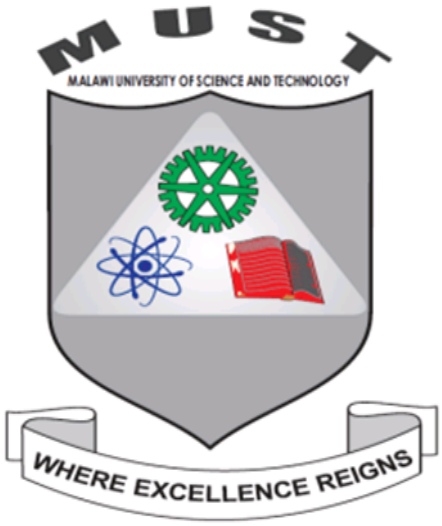


LANDSLIDE HAZARD ASSESMENT AND SUSCEPTIBILITY MAPPING: A CASE STUDY OF THE MARCH 2020 CHOZOLI LANDSLIDE IN RUMPHI DISTRICT

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Dissertation submitted to the Ndata school of Climate and Earth sciences of the Malawi University of Science and technology in partial fulfillment of the requirements for the Bachelor of Science Degree in Earth Sciences

July,2021

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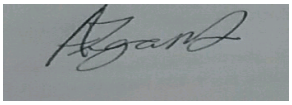
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ABSTRACT

Chozoli in the south of Rumphi experienced a landslide recently on 6th march 2020. Rumphi is a mountainous area characterized by a great number of hill and the area experience frequent high landslide occurrences causing a lot of damage to farmlands, non-cultivated lands, people's properties, and sometimes loss of lives. In this study five factors including surface texture of the soil, type of geology, Landcover/ land use, rainfall and slope gradient were used to identify which was the most contributing factor of the 2020 Chozoli landslide. GIS-based Statistical information value method was used in the preparation of the landslide susceptibility map where factors such as Land cover, slope gradient of the terrain, soil type and geology were used as the input data. The effect of these landslide causing factors was determined in relation to slope instability. Google earth imagery was used to determine the distance covered by a landslide and its depth. Chozoli landslide susceptibility map was categorized into five classes which included very low, low, moderate, high, and very high. The results from susceptibility mapping showed that high and very high landslide susceptibility areas fell under hilly areas with high slope gradient and mostly bare and agricultural lands. Landslide susceptibility mapping is of high importance since it can be used for regional land use planning and landslide hazard mitigation purposes.

Keywords: landslide, geographic information systems (GIS), susceptibility, land cover, information value, Rockfall, rotational, translational, geohazard, Debris flow,

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ACRONYMS/ABBREVIATIONS

a: Aplite

DEM: Digital Elevation Model

DoDMA: Department of Disaster Affairs

DRDMA: Department of Relief and Disaster Management

Ds: Dambo Soil

EARS: East African Rift System

G: Granite

GSD: Geological Survey Department

LC: Land Cover

LU: Land Use

MRV: Malawi Rift Valley

mSy: Microsyenite

NW: North West

NSy: Nepheline Syenite

PSO: Particle Swamp Optimization

Qs: Sandy Soil

SXCo: Sheared Cordierite Gneiss

Sy: Syenite

SRTM: shuttle Radar Transverse Mission

SVM: Support Vector Machine

TA: Traditional Authority

UTM: United Transverse Mercator

XCo: Cordierite Gneiss

XS'': Biotite Gneiss

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CHAPTER 1: INTRODUCTION

1.1. General introduction of the study

A landslide occurs when part of the natural slope is unstable to support its own weight. For example, soil material on a slope with slippery surface underneath can become heavy with rainwater and slide down due to overweight. Landslide is a general term used to describe the downslope movement of soil, rock and organic material under the influence of gravity and also the landform that results from the movement (Highland & Bobrowsky, 2008). Landslides can be classified into different types based on their type of movement and type of material involved. The type of movement describes the actual internal mechanics of how the landslide mass is displaced (Highland & Bobrowsky, 2008). According to (Weerasinghe, 2008) landslides are classified into six; slump, rock fall, rock slide, debris fall, creep, and debris flow. Landslides can be triggered by natural phenomenon and human activities. The effect of landslide triggered by natural causes vary widely and depend on factors such as steepness of the slope, shape of terrain, soil type, rainfall pattern, earthquakes, volcanism and underlying geology. The change in drainage pattern, excavation and vegetation removal are human activities that are related to landslide occurrence. In this research the causes of landslide were analyzed and a susceptibility map to identify landslide prone areas was made using slope map, geology, soil and land cover,

1.2. Problem statement

Rumphi is a mountainous area characterized by a great number of hills and the area experience frequent high landslide occurrences causing a lot of damage to farmlands, non-cultivated lands, people's properties, and sometimes loss of lives. A number of historical landslides have been documented in Malawi and one of the areas that have registered a great number of landslides is Rumphi. In 2003, Rumphi registered 98 landslides at Ntchenachena and Chiweta areas (Moses, 2019). When these natural catastrophic events occur more lives of productive citizens are lost (Msilimba, 2007). The report from DODMA (The Department of Disaster Management Affairs) in 2019 indicated that at least three people died in a landslide hazard which was triggered by a rainstorm in Rumphi district on 20th April that year, and five people went missing in Sub-TA Chapinduka mainly in Tcharo

area (DoDMA, 2019). The greatest challenge faced in this area is the frequent experience of landslide

1.3. Main and specific objectives

1.3.1. Main objective

The main aim of this research study was to assess the landslide hazard that occurred in March 2020 at Chozoli in Rumphi district and propose some mitigation measures that can be put in place to prevent the effects that come due to the occurrence of the hazard and prevent the re-occurrence of the hazard.

1.3.2. Specific objectives

To achieve the intended purpose of this research the following objectives were be considered and dealt with:

I. To determine the factors that triggered the landslide
II. To determine the nature of the slope
III. To identify other areas prone to landslide and propose mitigation measures that can be help reduce the effects and the recurrence of the hazard

1.4. Research questions

The research questions of the study are:

I. What are some of the factors that triggered the Chozoli 2020 landslide?
II. What is the nature of the slope?
III. What other areas are prone to landslide occurrence in south Rumphi?
IV. What measures can be put in place to help reduce the effect of the hazard and its recurrence?

1.5. Significance of the study

The study is of great importance in different angles. Firstly the study will generate information on landslide occurrences which will be used for comparative purposes. More importantly, this will help fill the critical gap since landslide studies have been concentrated in the southern and little has been done in the north (Msilimba, 2007); most importantly the 2020 Chozoli landslide which has not been studied in the southern part of Rumphi district. The landslide susceptibility map aids decision makers and planners for the prevention and mitigation of landslide hazard (Chawla, 2018). The information in this study can be used by

the Rational Road Authority (NRA) in the stabilization of unstable slopes such as in the case of the 20

CHAPTER 2: LITERATURE REVIEW

These landslides cause a great loss to the government of Malawi in order to recover from the loss; for example, in the landslide which occurred in Rumphi in TA Chapinduka in the year 2019 the government offered its assistance on the incident through DoDMA by providing financial support to cover medical expenses for the injured and also towards funeral arrangements for the deceased (htt://floodlist.com/Africa/Malawi-landslide-rumphi-northern-region-april-2019). Some regions in Malawi are more at risk for landslides and mudslides after heavy rainfall, particularly the Shire region of the south and central western coastal areas of Lake Malawi (Groen & Jacobs, 2012). Landslides occur when the stability of a slope changes from stable to unstable condition. Both natural and anthropogenic factors can change the stability of a slope by acting altogether or alone. Natural causes of landslides include, groundwater pressure acting to destabilize the slope, erosion of the toe of a slope by rivers or ocean, weakening of the slope through saturation by heavy rainfall, earthquakes adding loads to barely stable slope, earthquake cause liquefaction destabilizing the slopes, volcanic eruptions and loss or absence of vertical vegetation structure, soil nutrients and soil structure. Out of the factors that trigger landslide occurrence in Malawi it has been noticed according to the records that most landslides in Malawi especially in Rumphi are triggered by heavy rains. Finding the measure on how to reduce the effects and avoid the recurrence of these landslides has been a challenge since less studies have been conducted on landslide mitigation measures. Landslide prone areas have not yet been identified in most of the areas in Malawi especially in the north eastern part of Rumphi district. To overcome these problems the geology of an area has to be assessed, the factors the triggered the landslide occurrence need to be identified, landslide prone areas need to be identified to reduce these adverse effects and mitigation measures need to put in place these geohazard effects.

2.1. Factors triggering landslide

Factors that directly and indirectly affect slope stability are responsible for landslide occurrence which include: rainfall, lithology, structure, soil depth and texture, geomorphology, amount of slope and slope angle, weathering, land use cover type

(Odhiambo, Kataka, & Mashudu, 2018).

Rainfall is one of the greatest factors that triggers landslides since it increases the weight of the overburden thereby decreasing the stability of the slopes as it increases the force of movement and decreases the cohesion forces. (Gazibara, et al., 2017); did his studies on Extreme precipitation events and landslide activation in Croatia and Bosnia and Herzegovina in which he analyzed the relationship between extreme precipitation and rainfall triggered landslides in Croatia and Bosnia and Herzegovina. Extreme weather conditions (re)activated more than 900 landslides in NW Croatia during the winter and spring of 2013. Analysis of extreme precipitation conditions showed that both short- and long-duration rainfalls were responsible for the large number of landslide initiations in NW Croatia and central Bosnia and Herzegovina.

Most of the landslides in Malawi have been triggered by rainfall, except for the Manyani Hill landslide (Msilimba G. C., 2007). Gondwe and Govati, (1991), Mshali (1992), Cheyo, (1999) studied the causes of the 1991 Phalombe Landslide, and concluded that rain water acted as the sole lubricant between the sliding masses and underlying rock. All the studies agree on the fact that the regolith became heavily water laden during three days of heavy precipitation, resulting in hill slope failures in several places in the Michesi Mountains. The causes and circumstances for landslide occurrences are many and a summary is presented in Table 1.

Table 1: *Causes* of landslides (Source: (Msilimba G. , 2012)

External causes	**Internal causes**
1. Geothermal change • Height • Gradient • Slope	**1.progressive failure (internal response to uploading)** • expansion and swelling • fissuring • straining, softening • stress concentration
2. loading • natural	**2.weathering** • physical property changes

• man-induced	• chemical changes
3. shocks and vibrations • single • multiple/continuous	**3.seepage erosion** • removal of cements • removal of fine particles
4. unloading • natural • man-induced	**4.water regime change** • saturation • rise in water table • excess pressures • draw down

In every slope there are forces which tend to promote downslope movement and opposing forces which tend to resist the movement (Popescu, 2006). A general definition of the safety factor of a slope results from comparing the downslope shear with the shear strength of the soil in that site. (Terzaghi, 1950) Divided landslides into external causes which result in an increase in shearing stress (e.g., Geometrical changes, unloading the slope toe, loading the slope crest, shocks and vibrations, and also the changes in water regime); and internal causes which result in the decrease in shearing resistance, for example progressive failure, increased weathering, seepage and erosion). (Varnes , 1978) outlined a number of both external and internal causes which mostly operate to increase the shearing stress. Landslide Controlling factors influence the form, rate and duration of the movement (Crozier, 1984).

2.2. Types of landslides

Landslide is a general term used to describe the downslope movement of soil, rock, and organic materials under the influence of gravity and also the landform that result from such movement (Highland & Bobrosky, 2018). There are various terms commonly accepted and used in showing the various parts of a landslide as shown in the figure 1 below.

