEM in Arc Map. In the calculation of drainage density the line density tool calculates density as magnitude per unit area. The basic steps for the calculation are: Download DEM of study area, Create Drainage Network, Fill sink, Calculate Flow Direction, Calculate Flow Accumulation, Extraction of Drainage Network, Creation of Drainage Density Layer.

3.3.1.2.6 Criteria: Topographical Positional Index

TPI is an abbreviation for Topographical Positional Index which is generally used to determine how rugged a terrain is, in technical terminology it is the measure of a cell/pixels position (in DEM) relative to the surrounding. In general, the higher TPI values indicate hilltops or steep areas with greater chances for accumulating/receiving runoff and causing flash floods. A study was conducted to determine the effects of morphological factors on floods amongst which TPI analysis in said study represented levels of waterlogging which aided in the determination of flash flood susceptibility (Bashir, 2023). TPI can be calculated from the study area's DEM by using of formulas specific to this index. The basic steps for the calculation of TPI is as follows: Use Focal statistics Tool on DEM, Then Use Minus tool on DEM and Focal Statistics Layer, The Resulting Layer Is TPI. In simpler terms the TPI can be calculated by comparing slope values to the mean slope of the cell's neighbors.

3.3.1.2.7 Criteria: Topographic Wetness Index

TWI is an abbreviation for topographic wetness index as the name implies the primary use of this index is to refer to the tendency of an area to accumulate water. In Simpler terminology it is used to describe how "wet" an area is, the higher the TWI value the more wetter the area and vice versa. This is significant as higher TWI values represents areas with greater wetness/ high saturation and low drainage potential and hence more likely the chances of flash flood event. TWI values represent the water contained in a slope hence it influences slope instability which greatly influences flash floods (Science, 2021). TWI is an index that can be calculated through the following formula:

$$ln\frac{CA}{Slope}$$ -------------------------Equation 3.3

Where CA represents upslope catchment draining through a grid cell while slope represents the steepest outward slope for each grid cell, measured as tan of the slope angle.

3.3.1.3 Snow Avalanche Susceptibility Triggering Factors

The factors to be used as criteria in AHP analysis for snow avalanche susceptibility are as follows: LULC, NDSI, Slope, Aspect and Curvature which were considered after going through relevant literature and expert opinion. Since Slope, Curvature, LULC and aspect have already been defined the only factor represented in this section would be NDSI. Hence the table in the appendix would only include one factor.

3.3.1.3.1 Criteria: Normalized Difference Snow Index

It is an abbreviation for normalized difference snow index, as the name implies it is used to determine snow cover over an area of interest. The reflectance of snow is similar to clouds hence it becomes difficult to distinguish between them but at 1.6mm snow absorbs sunlight giving a darker shade than clouds hence satellite in general observe snow cover at ranges of 0.66mm to 1.6mm As it determines the presence of snow in a pixel. The range of values is from -1 to 1 where a NDSI value >0.0 represents some snow cover while a value of <=0.0 represents snow free areas. As NDSI in simpler terms provide information regarding the spatial distribution and depth of snow cover such information when combined with slope angles, etc. greatly influences snow avalanches. Since NDSI is an index, it can be calculated using specific formulas for manipulating band values of satellite images. The formula used to calculate NDSI is as follows:

$\mathrm{NDSI} = \frac{\mathrm{GREEN} - \mathrm{SWIR}}{\mathrm{GREEN} + \mathrm{SWIR}}$ --------------------------------------Equation 3.4

Where the GREEN represents the band #3 and the SWIR (Short wave infrared) represents the band #6. Snow shows great absorption in short-wave infrared spectrum and is visible in the visible spectrum; hence, these band are used.

3.4 THEMATIC LAYERS CREATION AND PREPARATION

Thematic maps as the name implies are maps that represent a specific theme, in simpler terms they represent how a factor or variable changes geographically over a region. Thematic maps are composed of standard content elements such as mathematical elements, geographic elements, socioeconomic elements, and auxiliary and additional elements (Kovarik & Talhofer, 2013). In fact a study was carried out to compare scientific visualization to thematic visualization where thematic visualization was defined as the mapping that puts importance upon the communication of known information to the users through perceivable graphics and that in terms of data processing thematic visualization is better than scientific visualization (Ding & Meng, 2014). For this study the type of thematic map used would be a choloropeth map Choropleth maps are commonly used to show statistical variation among map enumeration units, Choropleth maps show the variation in quantitative data among enumeration units such as countries, states, or counties (Stewart

& Kennelly, 2010). The Slope thematic map has been classified into five classes as 0°-15°, 15°-26°, 36°-47°, 47°-81° and onwards. Since aspect represents the orientation of slope it has been classified into 10 different classes based on theoretical classification, each class represents the direction in which slope angle varies. For cases of no slope -1 is the value given (the gray color represents that). The classification units are ° degree. There are different kinds of curvature datasets such as Profile curvature and Plane curvature etc. The curvature represented above is Profile Curvature which represents curvature parallel to the maximum slope direction, where a surface is upward convex at a cell if value is negative and upward concave if the value is positive while 0 value represents linearity of surface. The unit of classification is radians per linear units, the curvature has been classified into five classes which are: (-50.73- -4.42), (-4.42- -1.36), (-1.36- -0.82), (-0.82-3.88), (3.88-60.67 and onwards). While as the name implies the Land use/ Land Cover thematic map represents the distribution of resources on the region of interest, as discussed in the section 3.3.1.1.6 the land cover map has been classified into 8 different classes.

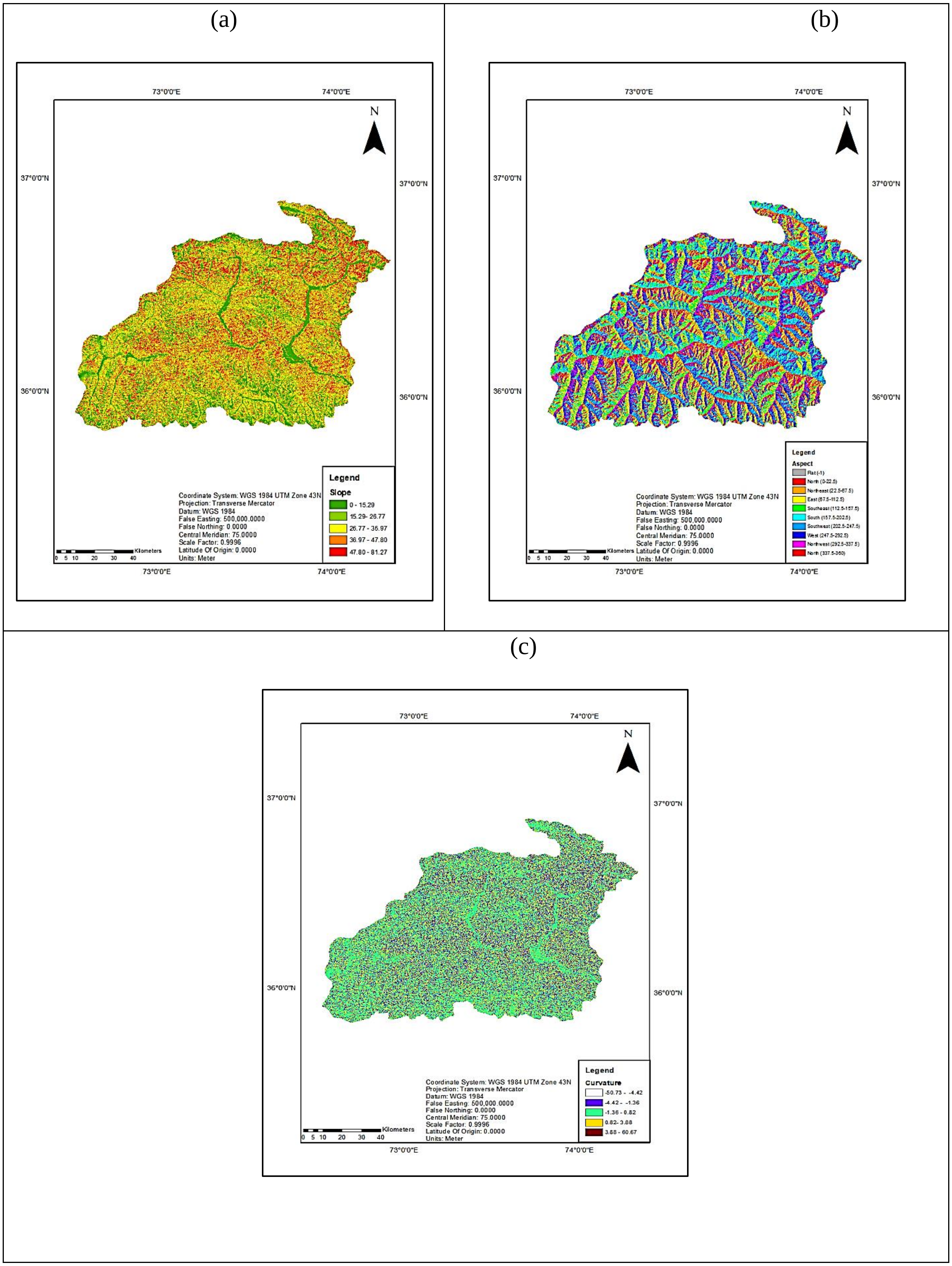


Figure 3.2. Showing (a) slope, (b) aspect, and (c) curvature thematic map of the study area.

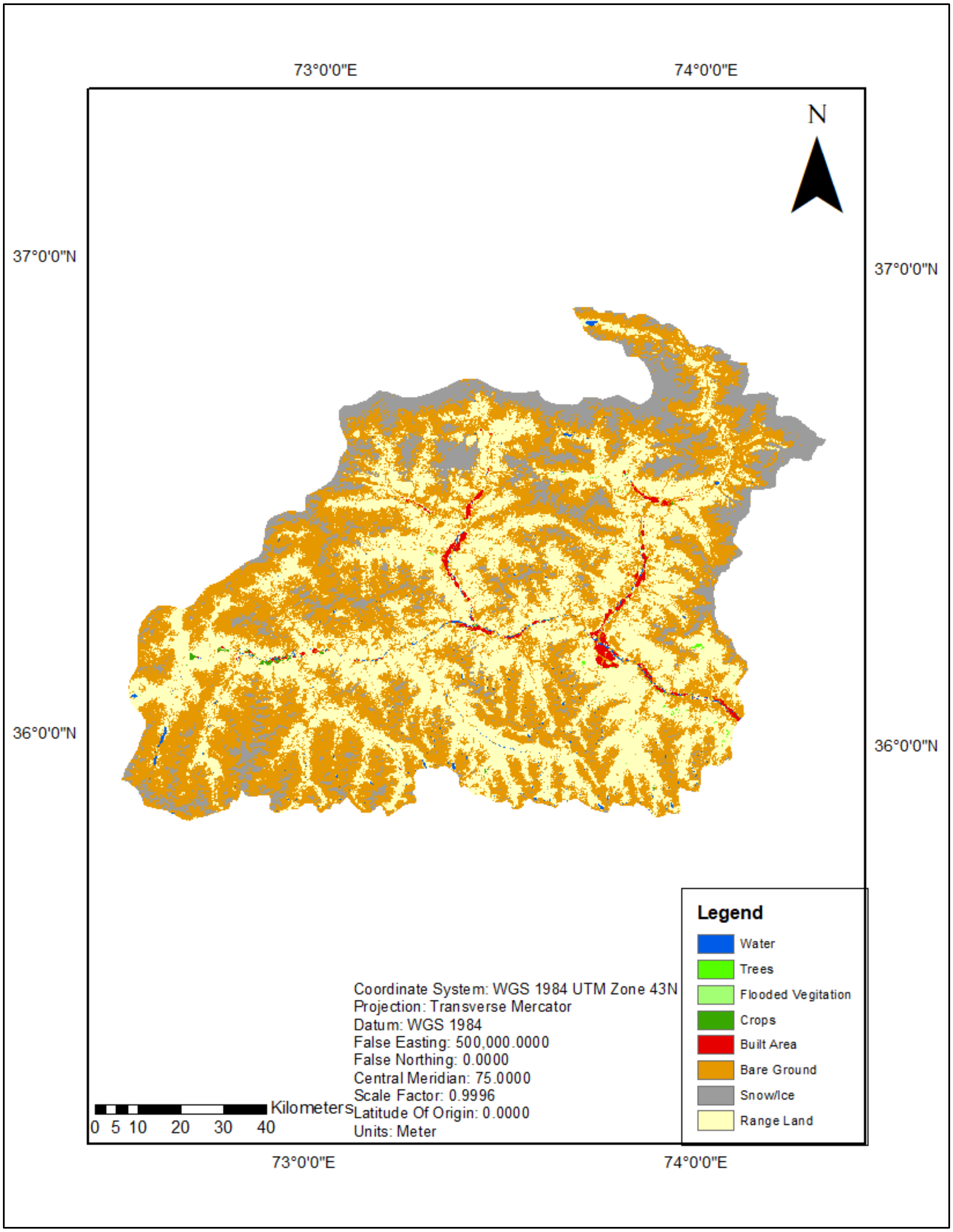


Figure 3.3. Land use land cover map of the study area.

3.4.1 Annual Precipitation (2022) and Drainage Density Thematic Map

This map represents the fact that for the afro mentioned year the precipitation was greater in the south-west potion of the region. The Annual Precipitation thematic map was classified into 5 different classes which are as follows: (226.21-260.95), (260.95-286.63), (286.63-323.64), (323.64-371.22) and (371.22-418.81). The thematic map for Drainage Density on the other hand was also classified into 5 classes which are as follows: (12.68-72.92), (72.92-97.46), (97.46-114.56), (114.56-134.64), (134.64-202.31).For calculating the susceptible zones of the region of Ghizer District it becomes important to take into account both Annual Precipitation and Drainage Density as triggering factors. These triggering factors also effect each other as precipitation greatly influences the formation of said drainage density networks. Precipitation in general can effect drainage density as precipitation leads to erosion which can lead to creation of various channels as time progresses, precipitation also effects the amount of sediments in waterbodies as precipitation generally creates runoffs that carry sediments which can affect the topology of said drainage networks. Groundwater reservoirs are also replenished by precipitation which can indirectly effect drainage density. In fact a study was conducted regarding the effects of various environmental variables on drainage density, in this study precipitation somewhat increased drainages density and then decreased drainage density as with increase in precipitation the vegetation increases as time progresses which decreases the drainage density (Gao, Liu, Yan, Qin, & Li, 2022). There are cases for how precipitation and drainage density affect Flash-Flood occurrence such as the case of the 2013 Flash- floods of Uttarkhand India caused by great influx of precipitation and poor drainage networks.

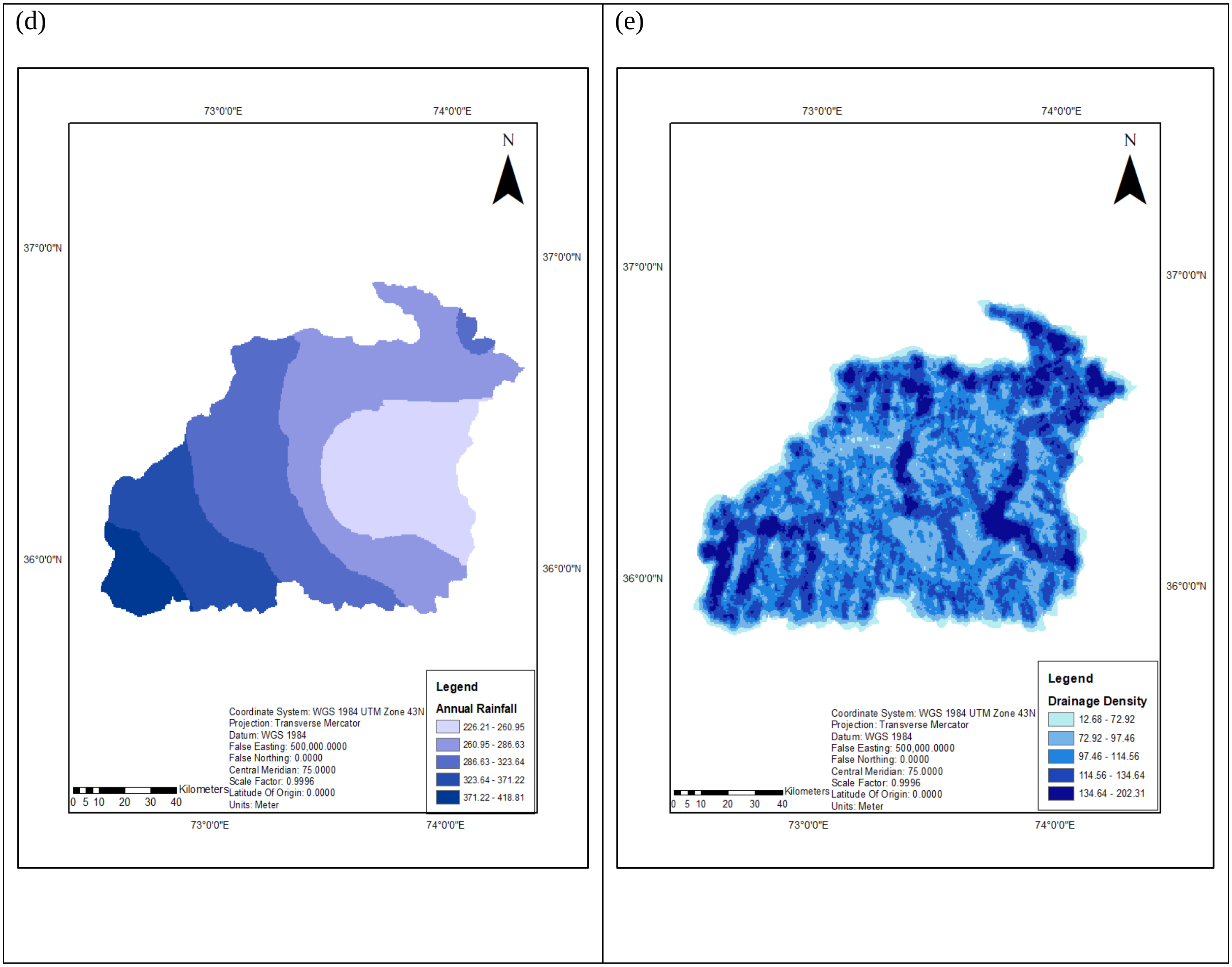


Figure 3.4. showing (d) annual precipitation and (e) drainage density thematic map of the study area.

3.4.4 NDVI, NDWI and NDSI Thematic Map

The NDVI values have been classified into 5 categories based on the region, the classification are as follows: (-1 - -0.45), (-0.45 - -0.09), (-0.09- - 0.004), (-0.004 – 0.33) and (0.33 – 1). As already explained in section 3.3.1.2.3 -1 value indicates no to very little vegetation while +1 value indicates healthy and dense vegetation. The NDWI value range is from -1 till +1 hence the values have been classified as follows: (-1 - -0.55), (-0.55 - -0.15), (-0.15 - -0.02), (-0.02 – 0.22), and (0.22 -1). Keep in mind that NDWI values also represent moisture to a specific degree as well hence the dark blue color shows water bodies. Values >= 0.4 start showing moisture values with values of and greater than 0.7 represent water bodies and such (Kemarau & Eboy, 2021). NDSI values in general are greatly affected by the environmental conditions of the region (Poussin, Timoner, Chatenoux, Giuliani, & Peduzzi, 2023). Although the NDSI value ranges from -1 till +1 but for simplicity purposes, the values have been classified as those representing snow cover and those that do not, as shown in the figure below. Natural hazards such as Flash-Flood Susceptibility is greatly affected by NDVI and NDWI on the other hand Snow Avalanches are greatly affected by NDSI. These indices also influence one another in certain ways such as for the case of a region which has snow cover the NDSI of said region would have a negative or inverse relation with the NDVI of said region as the greater the snow cover the less healthy the vegetation in such climates. But for the case of a region with very little to no snow cover no to very little relationship is formed between NDVI and NDSI. Similarly the influence of NDVI on NDWI and vice versa is also effected by the environmental conditions of a region. NDVI and NDWI would have a positive relationship for a region of dense vegetation.

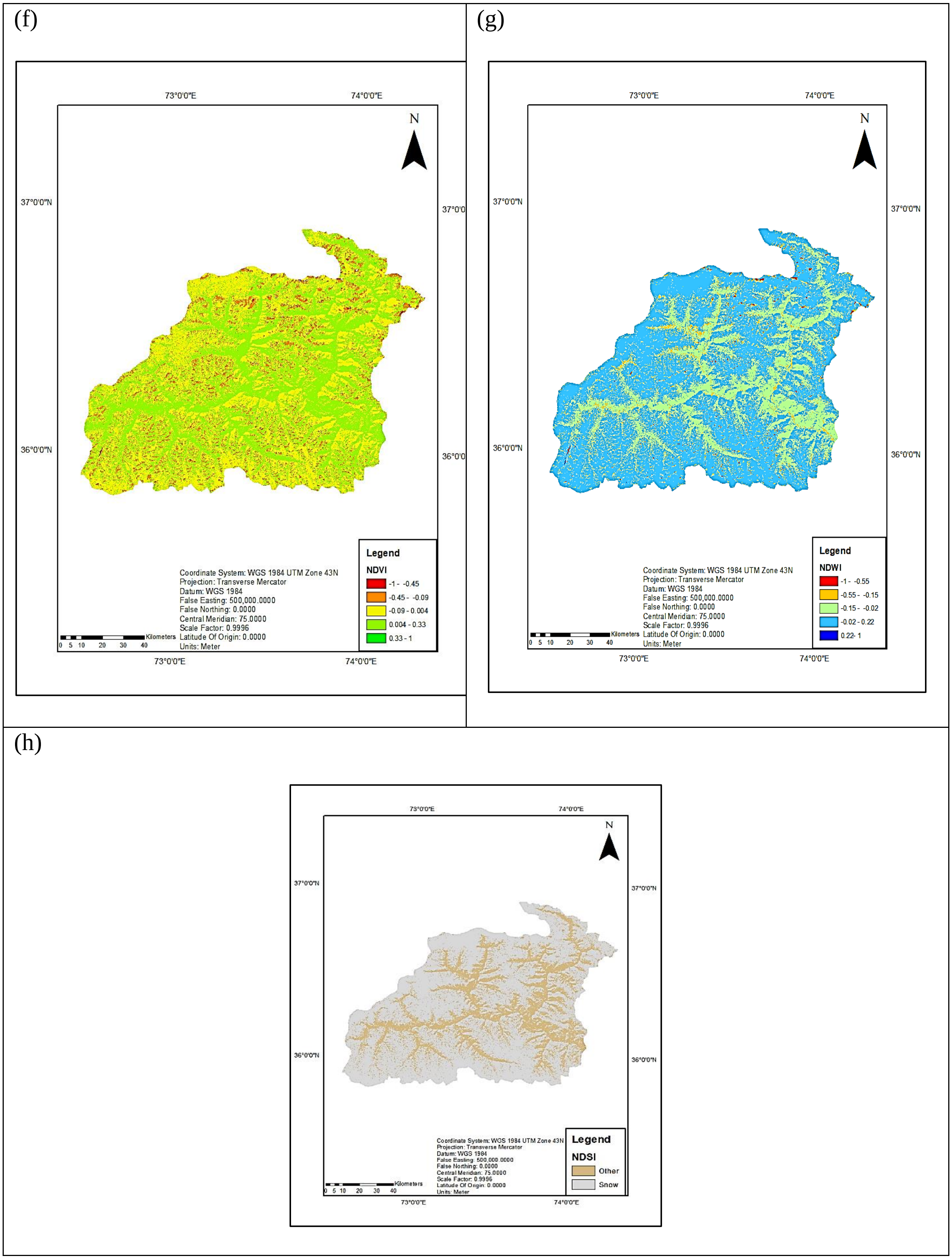


Figure 3.5. Showing (f) NDVI, (g) NDWI and (h) NDSI thematic map of the study area.