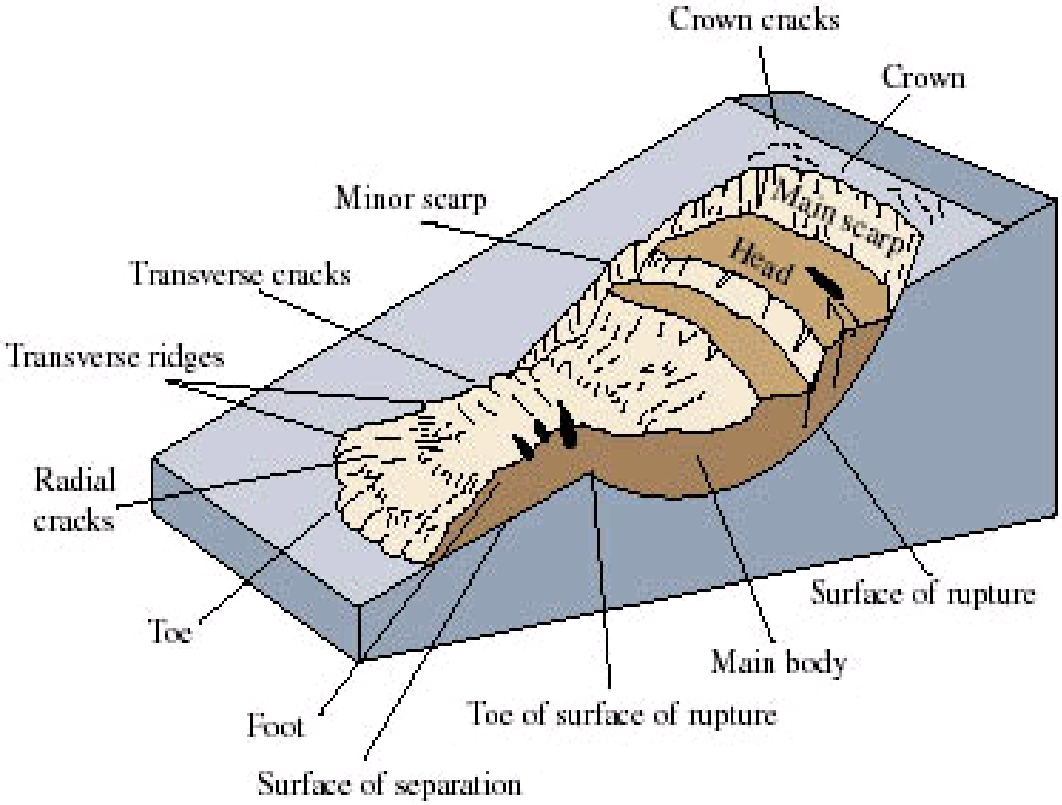


Figure 1. The graphic that illustrates the commonly used parts of landslides (Varnes , 1978)

The image shows the rotational landslide that has evolved into an earthflow. Table 2 below explains the definition of each part of a landslide.

Table 2: Definition of landslide parts (Hermanns, 2018)

Term	Definition
Crown	The undisturbed material uphill of the scarp

Main scarp	Steep slope at the upper edge of the landslide (at the head), caused by the movement of displaced material away from the undisturbed ground. It is the visible part of the slide surface
Flank	Undisplaced material adjacent to the sides of landslide. Flank usually describes the left and right lateral extents of the mass wasting material.
Rupture/slide surface	Lower boundary of the movement below the original ground surface. This is the surface along which the material slides.
Main body	Part of the landslide that overlies the rupture surface
Tension cracks	Cracks formed as a result of the middle part of the slide being pulled apart usually found in the middle of the slide.
Separation surface	Part of the original ground surface that is now covered by landslide material.
Foot	The part of the landslide that overlies the original ground surface.
Toe	The downhill end of the slide. The most distant part of the slide from the main scarp.

The type of material, speed of motion, slope angle, potential frequency of occurrence, weather and climate influences, and manmade disturbances as well as other factors are other factors have a bearing landslide motion, size and impact (Highland & Bobrowsky, 2008). Various classification of landslide is mostly associated with specific mechanics of slope failure and the properties and characteristic of failure type. Landslides can be classified on the basis of the type of movement and the type of material involved (Cruden & Varnes, 1996). Landslides are therefore primarily described using two terms that refer to

material and movement.

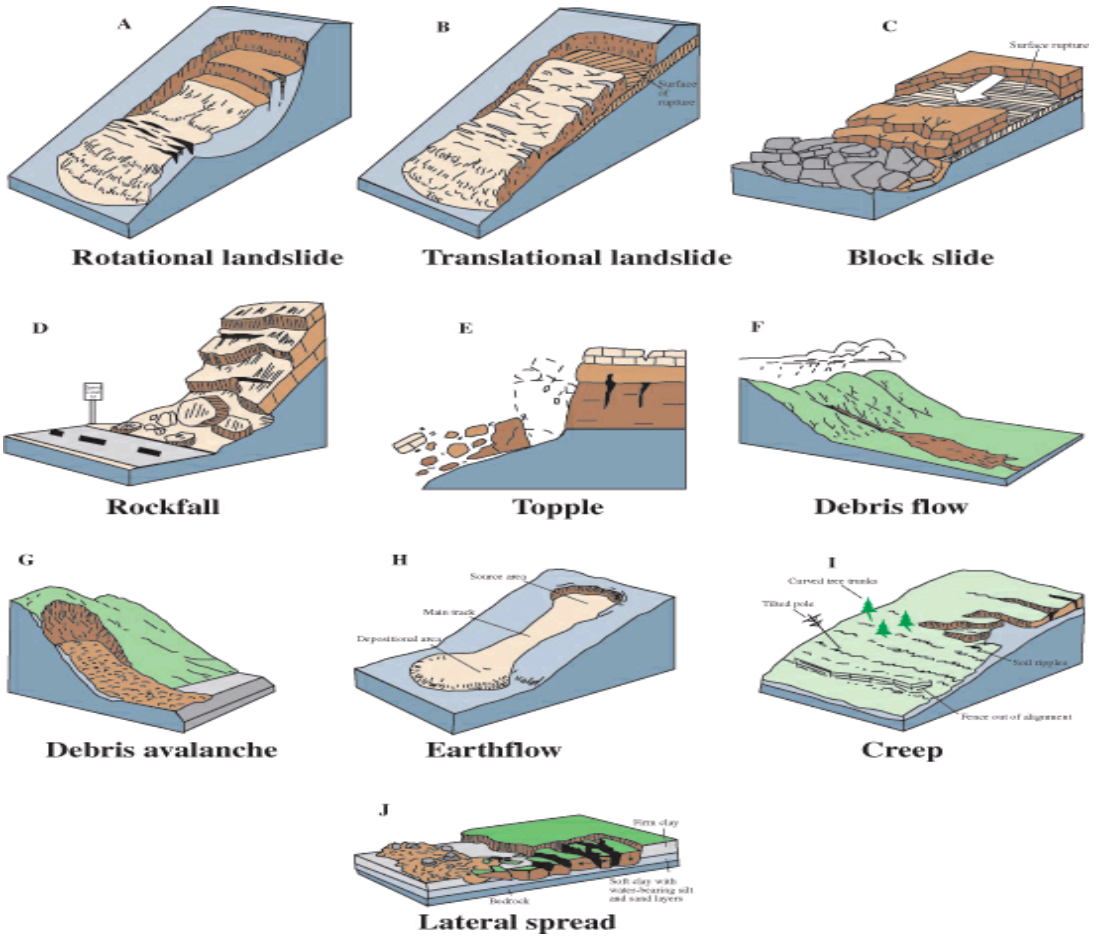


Figure 2: Mass movement classification (Cruden & Varnes, 1996)

The five kinematically distinct types of movement are described in the sequence: fall,

topple, slide, spread, rotational, translational, lateral spreads, flow and complex. Combining the two te

Table3: Classification of slope movement (Varnes, 1978)

TYPES OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominately course	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock Topple	Debris Topple	Earth Topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth Slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris Spread	Earth Spread
FLOW		Rock flow	Debris flow	Earth flow
COMPLEX		Combination of two or more types of movement		

2.3. Mapping landslide prone areas

Mapping landslide using remote sensing requires the extraction of relevant spatial information related to landslide occurrences. Remotely sensed data in conjunction with Geographical information systems have proved to be the most effective tools for generating and processing spatial information and facilitates effective landslide detection, mapping, monitoring and hazard analysis (Odhiambo, Kataka, & Mashudu, 2016)

(Chawla, 2018) Studied the landslide susceptibility mapping in Darjeeling Hills, west Bengal, Eastern Himalayas, and India. In his study, the statistics utilized were IRS-RESOURSESAT-II LISS-IV, CARTOSAT-I PAN satellite data of the National Remote Sensing Centre to produce a land slide susceptibility map which showed landslide prone areas in the area. The study area was divided into four respective susceptibility zones in which their values were presented in percentages according to which area was more prone to landslide than the other. The lower landslide prone areas were presented by

3.6%, moderate 58.35%, high 32.61% and very high 5.44% susceptible zones and in his findings lands

(Odhiambo, Kataka, & Mashudu, 2018) Mapped landslide prone areas in Makhado Municipality of Limpopo province in South Africa using remote sensing data in order to identify areas that are susceptible to landslides and map slope classes most prone to landslides. In his studies he found out that high landslide prone areas are have steep slopes more than 36^0. These areas are generally too steep for development, have high-cost factors with respect to low- and middle-income residential housing. And moderate Landslide areas has slopes ranging between 21^0-37^0; while low susceptible areas generally represent flat terrain surfaces with low slopes ranging between 0^0-20^0.

(Msilimba G. , 2012) Used aerial photography and topographic map interpretation to delineate the areas in his studies on landslide inventory and assessment for the Ntchenachena area in Rumphi, northern part of Malawi. As more recent maps and aerial photographs (aster 1995) were not available Msilimba used ground reference data and Landsat 7 ETM images to delineate the area. Reference data used to correct errors caused by scale distortions on aerial photographs and topographic maps. In his findings 79 landslides were classified as contemporary and the rest were ancient although these were re activated in 2003. Channel geometry varied enormously. The steep narrow valleys produced V-shaped channels while gentle wide valleys produced a U-shaped; 43 landslides had U-shape, 33 had U-shape while 12 had irregular channel morphometry. (Moses, 2019) Used Remote Sensing and QGIS techniques to map out landslides and assess susceptibility to landslide occurrence around Chiweta area in Rumphi district, north of Malawi.

2.4. Landslides in Africa

Since landslides are natural hazard, they occur in areas and different environments based on the factor that have led to their occurrence. They can occur both at ocean and inland. At a worldwide level two largest landslides have been recorded, the heart mountain subaerial land slide and storegga submarine landslide.

While landslides and associated hazards in Africa are not new, the current trend of slopes failure events leading to enormous loss of lives and property certainly is novel (Igwe, 2017)

. Landslide's dimension and frequency have not only increased, uncommon types of debris flow, debri

Table 4: Mass movements inventory in Malawi and their impacts *(Msilimba G. C., 2007)*

EVENT	DATE	IMPACTS
Zomba (debris flow)	1946	1. 21 facilities 2. 24 bridges destroyed 3. Road infrastructure damaged 4. Electrical and water reticulation disruption 5. Crops destroyed 6. Mtika and Phuka villages devastated
Lumbadzi (debris flow)	1975	Casualties recorded, bridges destroyed, and a tanker swept
Benga (landslide/flow)	1984	Crops destroyed
Ntonya-ulumba (slide)	1985	
Dedza (slide/falls)	1989	
Manyani (slide)	1989	
Phalombe (debris/mudflow)	1991	500 people killed, crops washed away, buildings, roads and bridges washed away
Malosa	1991	Minimal property damage
Vunguvungu/Banga	1997	1. Vegetation removed 2. Crops destroyed

		3. Water reticulation destroyed
Zomba	1997	Kuchawe road blocked
Chiweta	1999	Roads blocked
Cholomoni (Blantyre)	1999	No damage reported
Zomba	1999	Kuchewe road blocked
Nyankhowa	2000	1. Water reticulation 2. Road blocked

Apart from those landslides recorded by (Msilimba G. C., 2007) in table 4 above there are also other notable landslides wich have occurred rescently in Rumphi district. Table 5 below summerises some of the rescent landslides.