3.4.5 TWI and TPI Thematic Map

The basic things to be kept in mind while calculating the TWI value are as follows: Type and resolution of DEM, pre-processing of DEM, slope algorithm and the flow algorithm for catchment area (Kopecký, Macek, & Wild, 2020). The value range of TWI would greatly depend upon the landscape, such as areas with larger upslope catchment area and shallower slope gradient with higher TWI values and vice versa. In general as TWI is a natural log calculation it would have negative values but for certain cases where CA< Slope. The primary purpose of the TWI is to account for soil moisture hence it has been classified into the following classes: Very Low, Low, Medium, High and Very High for simplicity purposes. The TPI value where positive (above zero) represents places/location higher than the average while negative values represent locations lower than the average. On the other hand Zero values represent flat surfaces. TPI has been identified to be a good tool for landform and slope position classification (Reu et al., 2013). The TPI values have been classified as follows: Very Low, Low, Medium, High and Very High for simplicity purposes. Both TWI and TPI are destine indices but they can influence one another to an extent for example as TPI measures and references the position such that negative TPI values in general represent lower than average locations such as valley or depression where water in general tends to accumulate leading to an increase in TWI values but these influences are indirect as the relationship between TWI and TPI greatly depends upon the landscape of the region. A study was conducted for the region of Inverloch, Victoria, Australia that clearly represented TWI as the cost-efficient technique for Flood-Risk based land use planning as compared to traditional hydrological models (Pourali et al., 2016). Both the TWI and the TPI are represented side by side in the figure 3.6 below.

(i) (j)

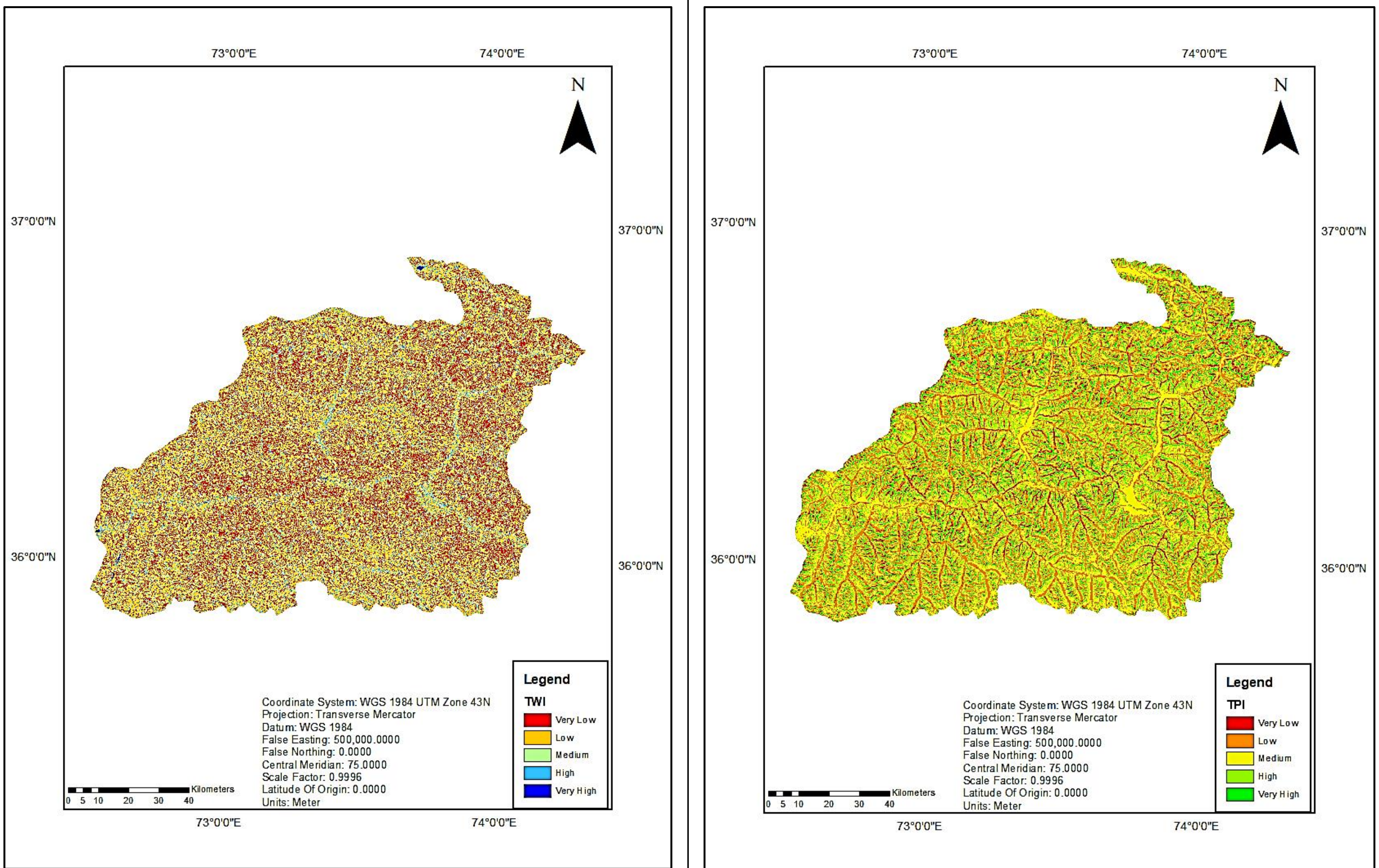
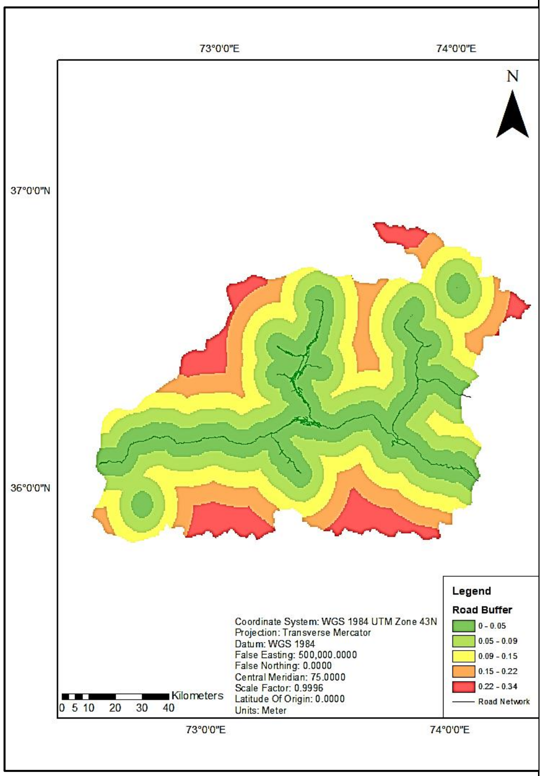


Figure 3.6. Showing (i) TWI and (j) TPI thematic maps.

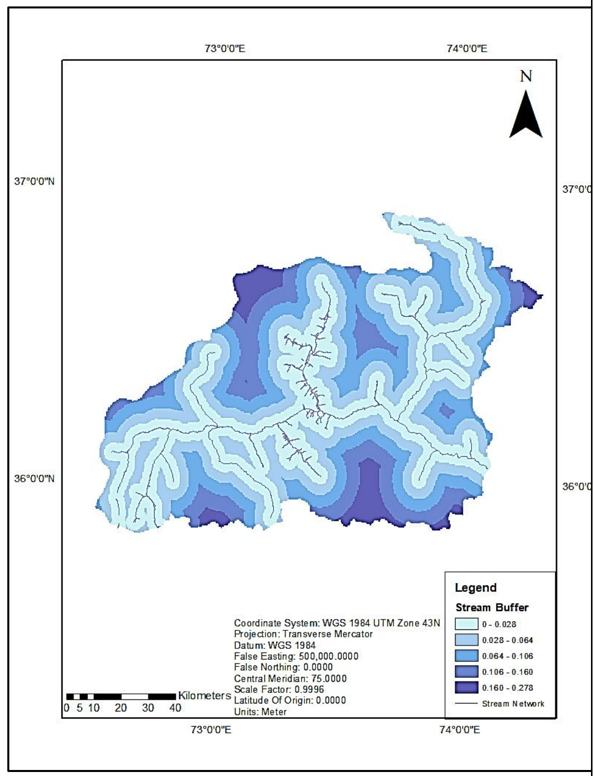
3.4.6 Stream Buffer, Road Network Buffer, Fault line Buffer and lithology Thematic Map

The streams in the map shown in the figure below are represented by a vector shapefile as mentioned in the legend, the calculation units was meters. The values have been classified as follows: (0 – 0.026), (0.026 – 0.064), (0.064 – 0.106), (0.106- 0.160) and (0.160 – 0.278 and above). The road network data is represented in the map shown in the figure below through a vector shapefile as represented in the legend, the units of distance calculation were meters. The data has been classified into 5 classes which are as follows: (0 – 0.045), (0.045 – 0.094), (0.094 – 0.147), (0.147- 0.211) and (0.211- 0.347 and above). The fault line are represented as vector shapefile as shown in the legend. The values have been classified as follows: (0 – 0.04), (0.04 – 0.09), (0.09 – 0.16), (0.16 – 0.24) and (0.24 – 0.41 and above). These factors greatly influence natural hazards such as Flash-Floods and landslide for example the locations near to a waterbody such as a stream would have a higher chance of Flash-Flood occurrence as compared to the regions which are far from streams or water bodies and as Flash-Floods can cause liquefaction of the soil it can somewhat lead to land sliding hence distance to streams effect the chances of occurrence of both Flash-Flood and Land Slide. On the other hand distance to fault lines can greatly affect the occurrence of Land Slide such as the regions near a fault line would be more prone to an earthquake which can cause landslides to occur as compared to the region farther away from fault lines. Distance from roads on the other hand can represent the location of the urban zones prone to said natural hazards. These three triggering factors/ Criteria are shown in the figure side by side. While the lithology thematic map is categorized in accordance with USGS global lithology classes and is shown in figure 3.8

(k)



(l)



(m)

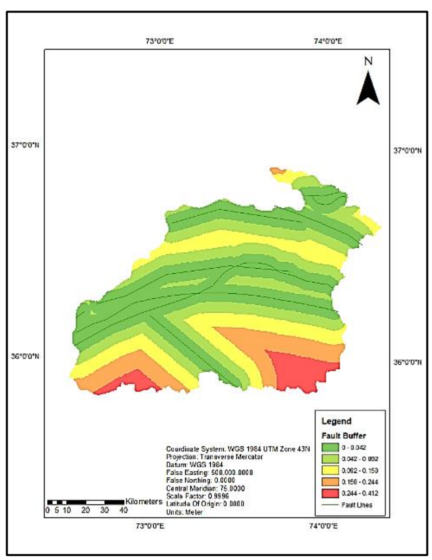


Figure 3.7. Showing (k) road network, (l) stream network and (m) fault line buffer thematic maps.

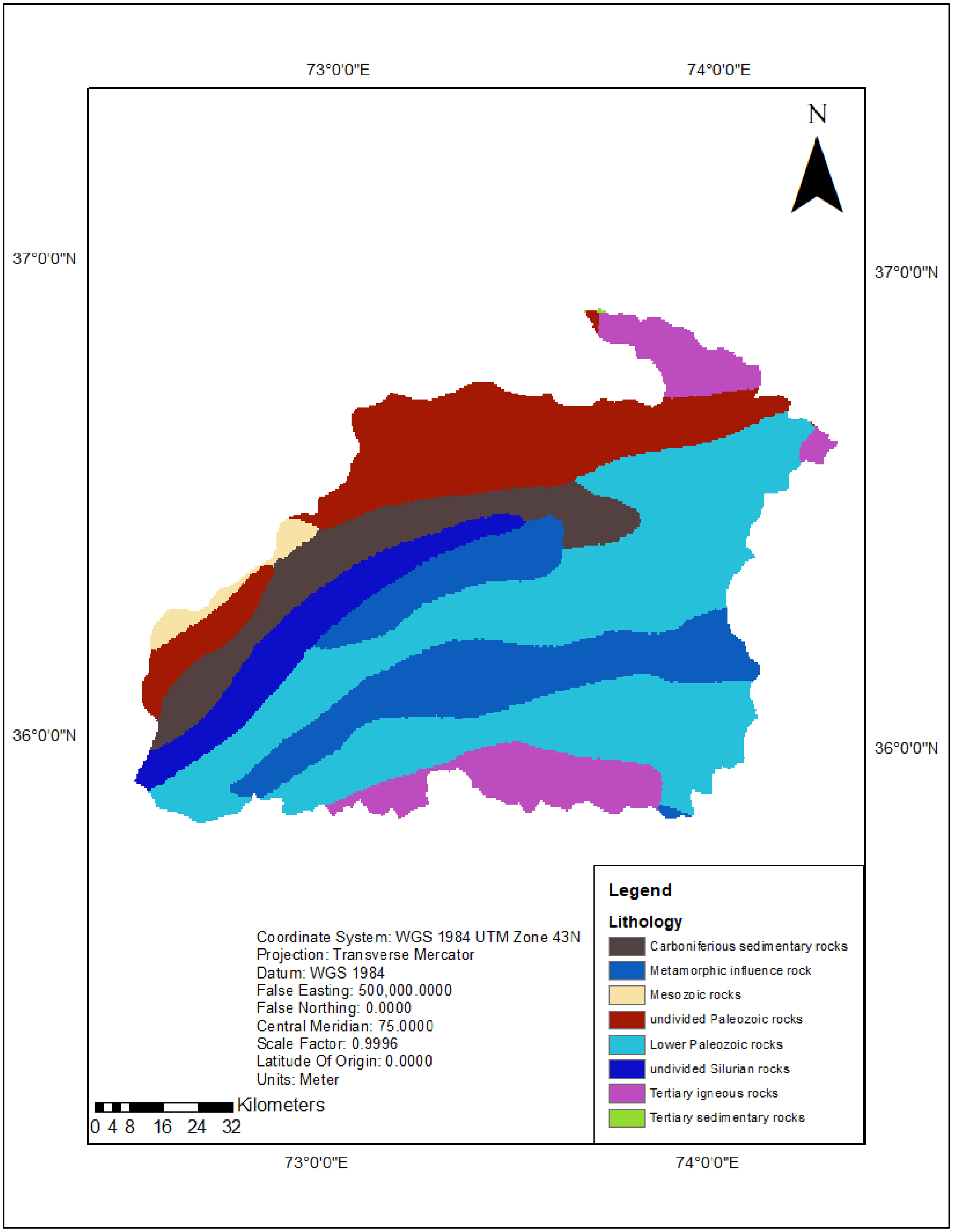


Figure 3.8. Lithology thematic map.

3.5 METHODOLOGY

3.5.1 Methodology Flow Diagram

From the figure 3.9 represented below the basic work flow can be concluded through the following steps: (step:1) Collect Satellite Image Data, (step:2) Collect DEM, (step:3) Collect Meteorological Data, (step:4) Collect Vector Data from Open Street Map, (step:5) Collect Fault data, (step:6) Extract Necessary data from collected fault data, (step:7) Extract Necessary Data from DEM, (step:8) Generate Necessary Data from Open Street Map data, (step:9) Generate Necessary data from Satellite Imagery, (step:10) Geoprocessing and select causative factors (from all the data collected), (step:11) Use WLC method for creation of hierarchy of criteria, (step:12) Generate Susceptibility Maps through use of AHP model and Validate the model through the use of AUC method.

3.5.2 The AHP Model

Any process involving decision taking must be handled with extreme care as the outcome greatly depend upon the decisions. In terms of Geographic task such as planning for site selection, site allocation, location based problems and natural hazard susceptibility and other complex scenarios, there are a lot of things to consider in such cases before making a decision hence Multi-Criteria Decision Analysis technique (MCDA) is used. As the name implies, MCDA techniques are used when there are multiple solutions to a complex problems; in such cases, all solutions needs to be considered. The general working methodology of the MCDA technique includes the following: Alternatives which are the possible solutions to a specific problem, Criteria: the possible solutions which are evaluated and then compared, Weights: the values assigned to the possible solutions in order to organize said solutions, Decision maker: the stake holders whose decisions need to be considered in the outcome. MCDA tools can be used for a lot of processes for either single process which are process which involve alternatives are already understood generally in such cases the number of alternatives are in 10s or for multiple application and repeated process which involve alternatives in pools which are continuously changing. Other techniques such as statistical techniques can be used like information value (IV), weight of evidence and regression techniques although a comparative study was done in order to compare MCDA techniques with statistical methods, it was observed that MCDA techniques had better prediction accuracy and accurate case specific zoning compared to statistical techniques (Mousavi, Ataie-Ashtiani, & Hosseini, 2022). The Technique that is being used for this particular study is the Analytical Hierarchy Process (AHP) which in simpler terminology is a technique that uses both mathematical and psychological concepts. It was introduced and developed by Thomas L. Saaty in the 1970s, it is a structured approach having three important elements which are: The definition of the problem to be solved, Identification of possible solutions and alternatives for solving said problem and the creation of criteria for the evaluation of the options. The creation of the criteria is the most important element of the AHP method as through these criteria a decision is made based on assigning value to these criteria in order to create a hierarchy, which is done through the pairwise matrix comparison method which was introduced by Fechner in the 1860s and further developed by Thurstone in 1972. In order to assign values to the criteria the value scale was proposed by Saaty which is as represented in the table 3.2. Another important technique to be kept in mind while using the AHP model is the Weighted Linear Combinations Method as the name implies the assignment of weights to the criteria is due to this method. The

Hierarchy is formed during this process as the criteria are given importance with respect to their relative weight. The internal working of WLC method can be explained as follows: for the sake of the explanation let the alternatives be represented as $\{Xij|i = 1, 2, \dots \dots \dots . m\}$, where the "I" indicates the locations of the "ith" alternative. All alternatives or criteria are defined by their coordinates (location) and the attribute information associated with it. These general alternatives are map layers which have all the necessary data associated with the problem. The basic equation used to generate an outcome based on these alternatives is as follows:

$V(xi) = \sum_j WjVj(xi) = \sum_j WjRij$ ----Equation 3.5

Where the term "Wj" is the normalized weight. The weights represent the relative importance of the alternatives. The highest alternative is selected based on the V (xi) value. This formula was derived from the study (Malczewski, 2000) conducted to understand the importance of the WLC method.

3.5.2.1 Checking the Consistency in the AHP model

The Consistency plays a very important role in fact, if the result generated by the AHP model is not consistent then it is generally considered to be useless. Saaty created techniques to check whether the result of the AHP calculation were accurate or not through checking whether the decisions made in the pairwise comparison are consistent or not. According to Saaty in order to check whether the AHP results are accurate or not two things are needed to be calculated after the completion of the pair wise comparison portion of the AHP method, these things are the Consistency Ratio (CR) and the Consistency Index (CI). The CR in general indicates the consistency between the comparisons made in the pairwise comparison portion of the AHP process. The formula used to calculate the Consistency index is as follows:

$$\text{Consistancy Index} = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1} \text{ -----Equation 3.6}$$

Where λmax refers to the maximum eigenvalue of the pairwise comparison matrix, which is to be calculated with the following formula

$$\lambda\text{max} = \frac{\text{numbers of normalized criteria weight}}{\text{number of criteria}} \text{ -----Equation 3.7}$$

"n" refers to the number of alternatives or criteria. On the other hand the formula used to determine consistency ratio is as follows:

$$\textit{Consistency Ratio} = \frac{\textit{Consistancy Index}}{\textit{Randomn Consistancy Index}} \text{ ----Equation 3.8}$$

In this formula the random consistency index is and index created from a random matrix with data inserted randomly, the values generated in the random consistency index are based on the number of criteria being used. According to Saaty, the conditions for consistency are as follows: if CR>0.1, the pairwise comparison matrix result are inconsistent; while if CR <0.1, the pairwise comparison matrix results are consistent. The process is iterative, meaning that the process is to be repeated until the CR value is acceptable. As already stated that a hierarchy is created through the use of said criteria values the basic methodology flow diagram for the AHP is represented in figure 3.10

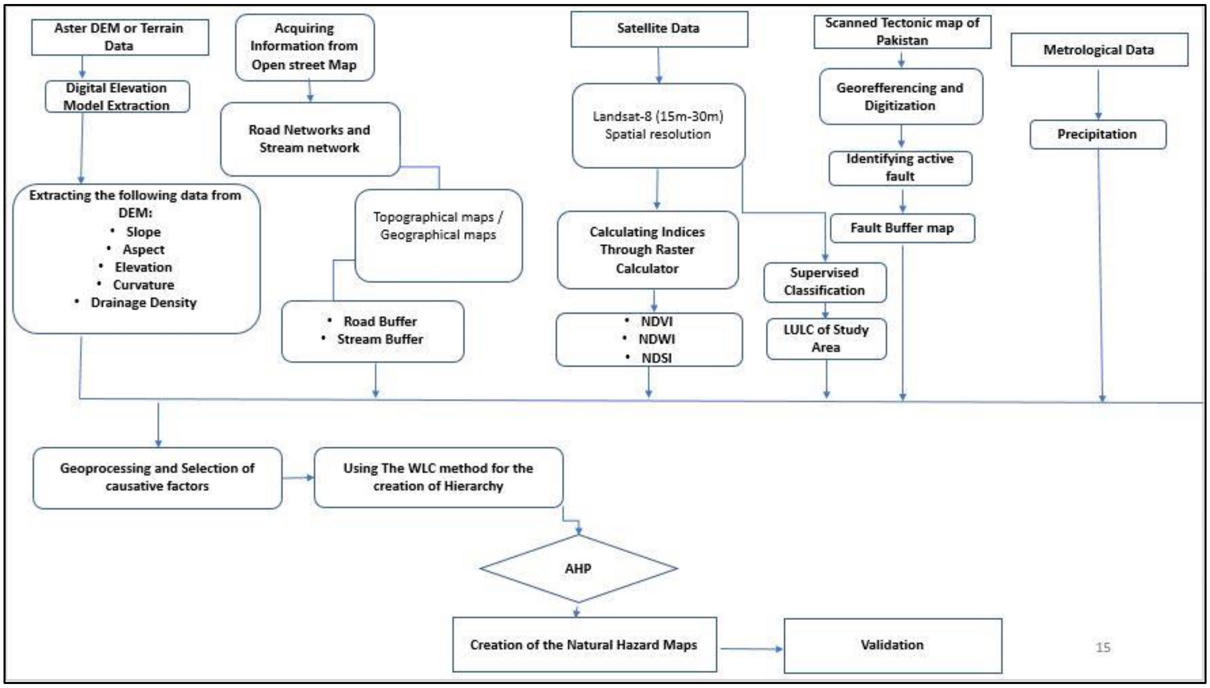


Figure 3.9. Shows complete detailed methodology flow chart of the study.