Table 5: Recent landslide envents and their impacts

EVENT	DATE	IMPACT
Ntchenachena	2003	➢ 4 people killed ➢ Houses destroyed ➢ Farmland destroyed
Mvai/Livilivi	2003	➢ Destruction of roads and bridges ➢ Destruction of vegetation
Chiweta	2003	➢ Blocked M1 road ➢ Destruction of vegetation ➢ Destroyed drainage system
Tcharo (Chapinduka)	2019	➢ Three people and five went missing
Mbuta	2020	➢ Blockage of Rumphi-Karonga

		M1 road

CHAPTER 3: METHODOLOGY

3.1. Basic design of the research study

The research is a qualitative study and no samples were collected in the area of study. Little calculations were done in this study but ninety percent of the data analyzed is qualitative. GIS software such as ArcGIS 10.5, QGIS 3.4, ENVI 5.3, and Google Earth pro were used for data analysis and interpretation of the results. Deskwork was mostly used for extra studies on both published and unpublished papers and the use of software such as ArcGIS to produce slope map, soil map, geological map and susceptibility map. To meet other factors leading to landslide quantitative studies (some calculations) were made in order to show the rainfall pattern in the area. The susceptibility map to show the landslide prone areas was produced by a statistical method known as statistical value information method which shows the predictive power of an independent variable in relation to the dependent variable

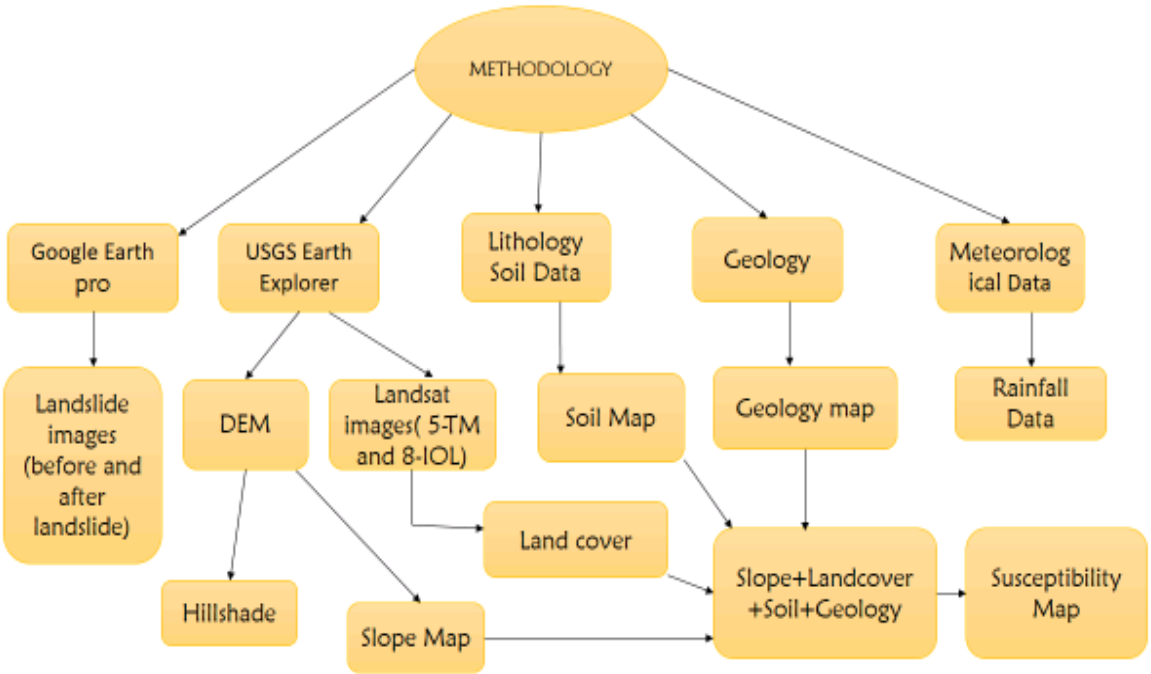


Figure 3: flow chart of the research methodology

3.1. Study area

3.1.1. Location of the study area

Chozoli is locates in the southern part of Rumphi district. The area covers about 350.940Km^2 and it is located 6.87 km away from Bolero and 8.59 km away from Rumphi central. The area lies within Nyika area which extends from just south of Karonga (near the northern end of Lake Malawi) to just north of Rumphi and lies on the geographical coordinates between 33^{0}46'40"E, 10^{0}57'30"S and 33^{0}46'40"E, 11^{0}00"17"S. The area is mainly drained by Runyina River which is in the western part and further west of it is Luviri which forms the main tributary.

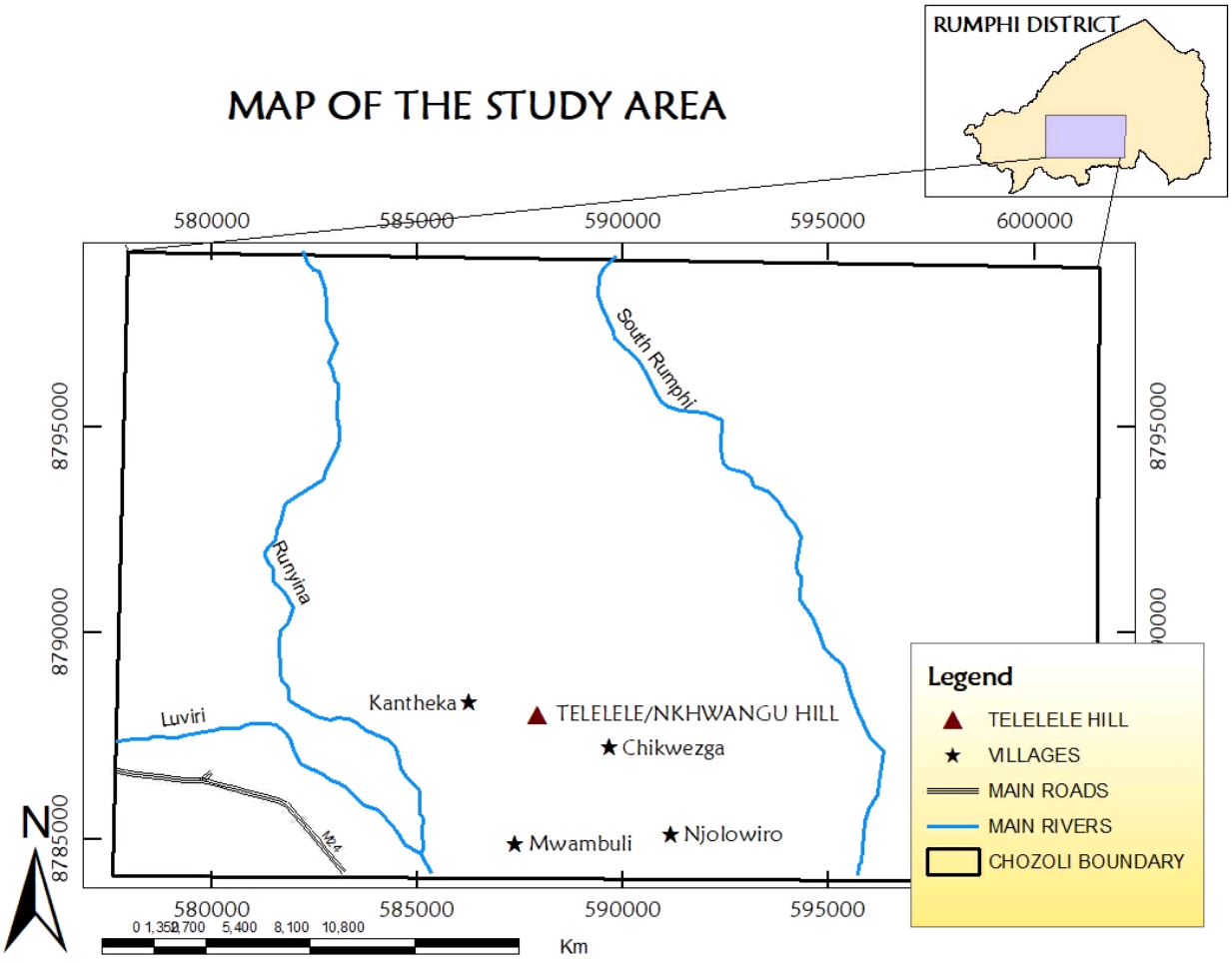


Figure 4: Map of the study area

3.1.2. General geology of the area

At a regional scale the area is chiefly underlain by metamorphic and igneous rocks of Malawi Basement complex, a heterogeneous association of Precambrian to lower Paleozoic age (Thatcher, 1974). The area lies within the northern sub province of the Malawi province polycyclic of the Mozambique Belt (Thatcher , 1974). The dominant rock types present in the area are gneisses, migmatites and granitic intrusions of the Ubendian belt.

The area falls within the Nyika area which extends from just south of Karonga (near the northern end of Lake Malawi) to just north of Rumphi. The Nyika granite is seen to interrupt a belt of sillimanite cordierite gneiss (a rock unit now designed cordierite gneiss) which is flanked by biotite gneisses on the north (Thatcher, 1974). To the Southeast of the Nyika granite the gneisses are intruded by the Rumphi igneous complex comprising of nepheline syenites at Telelele hill, syenites and granites. The Nepheline syenites occurs in its largest form at Telelele Hill. According to (Thatcher , 1974), Nepheline Syenite finds a wide use in the ceramic industry where it replaces feldspar as a source of Alumina and the alkalis in making glass pottery, floor and wall tiles, refractory cement and various other products. The area also contains sodalite bearing varieties with attractive blue color of which suggests a possible use as ornamental stone.

3.1.3. The general lithology of the area

Chozoli area is generally underlain by the gneisses of the Ubendian belt, which were intruded by different types of igneous rock units of the unknown age. The igneous rocks are generally dipping steeply at various dip directions. The igneous rocks in the study area, comprising dolerites, Microsyenite, nepheline syenites and granites. The study area falls with the nepheline syenites. Nepheline syenites, are medium-grained, grey to creamy-white rocks, typically pitted on weathered surface due to the preferential removal of nepheline. The dominant reference soil groups in the area are acrisols, alisols, cambisols and ferralsols (Dijkshoorn, Hunting, Kempen , & Leenaars, 2016). Largest deposits of fairly pure sand occur on the shores of Lake Malawi near Mwenilondo and along the south Rukuru in the Henga Valley (Thatcher , 1974). Only a small pocket of sand is found within

the area and some are also located in Nthalire area and along the south Karonga Rift Scarp zone. Lin

3.1.4. General seismicity of the area

The area lies within the Malawi Rift Valley (MRV) which is part of the East African Rift System (EARS). The MRV is bordered by the Livingstone border fault to the East and Usisya/Mlowe border faults to the west. Faults within the MRV are either Pre-Cenozoic or Cenozoic in age (Crow, M.C., and Crossely, 1980).

The mass movement occurred within South Nyika area on the flanks of the Malawi Rift which is near the Pre-Cenozoic faults and the shear zones of the Nyika Plateau where occasional earthquakes usually occur (Chipola, 1992). The half grabens and fault geometries that bound the Usisya-Mbamba accommodation zone and shear zones of the Nyika Plateau have NW-SE general trending pattern (Delvaux et al., 1992)

3.2. Materials and data analysis methods

3.2.1. Slope and hillshade

The Shuttle Radar Topographic Mission (SRTM) of the type Digital Elevation Model (DEM) was downloaded from the USGS (United States Geological Survey) earth explorer which was used to produce the hillshade of the area and a slope map. Both the hillshade the slope map was prepared from a Digital Elevation Model (DEM). Digital elevation Model is a 3D computer representation of the elevation data to represent the terrain, commonly of a planet, moon, or asteroid (Tofan , Segon , Agostini, Casagli, & Catani , 2013). DEMs are mostly used in geographic information systems and are the most common basis for digitally produced relief maps.

The input data (DEM) was in the form of raster type data with a spatial resolution of 30m, and this DEM was processed in ArcGIS software. The coordinate system was first assigned which is WGS_1984_UTM_Zone_36s used in Malawi, so that all the maps should have the same spatial reference for compatibility. The slope was measured as a maximum rate of change in values to its immediate neighbor (nearest neighbor). According to (Ligas & Banasik, 2011), the slope in a planar method is calculated as the rate of change (delta) of the surface in the horizontal (dz/dx) and vertical (dz/dy) directions from

the center cell to each adjacent cell using a formula as below;

Slope_degrees=ATAN (√ ([dz/dx]^2 + [dz/dy]^2).

To create the Hillshade, the input data (DEM) was in the form of raster type data with a spatial resolution of 30m. The Dem was used to produce both slope map and the hillshade of the area. The hillshades created at different angles was then combined using the weighted sum. The shapefile for the rivers of Malawi was added to the hillshade and then clipped to only extract the rivers found in Chozoli. The Hillshade tool creates a shaded relief raster from raster, and the illuminance source is considered to be an infinity; and it has an output integer value range from 0 to 255.

3.2.2. Landcover classification

Land cover maps represents an important factor in geological analysis, from physical studies to environmental analysis and spatial planning approaches (Mihai & Rujoiu, 2016). It is also a dynamic variable because it reflects the interaction between socio-economic activities and regional environmental changes, and because of this reason it is necessary to be updated about these changes frequently. Land cover and land use are mostly used interchangeably, and it is very important to define them clearly. According to (Mihai & Rujoiu, 2016), land cover represents the physical and biological cover of the earth's surface including classes as built-up areas, forests, agricultural areas, wetlands, semi-natural areas and water bodies; while on the other hand the land use represents the present and the future planned human activities on a territory characterized as residential, industrial, commercial, forestry, forestry and leisure. Land use is the expression of the human activity developed for social, economic, cultural and political purposes.

Table 6: Datasets used in the analysis and their characteristics

year	Sensor	Spatial resolution/ scale	Source	Format	Path/row
2000	Landsat4-5TM	30m	U.S Geological Survey	Raster	169/89

2009	Landsat 4-5TM	30m	U.S Geological Survey	Raster	169/89
2019	Landsat 8 OLI	30m	U.S Geological Survey	Raster	169/68

The preprocessing stage of the image classification was done using QGIS software. An SCP semi-automatic classification plugin was first installed within the QGIS software. This plugin was the one used for preprocessing. Landcover features were obtained using a supervised classification. By definition, supervised image classification is a procedure for identifying spectrally similar areas on an image by identifying training sites of known targets and then extrapolating those spectral signatures to other areas of unknown target (Mare & Mihai, 2016). A set of training areas was created using polygons for the land cover categories: forests, agricultural land, built-up areas and bare soils. These four land cover classes were separated using their spectral response on the current image. The spectral differences between pairs of defined land cover classes were assessed with the ROI (Region of Interest) Reparability tool, which showed high values of separability between the regions of interest.