Table 3.2. The analytical hierarchy process criteria values scale.

Intensity (Value of importance)	**Definition of said value**
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

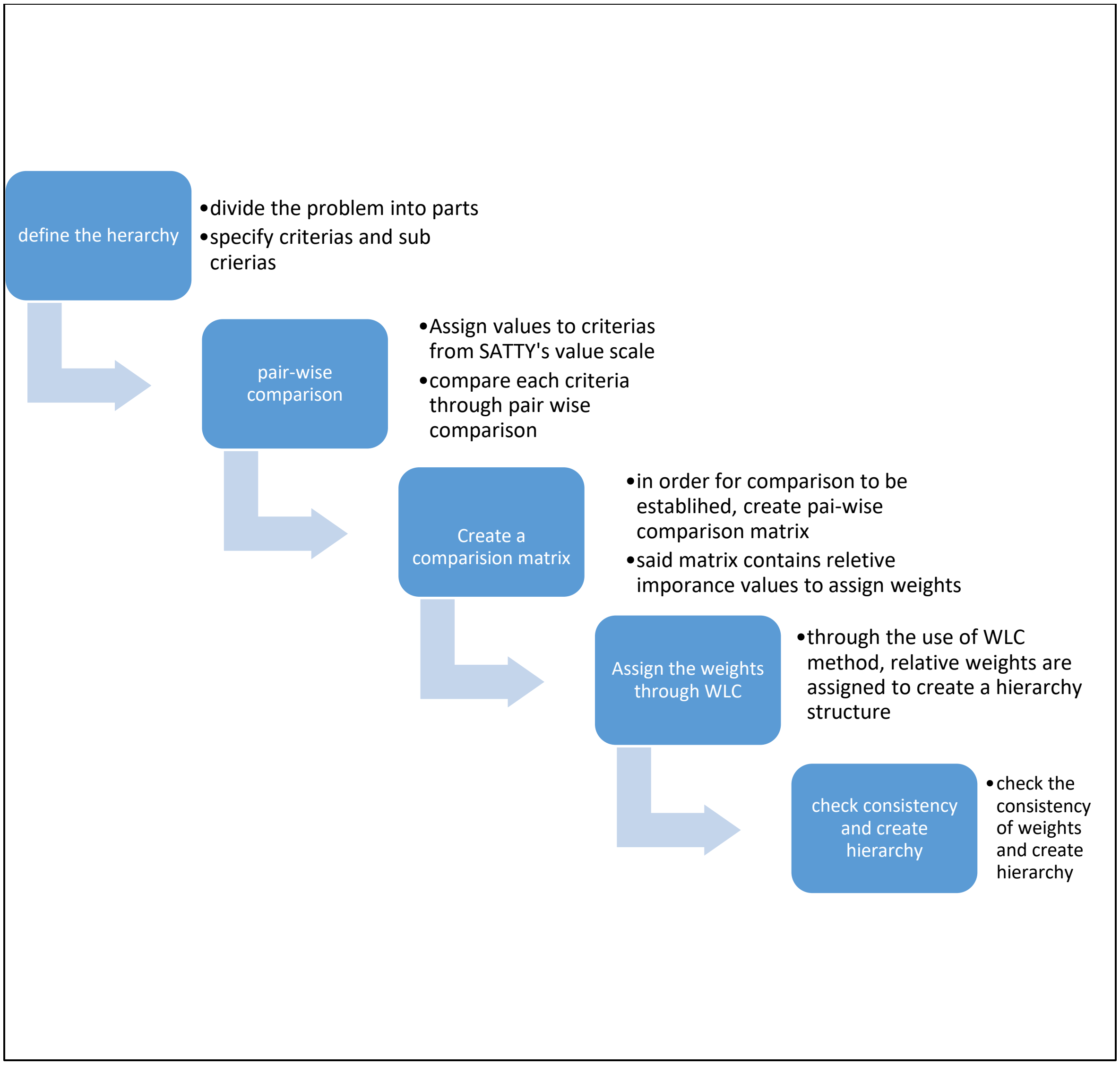


Figure 3.10. Work flow diagram for analytical hierarchy process.

Chapter 4

RESULTS AND DISCUSSION

This section deals with the working methodology used in order to create a multi-hazard susceptibility analysis model through the use of AHP along with discussions of the AUC (area under the curve) method used for determining the overall accuracy of the result along with description of the ROC curves generated as a result of AUC. As already discussed in the materials section, two extensions were used to generate multi-hazard susceptibility: EasyAHP of QGIS and Ext AHP 2.0 of the ArcMap. Both of these extensions are reliable open source plugins created to perform AHP analysis, but there are certain requirements such as the input datasets must be in raster form, and the input datasets must have the same projection units, they should have the same cell size and should have same extent.

4.1 LANDSLIDE SUSCEPTIBILITY ANALYSIS

The first thing to do to generate a landslide susceptibility zoning map is to define the criteria (triggering factors) that influence the occurrence of said natural hazard with respect to the study area. The criteria to be used have already been discussed in the section 3.3.1.1 seven factors were chosen to be the main triggering factors for said natural hazard, the maps of these factors are represented in the section 3.4. After the selection of the factors the next step is to use the AHP value scale as shown in the section 3.5.2 to give values to these factors and then create the pairwise comparison matrix as represented in the table 4.1.The result of the pair-wise comparison matrix is the assignment of weights to the criteria to create a hierarchy (the basis of the AHP process).The relative importance given to the factors in the pair-wise comparison matrix were in accordance with relevant research regarding the importance of said factors along with expert opinions. The resulting normailized weights for these factors after calculation are represented in the table 4.2. From the table 4.2 it can be observed that for the case of this study the main triggering factors of landslide susceptibility in the region of Ghizer district of Gilgit Baltistan are Slope angle with a weight of 34.61%, Lithology and Distance to Fault with weights 26.36% and 16.89% respectively. While the least important factor is Distance to Stream. The calculated CI and CR value for said pair-wise comparison matrix are represented in the table 4.3. As it can be observed from table 4.3 the CR value of 0.074731 is less than 0.1 hence the results of the pair-wise comparison matrix are consistent, while the CI value is 0.100139. Hence a landslide Susceptibility Zoning map can be created to represent the study area's susceptible zones. In order to check the validity or accuracy of the output historic landslide data was acquired from NASA landslide inventory along with acquiring occurred landslide locations through articles and local population. The Susceptible zones are classified into 5 classes as shown in the Map in the Figure 4.1. These Zones are classified concerning the probability of occurrence of landslides in said zones. The classes are Very Low, Low, Medium, High and Very High. The red dots in the Map below represent the historically occurred landslide inventory. It can be observed from the figure 4.1 that the region of high susceptibility to landsides is in accordance with the fault line data and the slope angle of the study area. The projection of this map is transverse Mercator while the coordinate system is the WGS 1984 UTM zone 43N.

Table 4.1. Landslide susceptibility pair-wise comparison matrix.

Factors	Slope	Lithology	Distance to Fault	Distance to Road	LULC	Aspect	Distance To Stream
Slope	1	2	3	4	6	7	6
Lithology	½	1	3	5	4	6	5
Distance to Fault	1/3	1/3	1	3	4	5	6
Distance to Road	¼	1/5	1/3	1	2	3	3
LULC	1/6	¼	¼	½	1	5	4
Aspect	1/7	1/6	1/5	1/3	1/5	1	2
Distance to stream	1/6	1/5	1/6	1/3	¼	½	1

Table 4.2. Landslide susceptibility normalized weights.

Factors	Normalized Weights (%)
Slope	34.61%
Lithology	26.36%
Distance to Fault	16.89%
Distance to Road	8.40%
LULC	7.22%
Aspect	3.48%
Distance to stream	3.01%

Table 4.3. Consistency check for landslides.

Calculation	Value
Calculated Consistency Index	0.100139
Calculated Consistency Ratio	0.074731

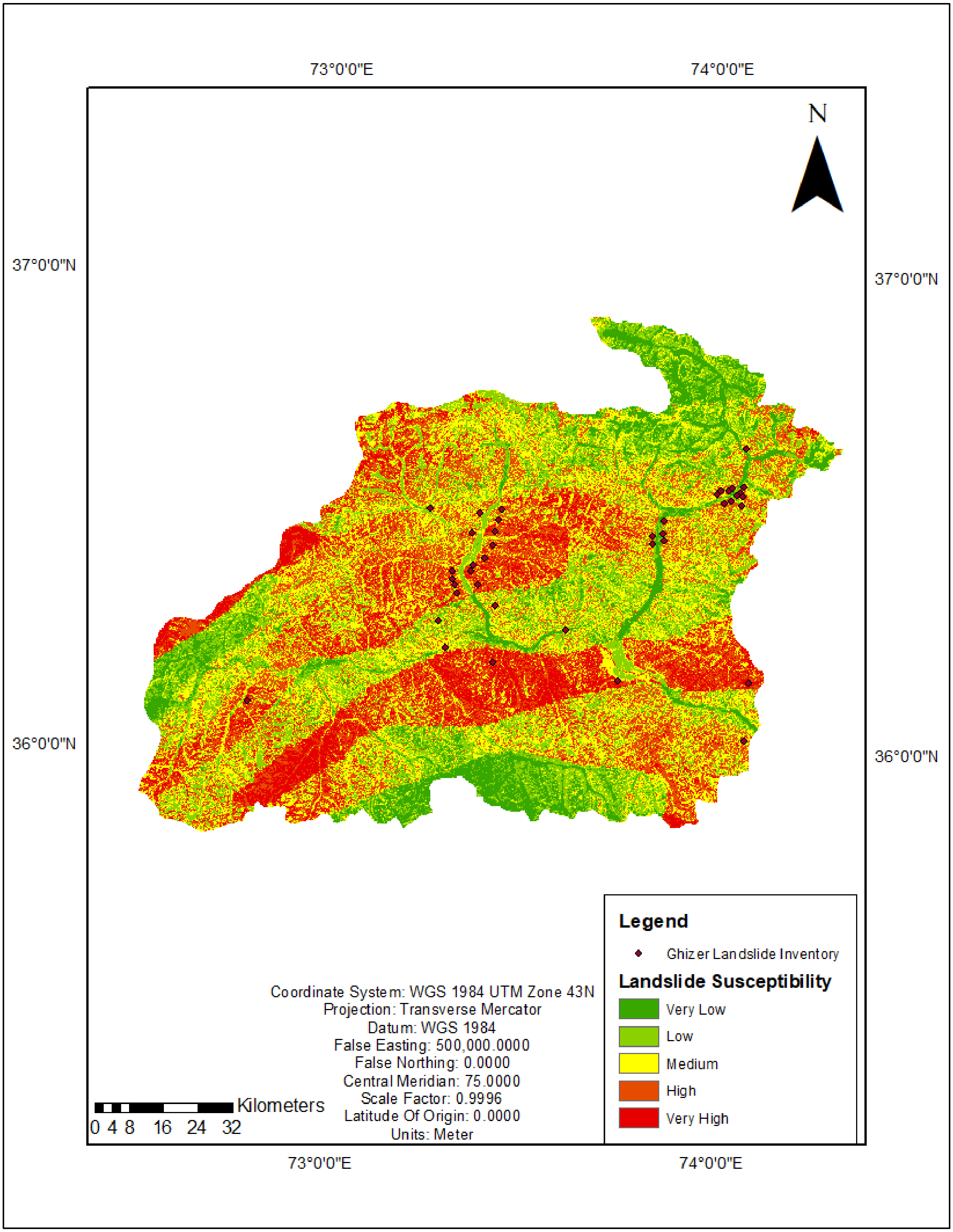


Figure 4.1. Landslide susceptibility zoning map of the study area.

4.1.1 Landslide Susceptibility Analysis Accuracy Assessment

The Primary method used to determine the accuracy of the result of AHP analysis was the AUC (Area under the Curve) method in conjunction with the ROC (Receiver Operating Characteristic). In general the basic working of the ROC method is to assess the accuracy of the results of the AHP model through the comparisons of the predicted ranking and the actual ranking of the criteria or alternatives. The AUC-ROC cure represents the performance of the model. The Graph of the ROC represents the plotting of the TPR (True Positive Rate) against the FPR (False Positive Rate) at different values. Both the TRP and the FPR represent the criteria. The AUC method on the other hand generally uses the ROC graph (curve) to calculate the AUC value which numerically represents the accuracy of the AHP analysis. Sensitivity and specificity are the two important terms to be kept in mind while using the AUC-ROC curve, sensitivity refers to the portion of positive classes that were classified correctly while specificity refers to the amount of negative classes that got classified correctly. The AUC value ranges between 0 to 1 where values greater than 0.5 refer to a AHP analysis with high predictive accuracy while a value of less than 0.5 refers to an AHP analysis with low predictive accuracy (Asmare, 2023). The resulting graph of landslide susceptibility analysis is represented in the figure 4.2. As explained above since the AUC value of the landslide susceptibility map is 0.713 which in simpler terms represents the fact that the result of the AHP model is satisfactory and hence the prediction values created by the AHP model are acceptable, however the AUC value can be improved by taking at least more than 20 or so true positives (historical data) of said natural hazard.

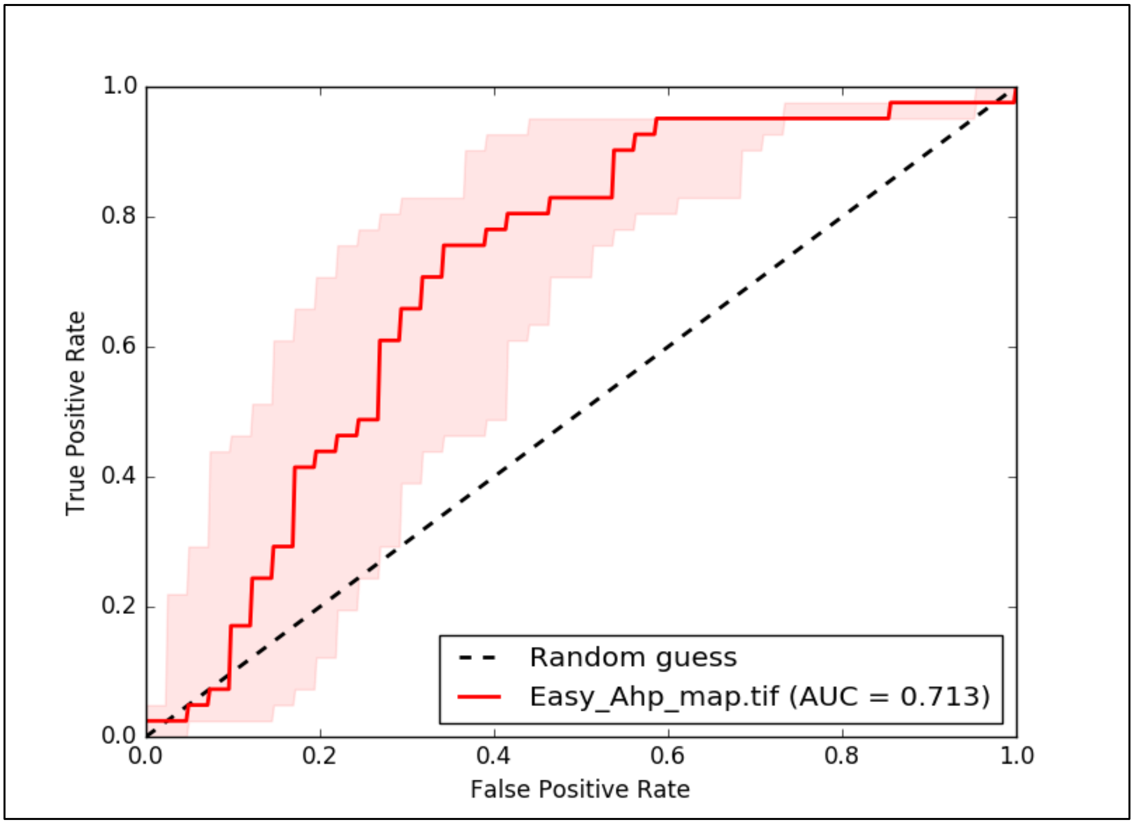


Figure 4.2. The roc graph for auc calculation for landslide susceptibility.

4.2 FLASH FLOOD SUSCEPTIBILITY ANALYSIS

Similarly, to determine the landslide susceptibility through the use of the AHP method, the criteria (triggering factors) must be defined. In the case of this natural hazard with respect to the study area there are 11 triggering factors. Relative importance should be given to these triggering factors through assigning each triggering factor a value according to AHP value scale as shown in the section 3.5.2 the thematic maps of said triggering factors are represented in the section 3.4. The triggering factors are discussed in detail in the section 3.3.1.2. The pairwise comparison matrix for said natural hazard is represented in the table 4.4. Normalized weights represent the relative importance given to these triggering factors similar to table 4.1, the normalized weights for said criteria are represented in table 4.5. The relative importance of each Criteria is described by its normalized weights and as seen from the Table 4.5 for flash flood concerning the study area NDWI, Drainage Density, Distance to Stream, Annual Precipitation and TWI are the most important factors. The relative importance values given to each criteria are based on research related to this topic. In order to check whether the results produced by the pair wise comparison matrix are accurate or not the calculated CR and CI values are represented in Table 4.6. The CR value is 0.065993, while the CI value is 0.099913.

Table 4.4. Flash flood susceptibility pair wise comparison matrix.

Factors	Aspect	Curvature	Slope	TWI	AP	D.T.S	D.D	NDWI	LULC	NDVI	TPI
Aspect	1	2	1/5	1/9	1/7	1/6	1/7	1/8	¼	½	1/3
Curvature	½	1	1/5	1/9	1/9	1/8	1/8	1/9	1/5	1/3	1/4
Slope	5	5	1	1/7	1/5	1/3	¼	1/6	2	4	3
TWI	9	9	7	1	3	5	4	2	8	9	9
Annual Precipitation	7	9	5	1/3	1	3	4	1/2	6	8	7
Distance to stream	6	8	3	1/5	1/3	1	½	1/4	4	6	5
Drainage Density	7	8	4	1/4	1/4	2	1	1/3	5	7	6
NDWI	8	9	6	1/2	2	4	3	1	7	9	8
LULC	4	5	½	1/8	1/6	¼	1/5	1/7	1	3	2
NDVI	2	3	¼	1/9	1/8	1/6	1/7	1/9	1/3	1	1/2
TPI	3	4	1/3	1/9	1/7	1/5	1/6	1/8	½	2	1

Table 4.5. Flash flood normalized weights.

Factors	**Normalized Weights (%)**
Aspect	1.53%
Curvature	1.15%
Slope	4.81%
TWI	27.18%
Annual Precipitation	15.70%
Distance to stream	8.89%
Drainage Density	11.64%
NDWI	21.02%
LULC	3.57%
NDVI	1.912%
TPI	2.59%

Table 4.6. Consistency check for flash flood.

Calculation	**Value**
CI	0.099913
CR	0.065993

As the CR value is less than 0.1, the pair wise comparison matrix results are consistent. The Flash Flood Susceptibility Map was created through the AHP model and historical data acquired through digitization from Google Earth. The historical data is to be taken as the True positive rate to check the accuracy of the result of the AHP model. The generated map is shown in the Figure 4.3. The projection of this generated map is transverse Mercator and the coordinate system is WGS1984 UTM Zone 43N. From Figure 4.3 it can be observed that the vector shapefile in the form of the line represents the stream network of the study area which was acquired from open street map, the shapefile in the form of points represents the historical data of occurred flashfloods while the thematic representation is of the flashflood susceptible zones.

4.2.1 Flash Flood Susceptibility Analysis Accuracy Assessment

The Area under the curve method was used for Flash Flood Susceptibility Accuracy Assessment. The details of the Area under the Curve method has already been explained in the section 4.1.1 and as explained in that section an AHP value greater than 0.5 is represents have high prediction accuracy. The AUC graph of said natural hazard susceptibility is represented in figure 4.4. As it can be observed from the Figure 4.4 is that the AUC value for the prediction of flash flood susceptibility trough use of AHP model is 0.728 which is satisfactory, hence the predicted values from the AHP model are acceptable. The AUC value can be improved by obtaining more true positives (historical data) in order to draw a greater comparison between the historical data and the predicted data generated from the AHP model.

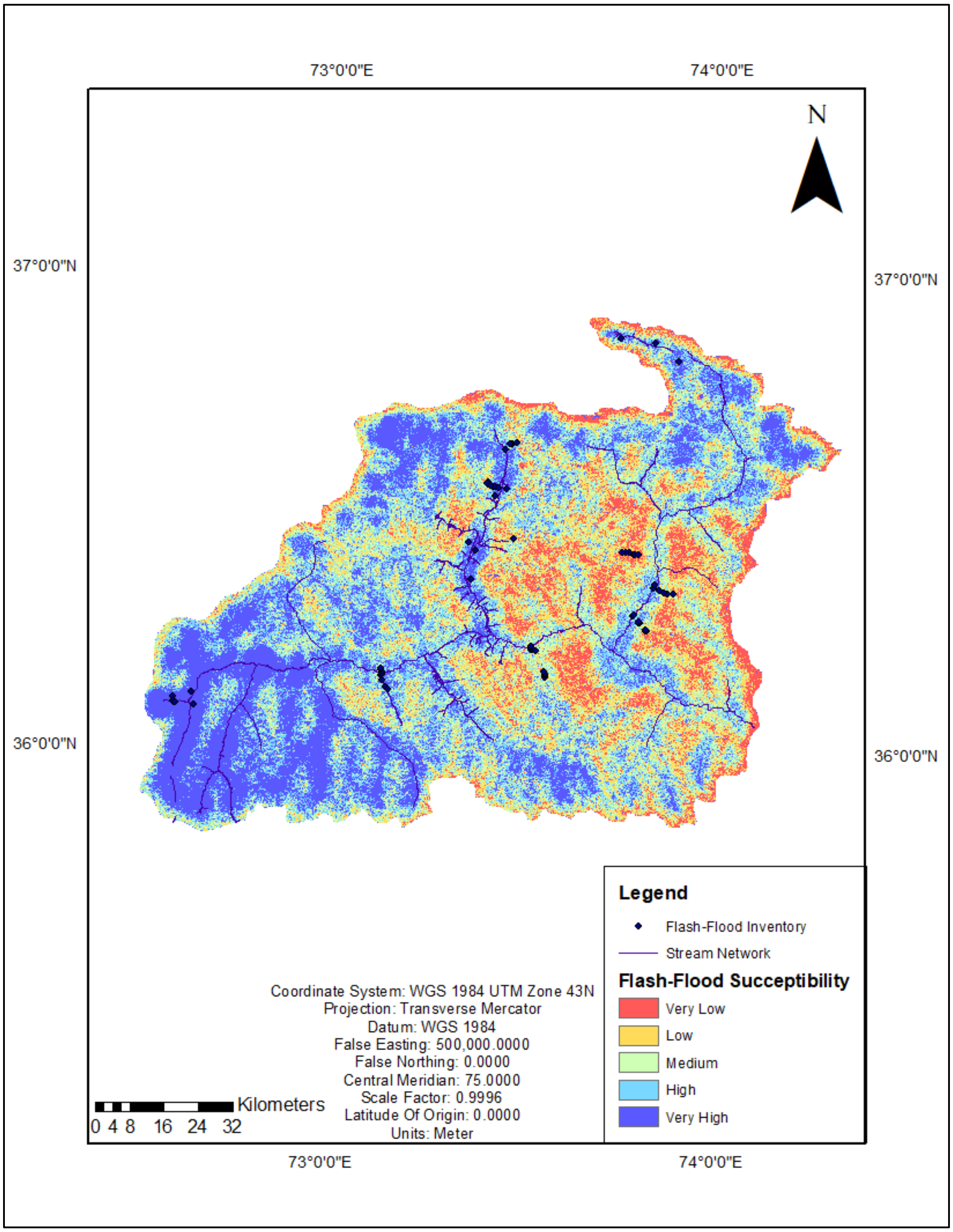


Figure 4.3. Flash flood susceptibility map.