During the supervised classification using ENVI 5.3, reference training sites for each land cover type was used in order to generate training signatures. The signature tool (using a polygon tool from the Area of Interest (AOI) tool) was used to define a polygon which is representative of each training site. In the validation stage, the normalized differenced indices were used by comparing the land cover categories for all the four classes; forest, agricultural areas bare soil and built-up areas. The normalized difference vegetation index (NDVI) is a standard vegetation index based on reflectance properties of the areas covered by both vegetation; and it shows the discrimination between different land cover categories by taking into account the changes in values of the green biomass, the content of chlorophyll and the canopy water stress (Mare & Mihai, 2016). Areas with vegetation those which were presented by forest(trees) and agricultural land have a high reflection in the near-infrared and a low reflection in the visible spectrum, and these NDVI bands show values from -1 to +1. The highest values indicate vegetated areas with high consistency, while the low values indicate the absence of vegetation (forested area and agricultural

areas). The normalized difference building index (NDBI) was created to differentiate the built-up area a

3.2.3. Soil and Geology map

The geology and soil were collected from the Malawi geological survey department. The geology for Chozoli was extracted from the regional geology shapefile of Rumphi. The soil was also extracted from the shapefile received from the Geological survey department. The geology of the area was classified using the Geo-ID and the soil was classified using soil texture.

3.2.4. Rainfall Data

Rainfall is the most common cause of landslides, either directly or indirectly (Brand , Premchitt, & Phillipson , 1984). Variable topographical, geological, and hydrological and land use conditions can affect the slope instability in the area but the most of the landslides in Rumphi were triggered by heavy rainfall (Msilimba G. , 2012). Landslide occurs when the shear stress is greater than the shear strength of the slope material (Getachew & Meten, 2021). Chozoli experience rainfall from October to April, but sometimes it extends up to May. Rainfall measurements obtained by Bolero meteorological station were used to analyze the precipitation pattern of Chozoli. The rainfall graphs were prepared using Microsoft excel. This data was collected from the Department of Meteorology and Climate Change Services. Daily precipitation data for the area includes the amount of rainfall recorded in millimeters. Since the rainy season in Malawi starts in October/November which is at the mid of the year, the 2019/2020 rainfall was plotted to show the pattern of rainfall in that year.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Analysis of Google earth images

Google earth images in figure 5 and 6 show the condition of telelele hill before and after the landslide.From figure 5 and 6, it shows that the point where the landslide occurred in figure 3 was a deppression which. This depresion might be interpreted as a fualt on the ground. The basement complex of the northern malawi (Rumphi) occupies a unique position within the geological framework in the East and Central Africa in that it lies at the

apprarent meeting-point of three major stuctural metamorthic belts, the ubendian Belt of Tanzania, the

Using google Earth, the distance covered by a landslide and its thickness were measured. It was found that the landslide covered a distance of about 867m from the top to bottom of the hill which is approximately 0.87 killometers. The thickness varried as the distance was increasing. At the top of the mountain the thinkness was measured up to 7 meters thick; as we go at the bottom it was found that the thickness increased from 7m to 9m, 11m, 23m up to 34 meters thick. And from figure 5 below the landslide shows that it passed through a crop/cultivated land which might have destroyed the plants. The destruction of crops may lead us to a conclussion that landslide was not only a nutural event but a hazard.



Figure 5. Google Earth image Before landslide (08/2019)

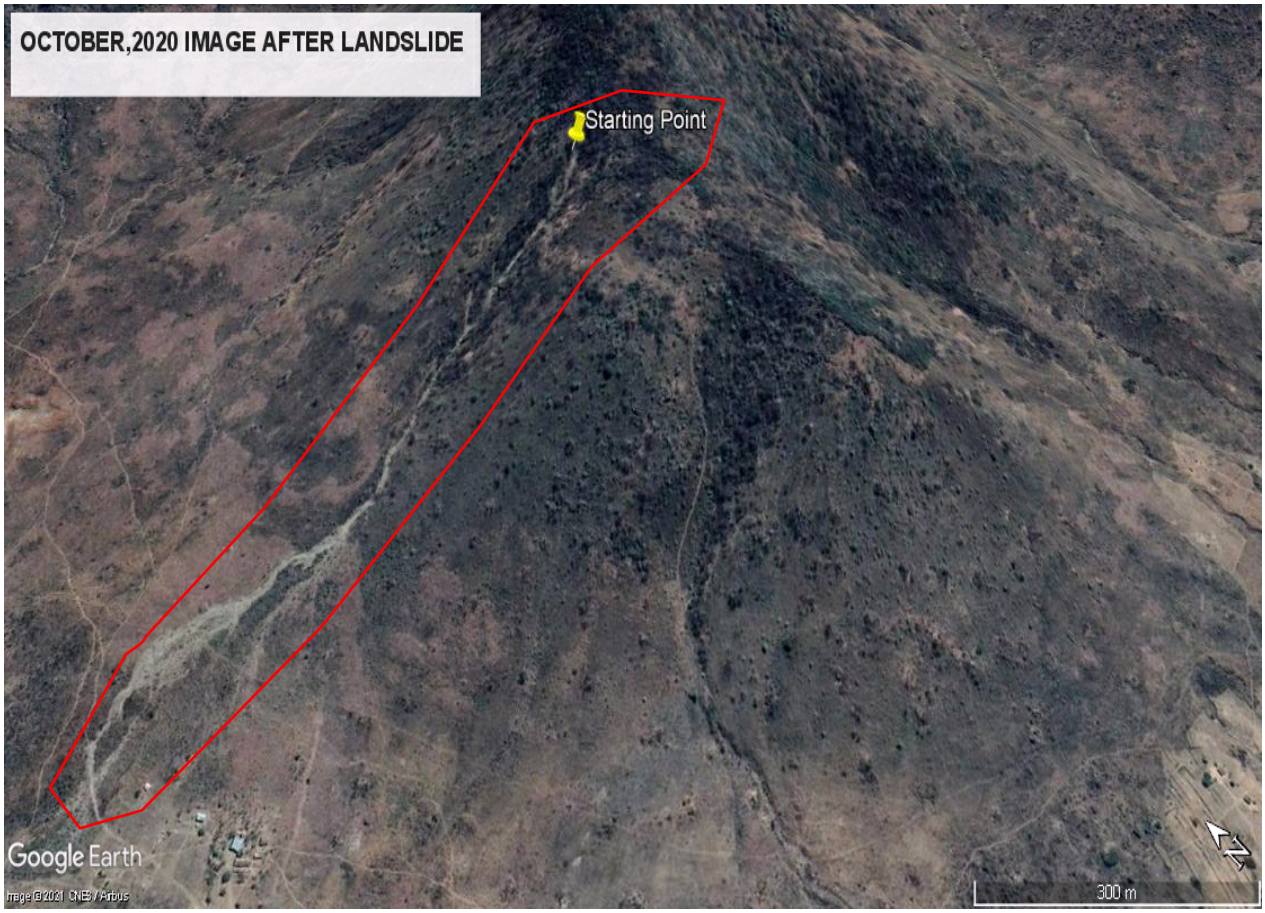


Figure 6: Google Earth image After Landslide (09/2020)

Figures 7 and 8 below shows the elevation before and after the landslide which were all plotted using the Google Earth pro software. Before the landslide in figure 7 the starting point of the landslide had an elevation of about 1422m, while in figure 8 after the landslide

the starting point elevation dropped up to about 1408m. This drop in elevation might be caused by the

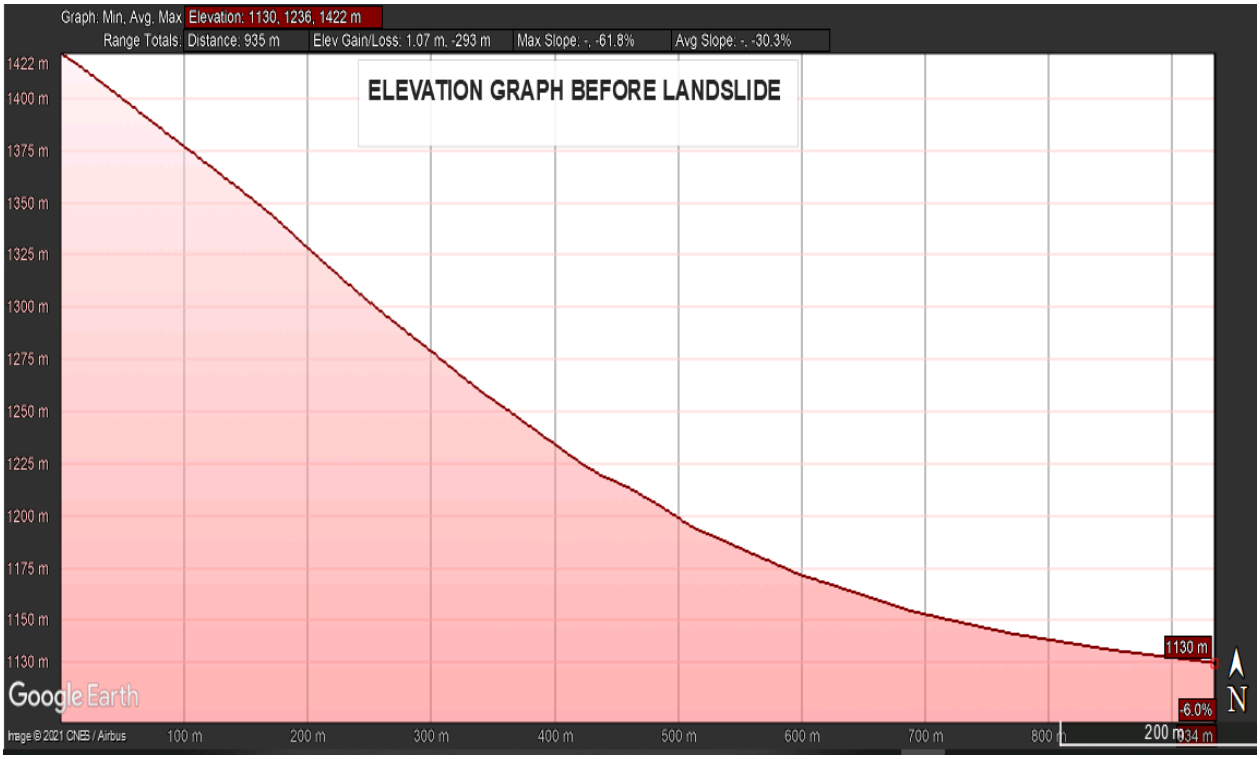


Figure 7: elevation before landslide

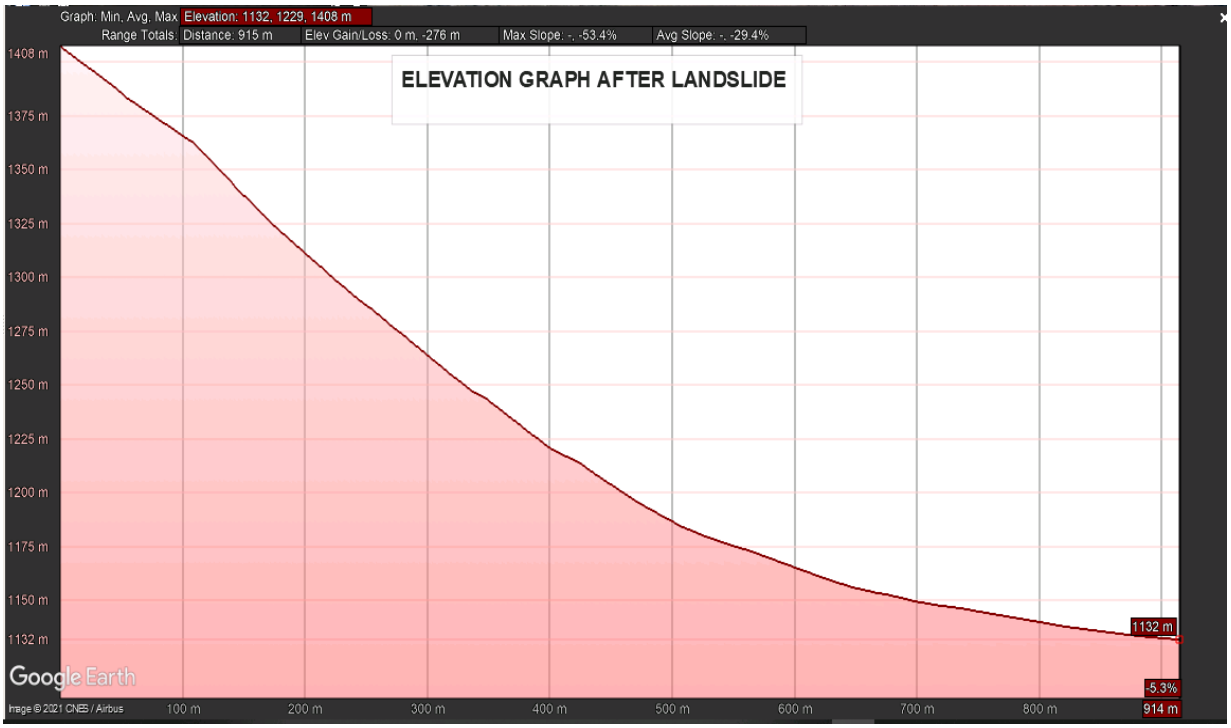


Figure 8: elevation Graph after landslide

4.2. Analysis of the factors controlling landslide

4.2.1. Analysis of the Landcover images

The land cover classification was divided into four categories of the training samples which included agricultural land, bare soils, forested areas and built-up areas. From figure 9,10 and 11 below representing the land cover classification for the years 2000, 2009 and 2019 respectively; the built-up areas were represented by a red color, the forested areas were presented a dark green color, the agricultural land were presented in light green color and the bare soils were presented by a brown color. Visually the year 2000 had a lot of forestry area as compared to years 2009 and 2019. The forested area got reduced in the year