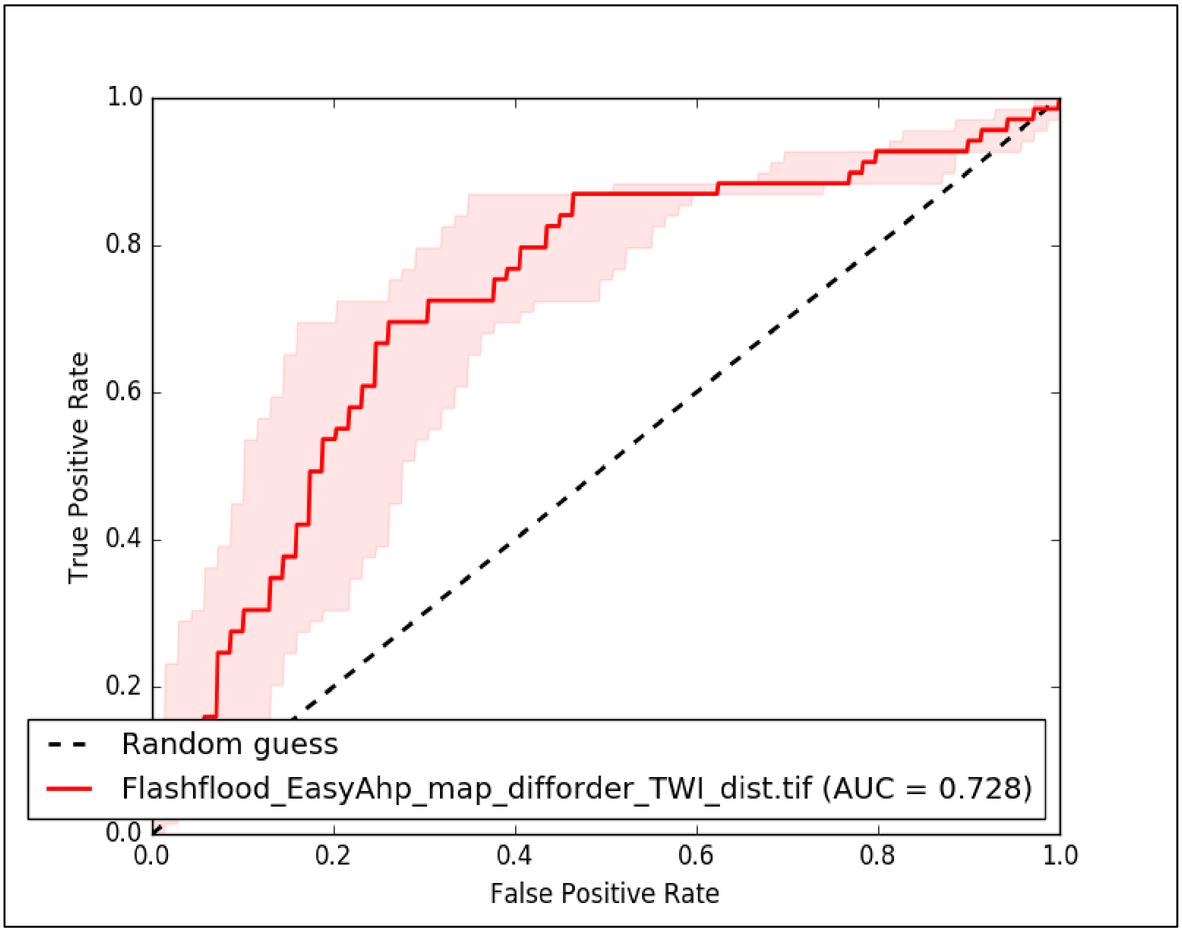


Figure 4.4. Flash flood area under the curve.

4.3 SNOW AVALANCHE SUSCEPTIBILITY ANALYSIS

The Snow Avalanche Susceptibility was also performed through the use of the AHP model, in order to create snow avalanche susceptible zones. In a similar fashion to Landslide Susceptibility and Flash Flood Susceptibility, the first thing to do is to define the criteria for said natural hazard, concerning the study area. The criteria have been defined in section 3.3.1.3 and the thematic maps for said criteria have been represented in the section 3.4. As represented in the sections that have been mentioned, 5 criteria were chosen to be used in the AHP model namely Slope, Aspect, Curvature, LULC and NDSI. Relative importance given to these criteria based on the value table given in section 3.5.2. The pair-wise comparison matrix used to assign weights to said criteria has also been explained in the mentioned section. The Pair-wise comparison matrix for Snow Avalanche for the study area is given in the table 4.7. From the table 4.8 containing normalized weights it can be observed that for the case of snow avalanche for the study the important triggering factors are NDSI with a weight of 41.607%, LULC with a weight of 20.434% and Slope with a weight of 23.171%. The CR and the CI value calculation are represented in the table 4.9. The CR value is 0.025304 which is less than 0.1 hence the results of pair-wise comparison matrix are accurate. As it can be observed from the figure 4.5 the point shapefile represents the snow avalanche inventory which was acquired from the research paper (Sardar, Raziq, Rashid, & Saddiq, 2019). In said research paper the inventory was provided in the form of snow avalanche hotspots for the district Ghizer of Gilgit Baltistan. It can be observed from the figure 4.5 that the natural hazard of snow avalanche is prominent in those portions of said region where there is greater snow cover and this natural hazards generally does not occur in the populated regions of said district. That does not mean that it has never occurred in an urban region but for the case of Ghizer district the occurrence of Snow Avalanches are in the mountainous regions of the district primarily near the glacier and snow covered mountains. But as mentioned in the section 1.5 there have been cases in which the extent of the snow avalanche has effected the population primarily the villages and the military outposts in mountains. The primary reason for said natural hazard occurrence is due to high slope of the mountainous regions along with the sub-polar weather of the study area which can cause extreme weather conditions to occur in said mountainous regions, on the other hand anthropogenic activities such as skiing and construction can also cause snow avalanches to occur. Other natural hazards such as landslide in an area of snow cover can cause avalanche as avalanche is somewhat a type of landslide as it involves a movement of mass (snow) downwards a slope. The Resulting Thematic map representation of Snow Avalanche for the particular study area is shown in the figure 4.5. The projection coordinates of the study area is in UTM zone 43N. The Snow Avalanche inventory was used as true positives in the AUC calculation in order to calculate the accuracy of prediction of the AHP method used to determine Snow Avalanche Susceptibility. The resulting graph is represented in the figure 4.6. The primary reason for high accuracy is their greater number of points taken as true positives as compared to those used for flash flood and landslide susceptibility. Generally, the more the ground points or historical data, the greater the comparison between the predicted susceptible zones (predicted by the model) and the historical damage done to locations based on historically recorder natural hazard events.

Table 4.7. Snow avalanche pair-wise comparison matrix.

Factors	**NSDI**	**LULC**	**Aspect**	**Slope**	**Curvature**
NSDI	1	2	7	2	5
LULC	½	1	4	1	2
Aspect	1/7	¼	1	1/5	½
Slope	½	1 ½	5	1	2
Curvature	1/5	½	2	½	1

Table 4.8. Snow avalanche normalized weight.

Factors	**Normalized Weights (%)**
NDSI	41.607%
LULC	20.434%
Aspect	5.018%
Slope	23.171%
Curvature	9.771%

Table 4.9. Consistency check for snow avalanche susceptibility.

Calculation	**Value**
Calculated Consistency Index	0.028088
Calculated Consistency Ratio	0.025304

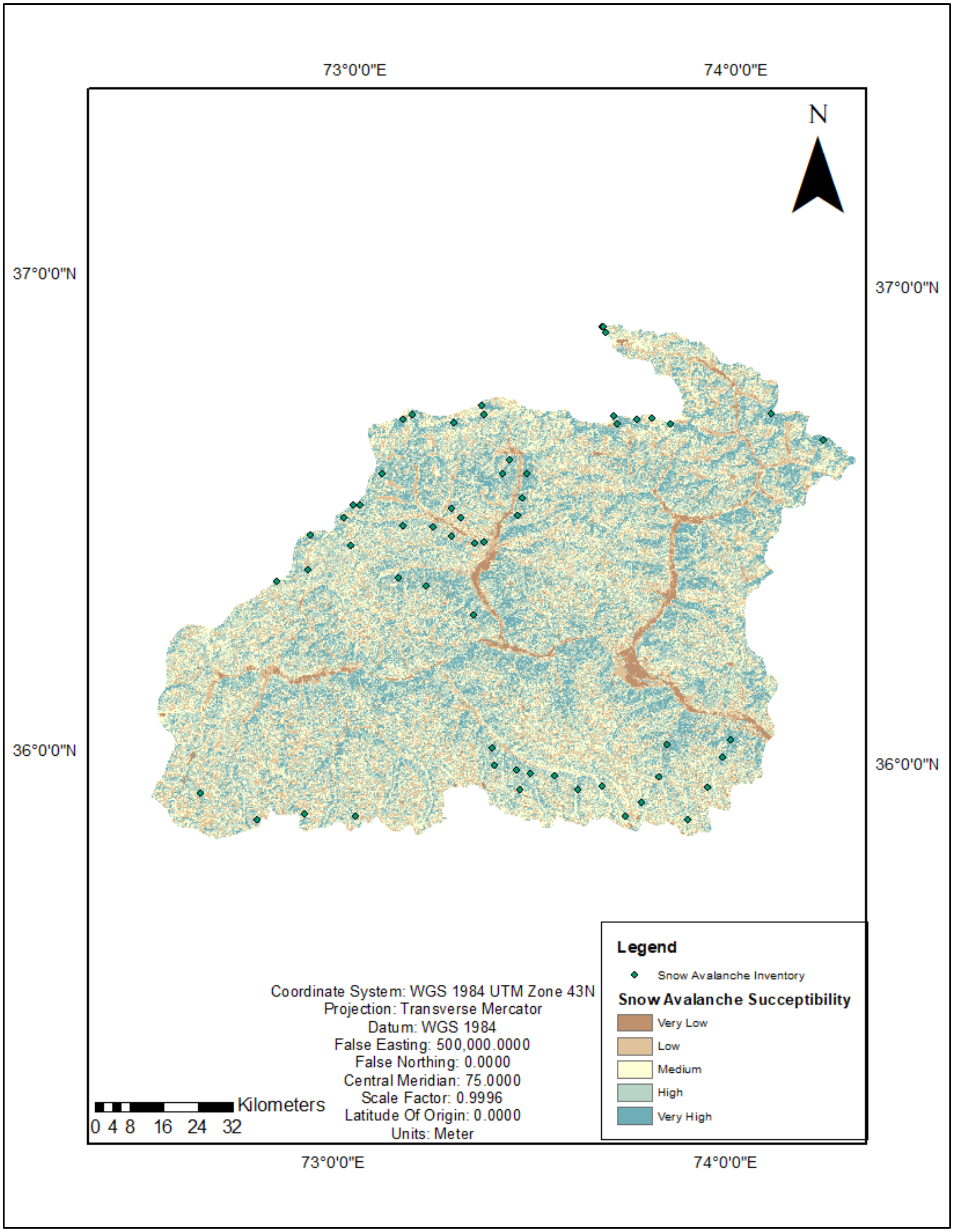


Figure 4.5. Snow avalanche susceptibility map.