2009 having an increase in the built-up areas. The agricultural areas were increasing throughout these

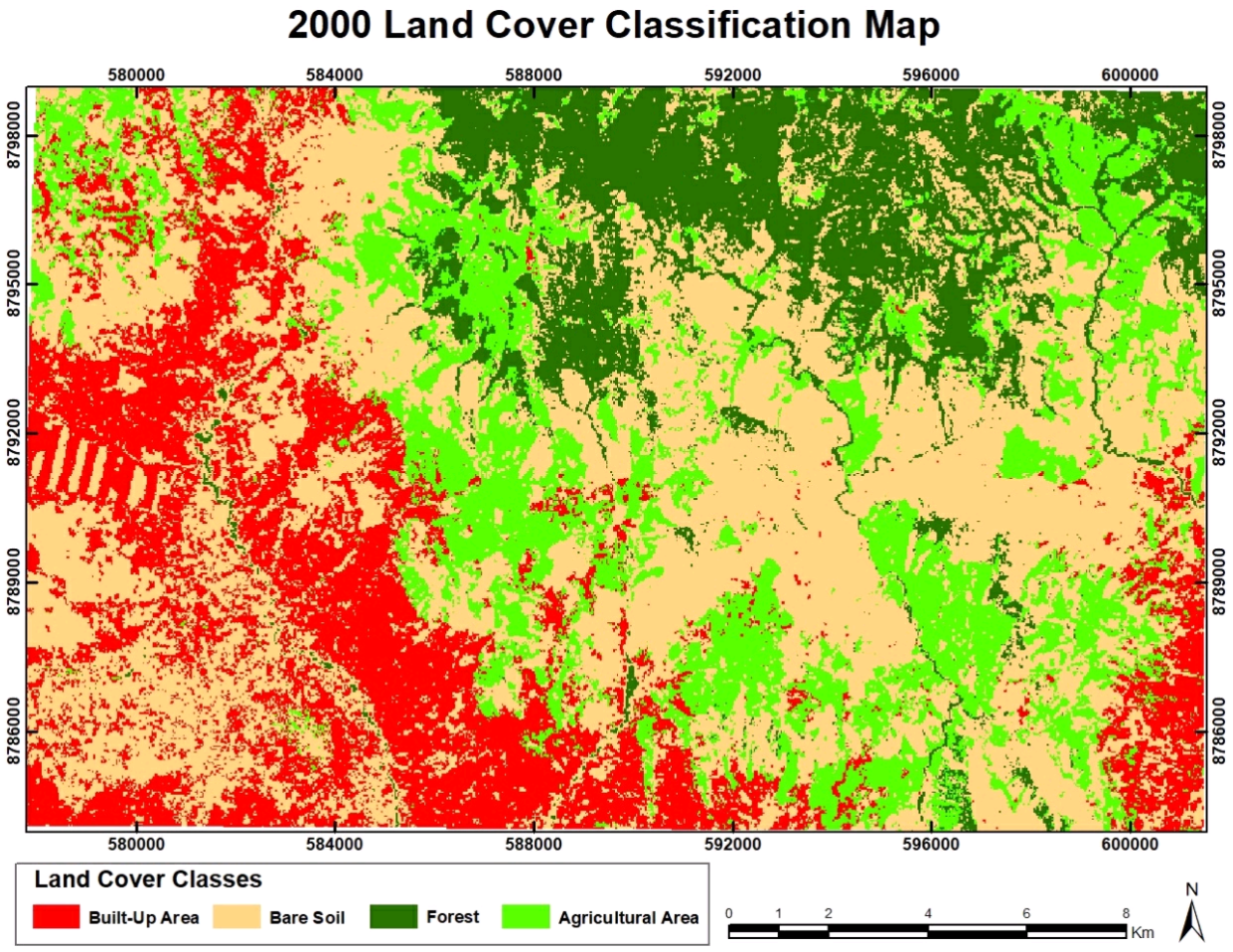


Figure 9: 20

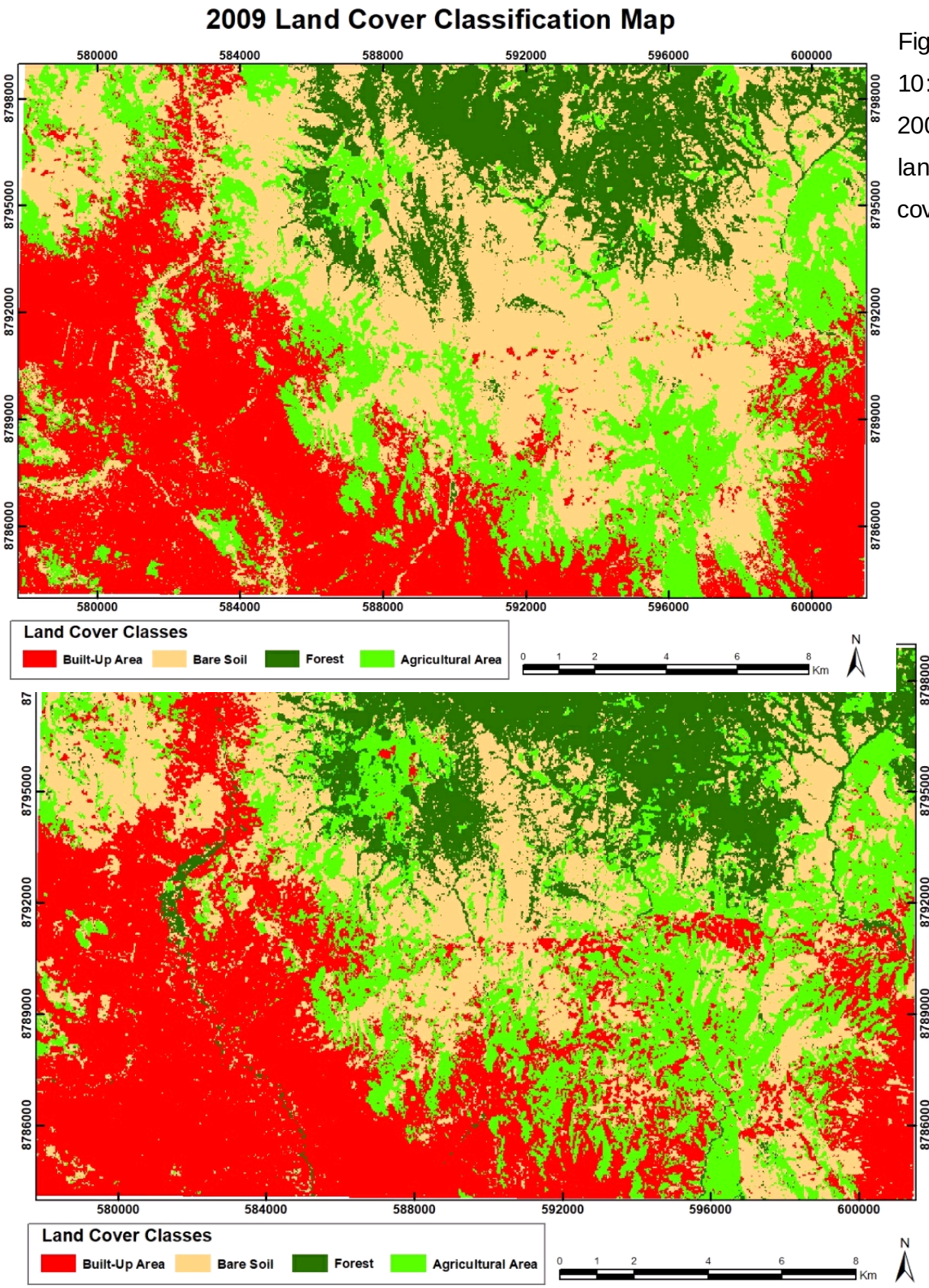


Figure 10: 2009 land cover

Figure 11: 2019 Land cover classification

The NDVI calculations in ArcGIS 10.5 showed that the number of trees were being reduced per unit area from 2000, 2009, to 2019. The results for the calculation for each area were presented in form of percentages in table 7 below. The percentage of built-up area was increasing which might have led to the reduction of trees in in the area. The area of the agricultural land was also increasing which means most of the trees were removed due to the opening of new farm lands. The percentage for bare soil areas were decreasing while the percentage of built-up areas were increasing from the year 2000, 2009 to 2019. The percentage of the forested area was decreasing from the year 2000 to 2019. The decrease in the number of trees in the area which were represented by a forest class may have led to the decrease in the stability of the slope

Table 7: The area of each class in percentages

Class Name	**2000**	**2009**	**2019**
Agricultural area	19.38%	20.32%	24.30%
Bare Soil	45.23%	35.18%	27.04%
Built-up area	20.42%	30.91%	38.00%
Forest (tree covered areas)	14.97%	13.53%	10.66%

Note: The percentage for each class was made from the area calculated

4.2.2. Analysis of rainfall data

In the 2019/2020 rainy season from the figure 12 below, Chozoli registered its first rainfall in October (0.9mm). From December 2019 to march of 2020, Chozoli experienced

prolonged and intense rainfall as shown in the graph below (figure 12). In January the area received a

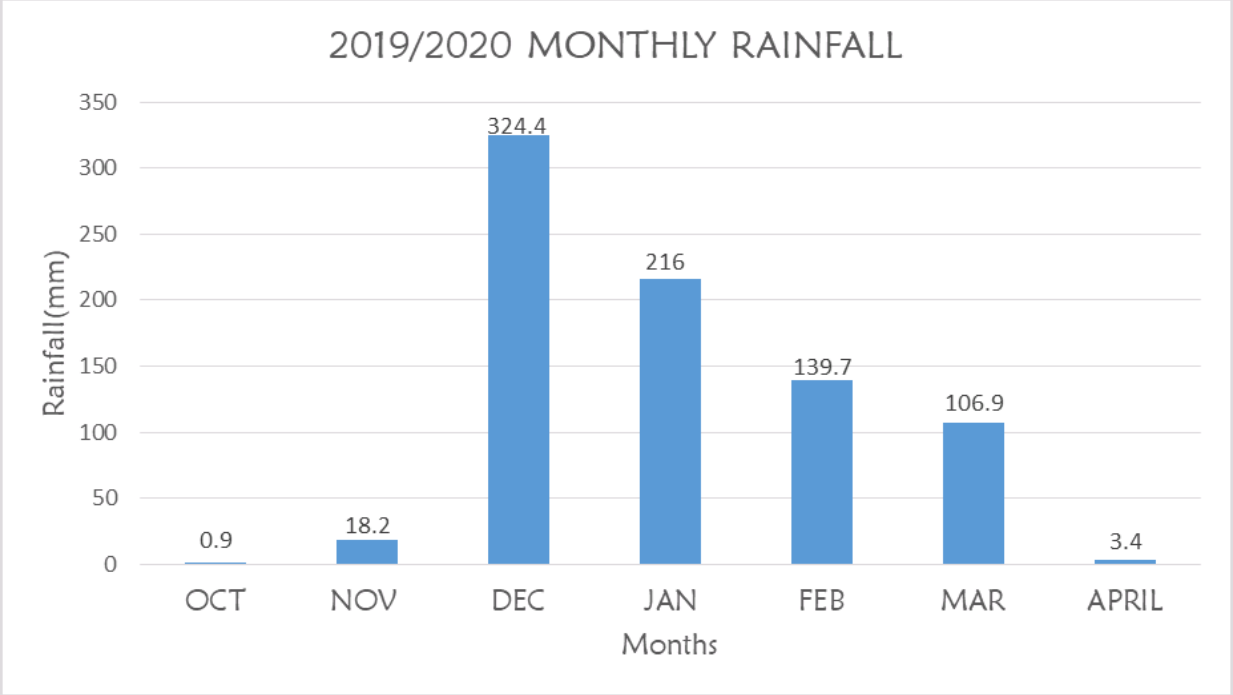


Figure 12: The 2019/2020 rainfall of Chozoli

Four days before the landslide there was continuous precipitation as shown in figure 13 below; 13.3mm on the 2nd of march, 8.0mm on third, 9.7mm 0n 4th of march and 1.2mm on the 5th March. This continuous rainfall might have weakened the slopes of the hill due to increased pore water pressure. Heavy precipitation was also recorded on the day of landside occurrence, having high leadings up to 31.3mm a day.

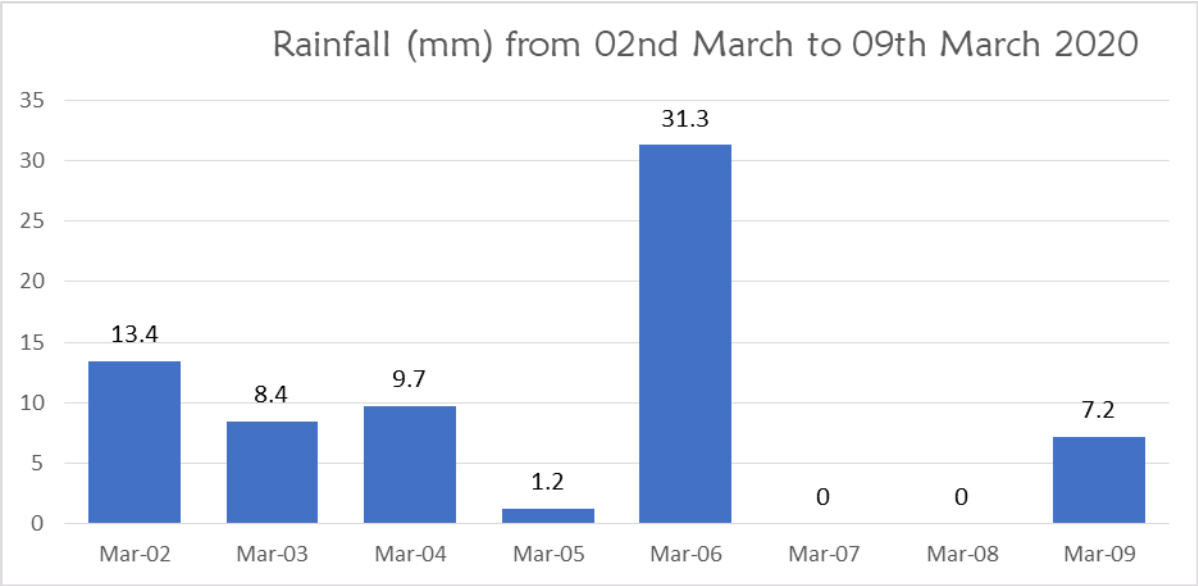


Figure 13: daily rainfall between 02nd March and 09th march)

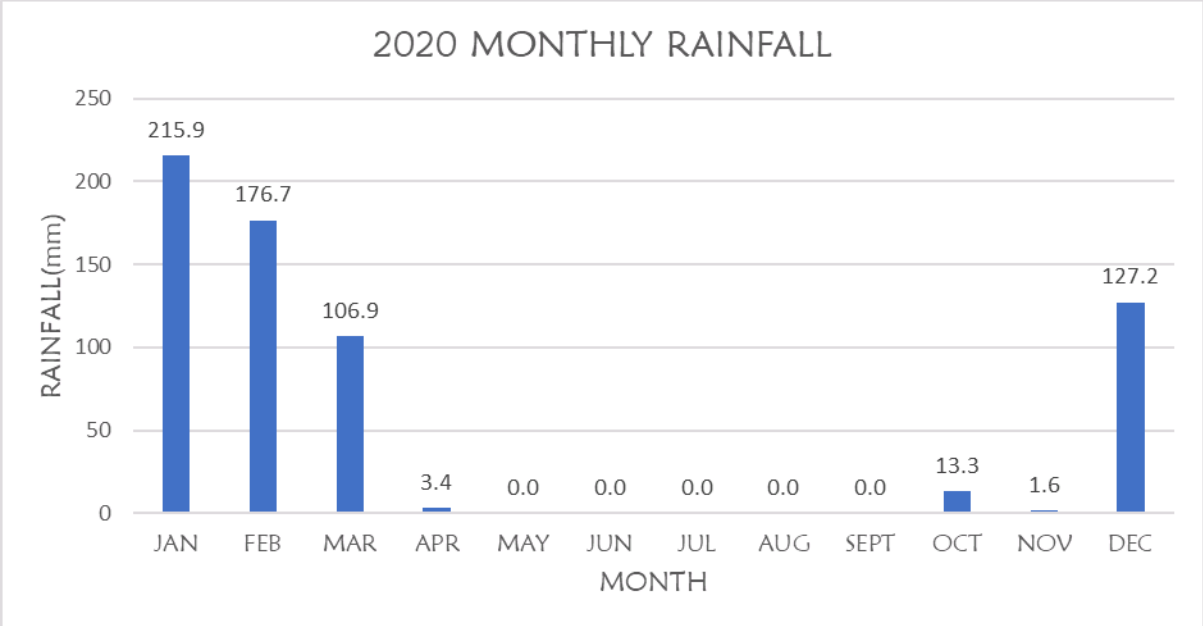


Figure 14: 2019 monthly rainfall

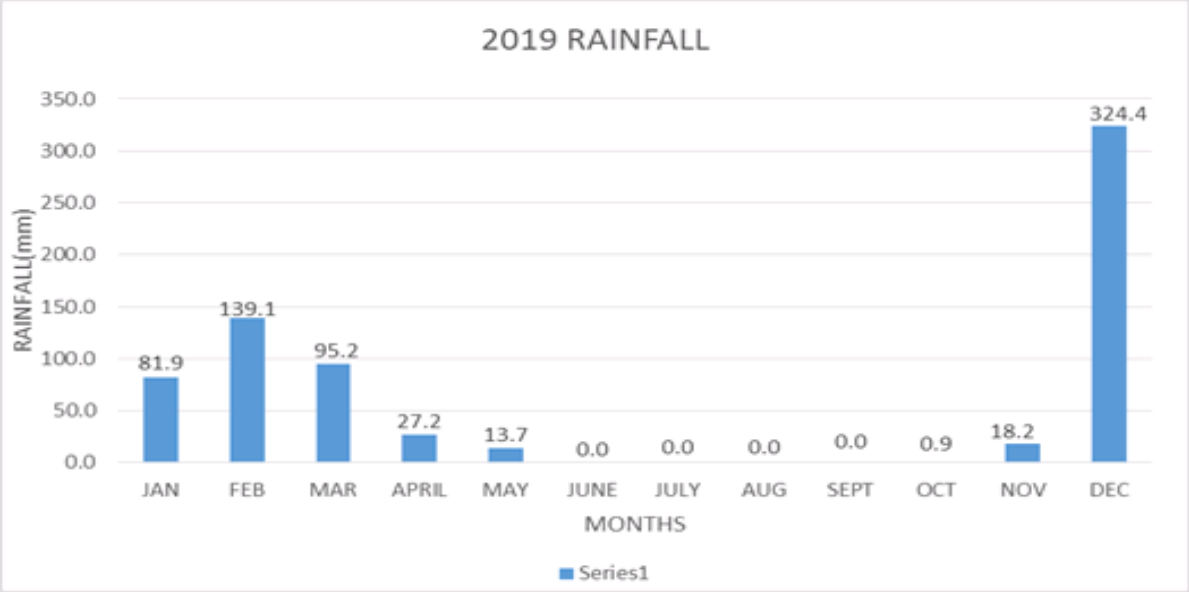


Figure: 2020 monthly rainfall

According to (Fell, Finlay, & Maguire, 1997), rainfall of 1-12 hours duration has a high probability of causing a landslide. Annually, Chozoli received a total precipitation amount of 608.1mm giving the annual average rainfall of 50.7mm. The area receives a very huge amount of rainfall; for example, from 2010 up to 2020 Chozoli have received an average annual rainfall of about 688.8mm as per the rainfall data collected by Bolero meteorological station which is located few kilometers away from Nkhwangu/Telelele hill. From the rainfall data in figure 16 below it shows that the highest rainfall values for the past 10 years were recorded in 2011 with the total annual rainfall values of 860.4mm. In 2019 there was a huge rainfall amount of about 700.6mm annually compared to 2020 the year which the landslide occurred which had a total annual rainfall of 645.0mm. The heavy

rains received in the past ten years may have been weakening the cohesion forces between the rocks

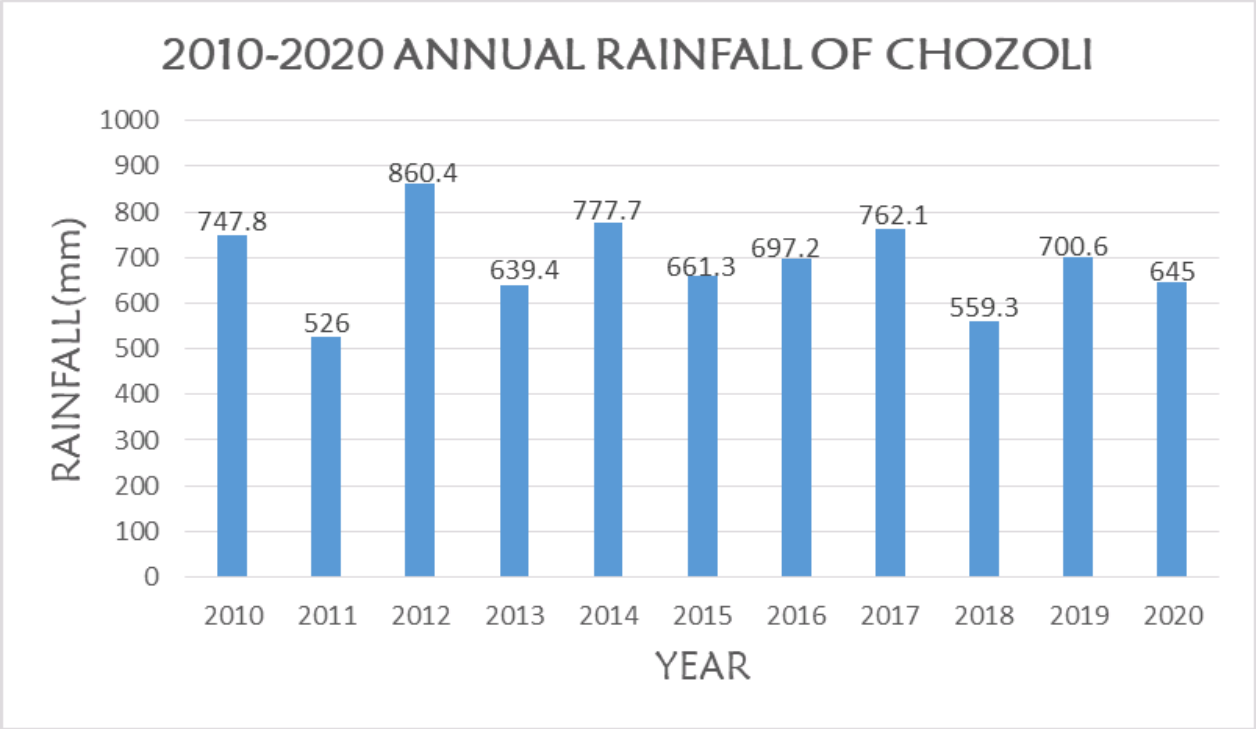


Figure 16: Annual rainfall pattern of Chozoli from 2010 to 2020.

4.2.3. Analysis of Geology

The geological map of Chozoli in figure 17 below shows that the area is mostly covered by biotite gneiss. Telelele/ Nkhwangu hill is mostly overlain by the Nepheline Syenite and the foot of the hill is covered by granite. To the western part of the hill there is a large area which is covered by Dambo soil while the northern part is also covered by granitic rocks. The cordierite gneiss occurs in smaller amount as compared to the biotite gneiss. Telelele hill is bounded by a fault both in the north west of the hill and the south east of the hill.