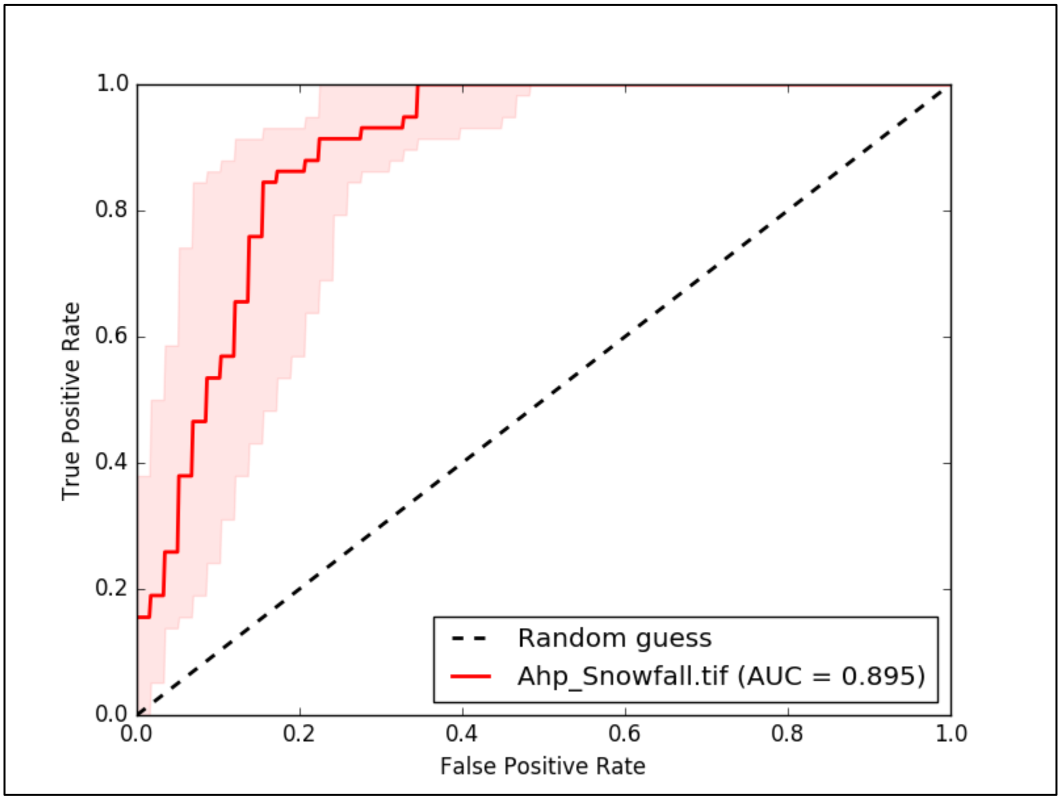


Figure 4.6. Snow avalanche susceptibility AUC curve.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 NATURAL HAZARD MITIGATION TECHNIQUES AND STRATEGIES

As it has already been mentioned above natural hazards have potential to cause a lot of damage to human population, said damage includes financial damage along with the loss of life and infrastructure. There are very few methods of accurately predicting natural hazard up to 100 percent hence natural hazards are generally predicted with probabilities (chance of said hazard happening), But through models such as AHP the zones that are highly susceptible to said natural hazard can be found and hence in order to prevent loss of life or to at least mitigate the damages of natural hazards certain techniques and strategies need to be implemented. These mitigation techniques and strategies can be anthropogenic and natural. They are discussed in detail as follows:

5.1.1 Landslide Mitigation Techniques and Strategies

The very first thing to do to solve a problem is to understand the problem thoroughly, hence the first strategy to use to mitigate the effects of the natural hazard is to increase the awareness of said natural hazard in all levels of the society. The next thing to take in mind is the economic conditions of the nation because most of the mitigation strategies require monetary funds. Two primary strategies were identified in the study (Sultana & Tan, 2021) conducted for the region of southeast Bangladesh, these strategies were Structural measures and non-structural measures. Structural measures include anthropogenic constructions such as guided plantation, slope stabilization through construction of walls, etc. While on the other hand non-structural measures included Early Warning Systems and evacuations. Another study was conducted to observe how the farmers of province KPK of

Pakistan cope with natural hazards such as landslide and flash floods, it was found that people which live in said susceptible zones have come up with different techniques to mitigate both financial loss and physical damage (due to natural hazards) the primary technique used by the farmers to mitigate the physical damage was terracing and tree plantation while the farmers diversified the income in order to mitigate the financial losses due to said natural hazards (Ahmad, Afzal, & Rauf, 2021). Strategies such as Slope stabilization (retaining walls and slope grading) and Drainage management (proper drainage systems) can also be used to mitigate damages due to Landslides. Natural Hazards in general are site-specific and hence would have site-specific triggering factors which need to be taken into account for the creation of mitigation strategies. The importance of evaluating site-specific triggering factors for Landslides in discussed in detail in this study (Chowdhury & Flentje, 2014), in which for the creation of an effective early warning system precipitation levels (along with other site-specific triggering factors) should be monitored by the construction of data collection and monitoring stations.

5.1.2 Flash Flood Mitigation Techniques and Strategies

Natural Hazard referred to as Flash Flood have already been explained and discussed in detail, similar to landslide mitigation the economic conditions of the nation play a very important role in the creation an implementation of mitigation techniques and strategies. There are two basic measures (strategies) taken to mitigate the damages caused by Flash Flood namely Structural means and non- structural means, Structural means generally include the creation of reservoirs and levees along with the construction of retention structures such as floodwater storage areas. On the other hand, non-structural means generally include strategies such as proper land use planning, zoning, reforestation and terracing. According to the study (Wang, Gourbesville, & Liu, 2023) the best strategy for the mitigation of damages due to Flash flood is the early warning systems. But in order to create effective early warning systems and evacuation plans in to model and observe the triggering factors of flash flood primarily the precipitation through monitoring of rainfall and flow rates along with water levels which can only be done through the creating of monitoring stations equipped with modern technology. In or der to increase the effectiveness of said early warning systems the data collected regarding precipitation must be adequate modeled and processed through up to date hydrological modeling models and software.

5.1.3 Snow Avalanche Mitigation Techniques and Strategies

The natural hazard referred to as Snow avalanche generally occurs in the region where there is snow cover to an extent, for the case of Ghizer district as discussed in the section 4.2 this natural hazard has occurred in the mountains somewhat distant to the main population of the region. Similar to the other natural hazard there are two main strategy to mitigate said natural hazard namely structural and non-structural measures. Non-structural measures/strategy includes avoidance through the means of either land use restrictions or evacuations through the help of early warning systems, on the other hand structural measures include the construction of diversion structures such as dams. Forest management and plantation can also mitigate damages done by said natural hazard. Structural measures are further categorized into Temporary and permanent measures (Acharya et al., 2023), as the name implies, temporary measures are utilized for short periods when the snow avalanche are expected, while permanent measures are applied for a longer period. Another important technique is community based risk mitigation and management which can only be done by spreading awareness to the local population regarding the natural hazard. As already mentioned preservation of forest cover or afforestation ("Avalanche Mitigation and Protection," online.) can help prevent damages done by said natural hazard

5.2 CONCLUSION AND RECOMMENDATIONS

All in all the prediction for natural hazards is generally in terms of probabilities and percentages as it can even be observed from the AHP model, and resources are in general required for structural and somewhat for non-structural measures/strategies for their mitigation. The amount of resources greatly depends upon the economic condition of a country. The most important thing to consider in any mitigation strategy is whether the people understand the natural hazard hence as already discussed it becomes important to increase the awareness of the people regarding the natural hazards, schools and offices should conduct regular natural hazard evasion practices/ drills. The accuracy of the overall AHP model for said three natural hazards can be improved further with access to more ground point data (in order to create a better hazard inventory), other data such as the criteria data (such as that of lithology, etc.) also effects the accuracy of the AHP model and hence should be carefully handled, which implies the fact that the data of all the criteria should be accurate or as accurate as possible (data such as LULC should accurately represent the natural resources on the land) in simpler terms the datasets derived from satellite imagery must be accurate hence the satellite image must be accurate, which can be done through the removal of any errors such as scan lines, noise and other errors from the satellite. The AHP model does contain biasness in terms of assigning of the criteria weights through the scale provided in table 3.2 but it is the most simple to use and is effective in certain scenarios.

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APPENDICES

Appendix-1. Landslide susceptibility analysis.

Dataset (factor)	Description	Source
Slope	Slope is the steepness or the degree of incline of a surface. Then, the slope for a particular location is computed as the maximum rate of change of elevation between that location and its surroundings.	This data would be calculated in GIS software through Slope calculation tool.
Aspect	Aspect is the orientation of slope, measured clockwise in degrees from 0 to 360, where 0 is north-facing, 90 is east-facing, 180 is south-facing, and 270 is west-facing.	Aspect would also be calculated through GIS software through Aspect calculation tool.
Distance to road	This data set contains road networks of an area, around which a buffer would be created.	This dataset is acquired through open street map
Distance to Stream	This dataset contains streams or water ways of an area, around which a buffer would be created	This dataset is also acquired through open street map
Distance to Fault lines	This dataset would contain the fault line data of the study area	This dataset would be digitized from fault line maps
Land use/Land cover	This dataset contains the land use /land cover map of the study region	This would be calculated through LULC calculation tools in GIS software
Lithology	This data contains lithology data	Would be collected online

Appendix-2. Flash flood susceptibility criteria.

Dataset factors	Description	Source
Curvature	Curvature in simpler terms represents the shape of the earth	This can be calculated from DEM
NDWI	The NDWI is referred to as Normalized Difference Water index which is used to identify water bodies in satellite images	This would be calculated through Raster calculator through the following formula. Normalized Difference Water Index (NDWI)= (G-NIR)/(G+NIR)
NDVI	Normalized difference vegetation index which is used to identify vegetation cover from satellite image	This can be calculated through raster calculator tool in Arc-map by the following formula (NDVI)= NIR−R/NIR+R
Distance to stream	This dataset contains streams or water ways of an area, around which a buffer would be created	This dataset is also acquired through open street map
Rainfall/ Precipitation data	This dataset contain the annual gridded precipitation dataset	https://crudata.uea.ac.uk/cru/data/hrg/
TPI	An abbreviation for Topographic Positional Index. Which in simpler terms is used to describe the ruggedness of a surface.	This would be calculated through the use of GIS software.
TWI	An abbreviation for Topographic Wetness Index. Which in simpler terms is used to describe the hydrological conditions of soil as far as the accumulation of water is concerned	This would be calculated through the Use of GIS software.
Drainage Density	This data set contains the Drainage density of the study area	This can be extracted from the DEM

Appendix-3. Snow avalanche susceptibility triggering factors.

Dataset (factor)	**Description**	**Source**
NDSI	This is an abbreviation for Normalized Difference Snow Index, which in simpler terms represents the snow cover of an area.	Would be calculated through the use of formula.