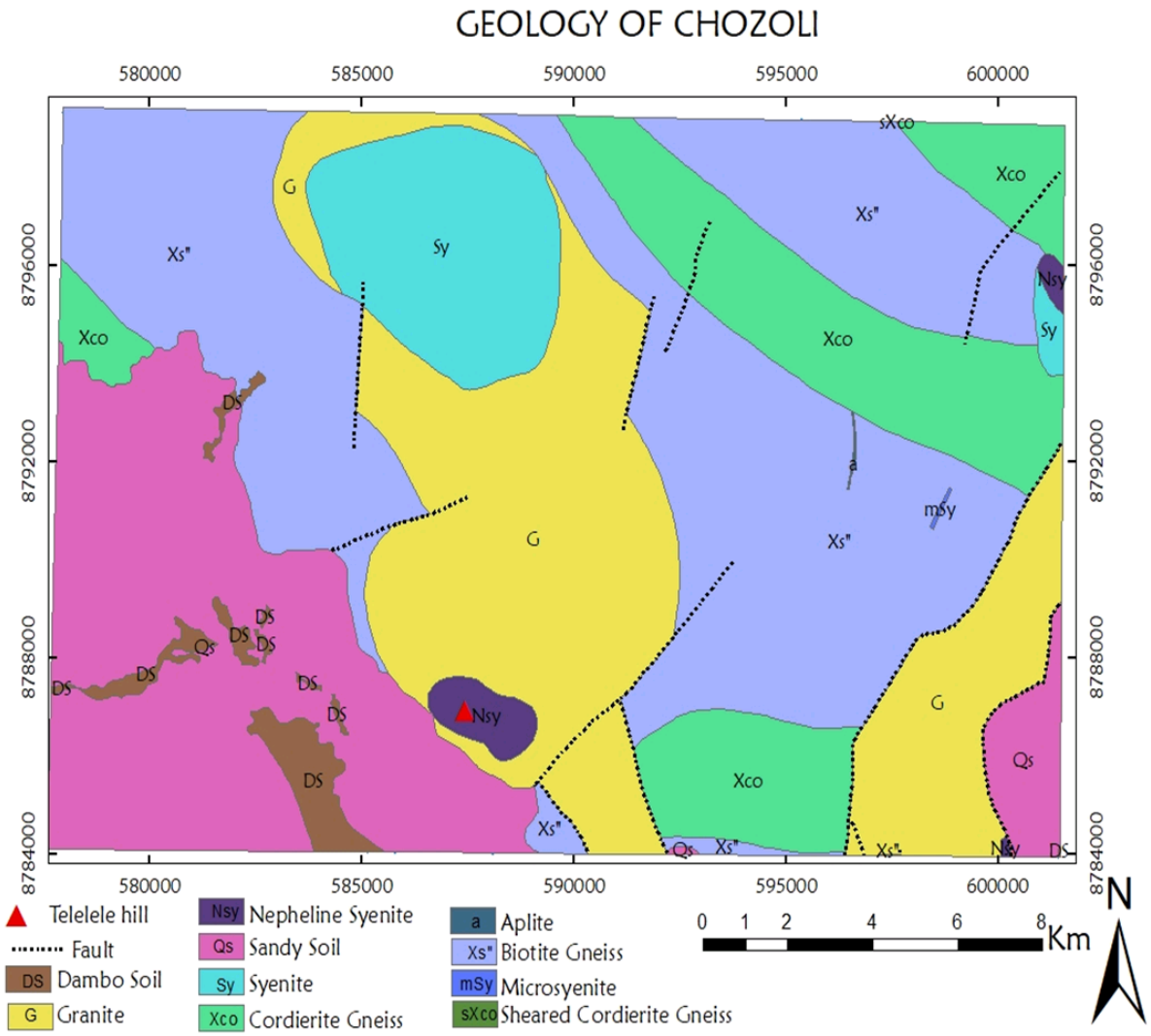

GEOLOGY OF CHOZOLI
580000
585000
590000
595000
600000
8796000
8792000
8788000
8784000
Telelele hill
Fault
DS Dambo Soil
G Granite
Nsy Nepheline Syenite
Qs Sandy Soil
Sy Syenite
Xco Cordierite Gneiss
a Aplite
Xs" Biotite Gneiss
mSy Microsyenite
sXco Sheared Cordierite Gneiss
0 1 2 4 6 8 Km
N

Figure 17: the geology map of Chozoli

4.2.4. Analysis of the Soil

From the figure 18 showing a soil map below the area was presented using the surface texture of the soil. The majority of the area is covered by sandy clay loam soil. Telelele hill is covered by the same sandy clay loam soil. The north eastern part, eastern part and the south eastern part of the hill is covered by sandy loam soil. The rock outcrop occurs in a very small amount. Clay loam soil and escarpment is also minimal. The sandy soils are located far from the hill in the south east occurring in small amount.

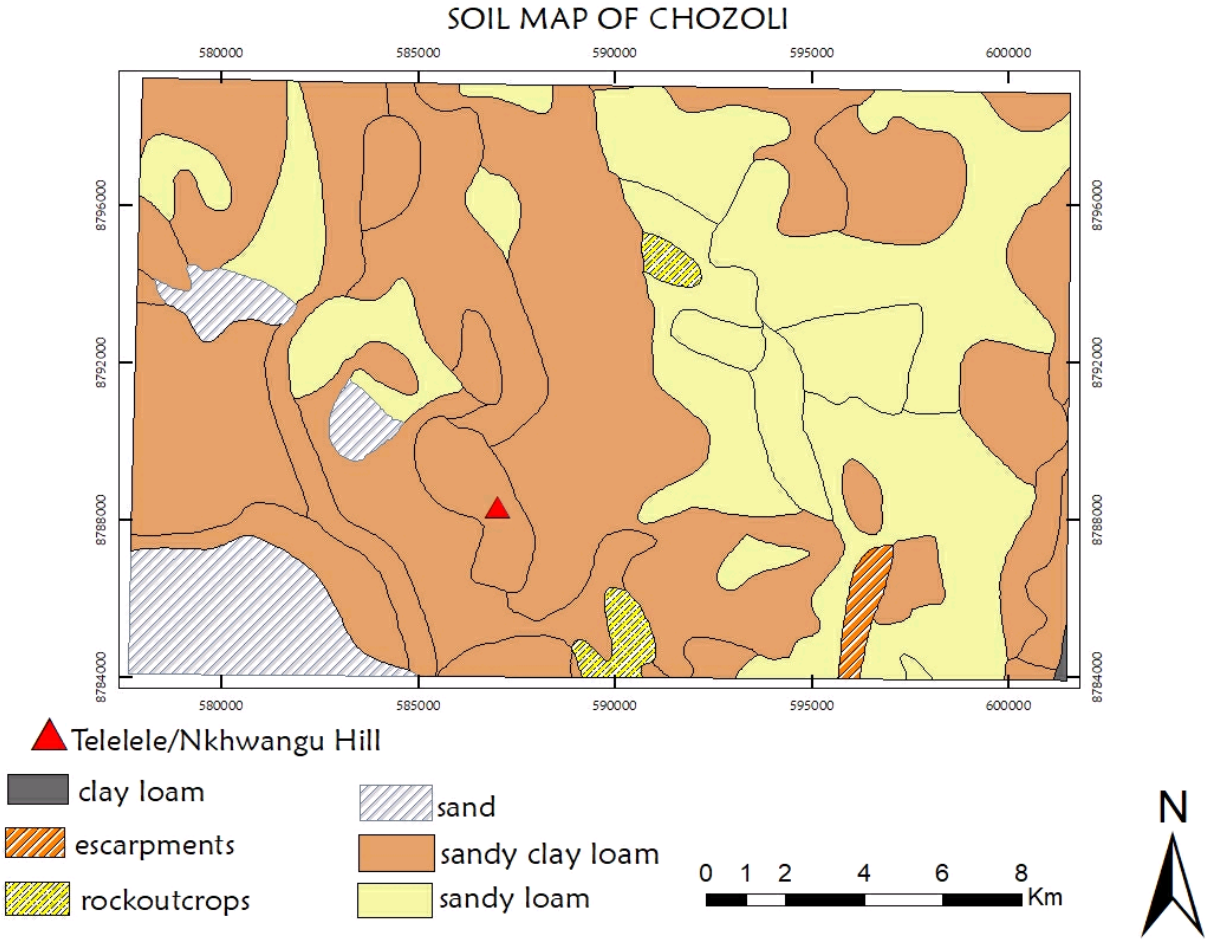


Figure 18: soil map of Chozoli

4.2.5. Analysis of Slope and hillshade

The main use of slope that it identifies the steepness of the terrain at each cell of the raster surface. The lower slope values represent the flat terrains; while the higher slope values are used to represent the steeper terrains. To calculate the raster values of a slope a planer method was used, where degree units were used, and the calculation was performed in on a projected flat plane using 2D Cartesian coordinate system (x- and y-coordinates). The slope was measured as a maximum rate of change in values to its immediate neighbor or nearest neighbor. According to (Ligas & Banasik, 2011), the slope in a planar method is calculated as the rate of change (delta) of the surface in the horizontal (dz/dx) and vertical (dz/dy) directions from the center cell to each adjacent cell using a formula as below;

$$Slope_degrees=ATAN\left(\sqrt{([dz/dx]^2 + [dz/dy]^2}\right).$$

From figure 19 below the terrain with values from 0-to-4.96 degrees which are in green in color represent the flat surface. Those which have a light green color with measurements ranging from 4.95-to-10.78 are a little steeper than those that are green in color. The surface that are presented by a yellow color have a moderate steepness which is greater than those which are green in color. The slopes that are presented in red have the highest steepness values which range from 25.64-74.31 degrees. The slope rises from green (flat), light green, yellow, orange to red (which are too steep). The light areas from the hillshade map in figure 18 areas while those that are dark/black show a low elevation.

In percentage measurements from table 8, the areas with slopes ranging from 0-to-4.95 degrees had a slope of 4.71%; the terrain with a slope angle ranging from 4.95-10.78 degrees had a slope of 10.59%; a terrain ranging from 10.78-17.58 degrees with a slope of 17.47%; from 17.58-to-25.64 with a slope of 23.53%. The highest slope which had a range from 25.64 degrees to 74.31 degrees with a slope of 100%

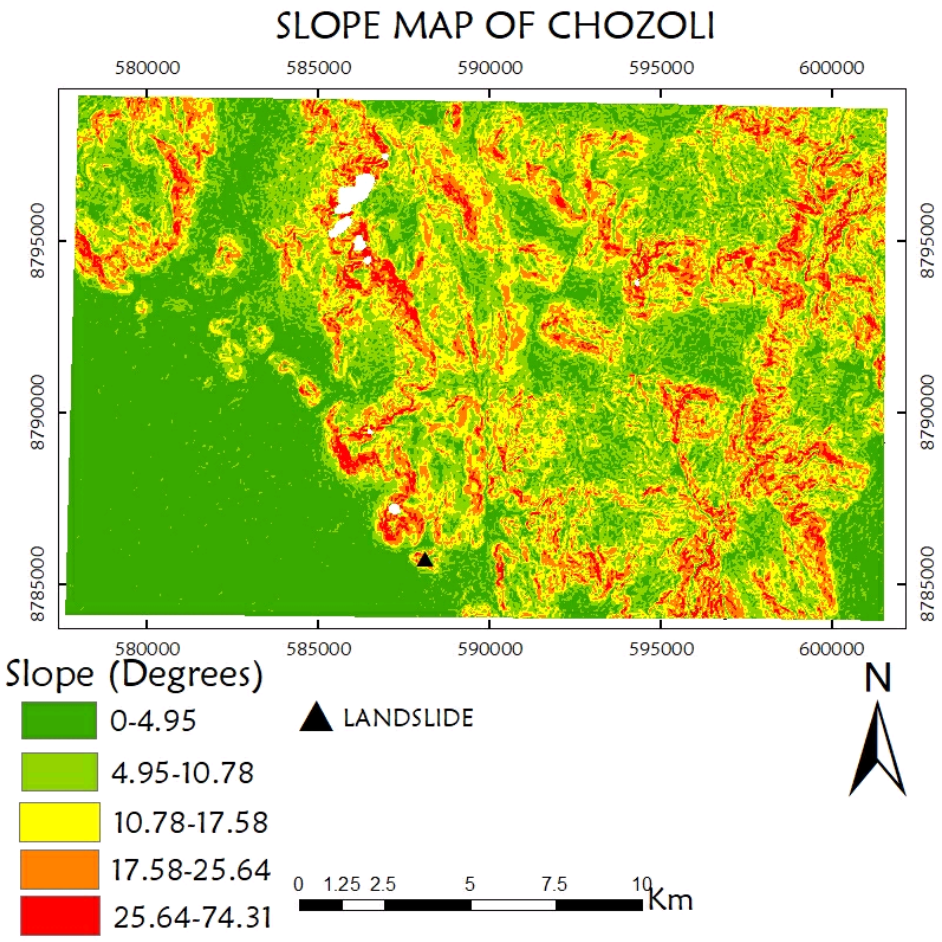


Figure 19: slope map of Chozoli

Table 8: slope values

Slope(degrees)	Slope percentage
0-4.94	4.71%
4.94-10.78	10.47%
100.78-17.78	16.47%
17.58-25.64	23.52%
25.64-74.31	100%

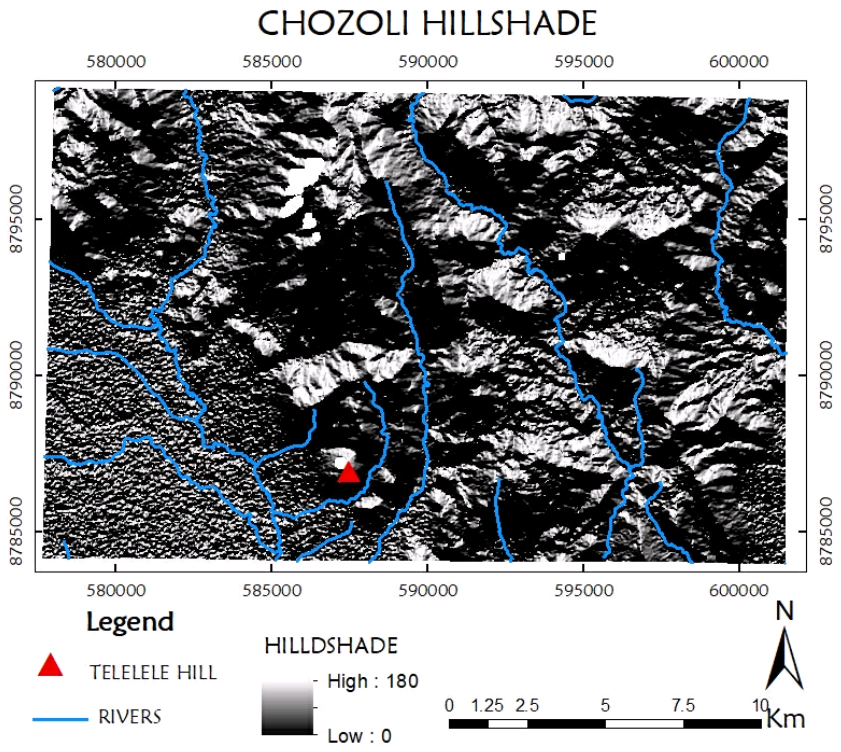


Figure 20: Chozoli Hillshade

4.3. Landslide susceptibility map and validation.

The Landslide susceptibility index map in figure 21 below was prepared using a statistical information value method in ArcGIS 10.5. In this method landslide causing factors such as

geology, slope, soil type (surface texture), and landcover were used to produce the landslide susceptil

For validation, the landslide point collected fron the google earth pro was overlaid with the susceptibility map as shown in figure 21 below. It was observed that Telelele hill from which the landslide occurred lies within the highly landslide susceptible areas.

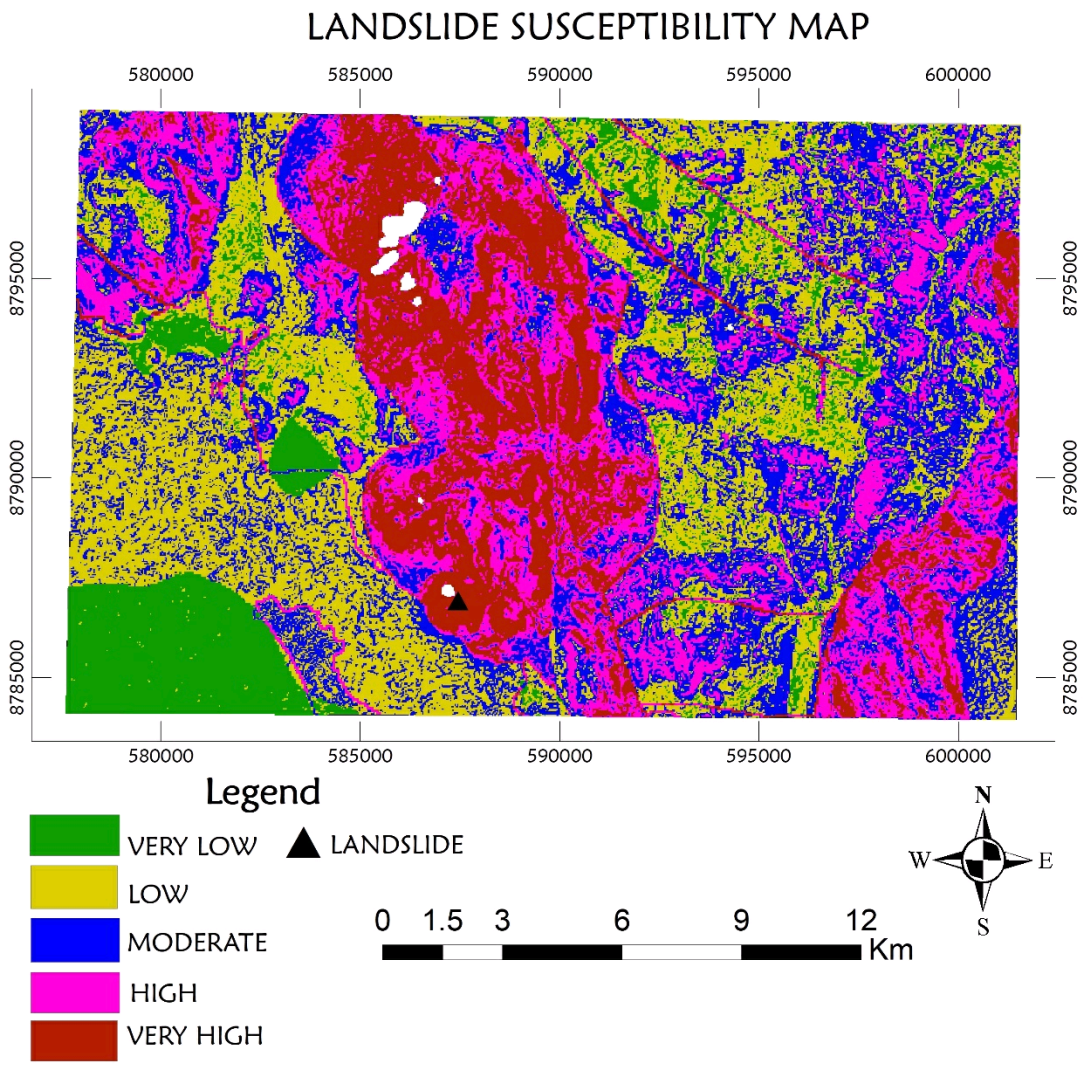


Figure 21: landslide susceptibility map

Table 9: Susceptibility Values

WEIGHT VALUE	SUSCEPTIBILITY PERCENTAGE
Very low	38.46%
Low	50%
Moderate	62%
High	73%
Very high	100%

4.4. DISCUSSION

Landslide susceptibility maps provides an important information where the landslides are more prone to occur in a region. It focuses on the relationship between preexisting landslide and the environmental conditions of the area. Landslide susceptibility maps also show the spatial distribution of predicted landslides where it is more likely to occur. Nevertheless, the predictive models can be important for the regional land use planning of landslide hazard mitigation and prevention (Wubalem, 2021). Landslide susceptibility map of Chozoli was classified into five categories; very low, low, moderate, high and very high susceptibility classes using the natural break method, which is mostly applicable to classify

unevenly distributed data, and has a capability of classifying the landslide susceptibility index map into

Water can trigger mass movements because it changes the pressure within the slope which leads to slope instability. Consequently, the heavy water-laden slope materials (soil, rock, etc.) will succumb to the forces of gravity. It is evident from figure 8 above that there was a heavy down pour within the area prior to the mass movement. According to (USGS website https://water.usgs.gov/edu/activity-howmuchrain-metric.html) this type of rainfall is categorized as very heavy rainfall. Therefore, the debris flow might have been triggered by heavy down pour. The heavy rains in the past months and past years might also have weakened the slope slowly which its results were shown later. Geology and geomorphological information of the area showed that the affected area is within a nepheline Syenite intrusion; it is located on steep slopes on the western edge of Telelele Hill which forms part of the South Nyika Foot-Hills (Thatcher, 1974). The mass movement occurred on the top layer of the nepheline Syenite intrusion (From geology map in Fig. 17) which comprise residual soils and highly fractured and jointed nepheline Syenite outcrops. Explanation on seismicity of the area concluded that there was no earthquake occurrence prior, during or after the mass movement. Therefore, the mass movement was not triggered by earthquake occurrence. Information from local people indicated that there was no earthquake felt within the area; however, it was verbally reported that there was a heavy pour down prior to the mass movement (this information agreed with results from analysis of rainfall data).

CHAPTER 5: CONCLUSSION AND RECOMENDATION

Seismic investigation showed no earthquake occurrence; rainfall data for the area showed heavy down pour prior to the event. It is therefore concluded here that heavy down pour on the steeply sloping mountain may have weakened and liquefied the highly weathered, fractured and jointed rocks thereby triggering the slide and debris flow. As a prevention measure it is therefore important to construct debris basins, which are designed to “catch” a flow in a depressed and walled area (https://www.universetoday.com/75745/debris-flow/) thereby diverting it from human populated areas. It is also recommended that, human activities that facilitate mass movement i.e., cutting down of trees or cultivating within the slopes of Nkhwangu Hills (and any other hill) should be stopped; such activities disturb the

slope thereby making it instable and prone to mass movement.

5.1. Limitation of the study

Lack of financial support became one of the greatest challenges in this study. Due to financial issues, there was no field visitation hence only secondary data was used. Poor quality of the data was another biggest limitation. For example, too much cloud cover in both Digital Elevation model and Landsat images led to gaps and not clear results in some area. The rainfall data which was used was only from one meteorological station and it was difficult to show the distribution of rainfall in the area.

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Appendices

Below are some of the rainfall data used for analyzing the rainfall pattern of Chozoli, landcover classification values and slope values.

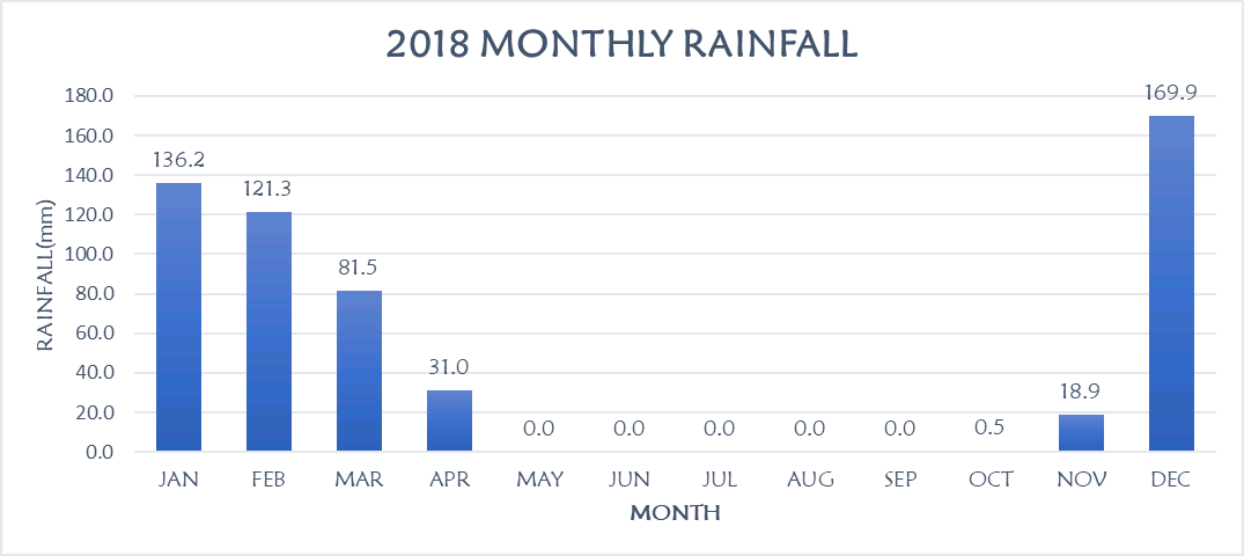


Figure 22: 2018 Chozoli rainfall data

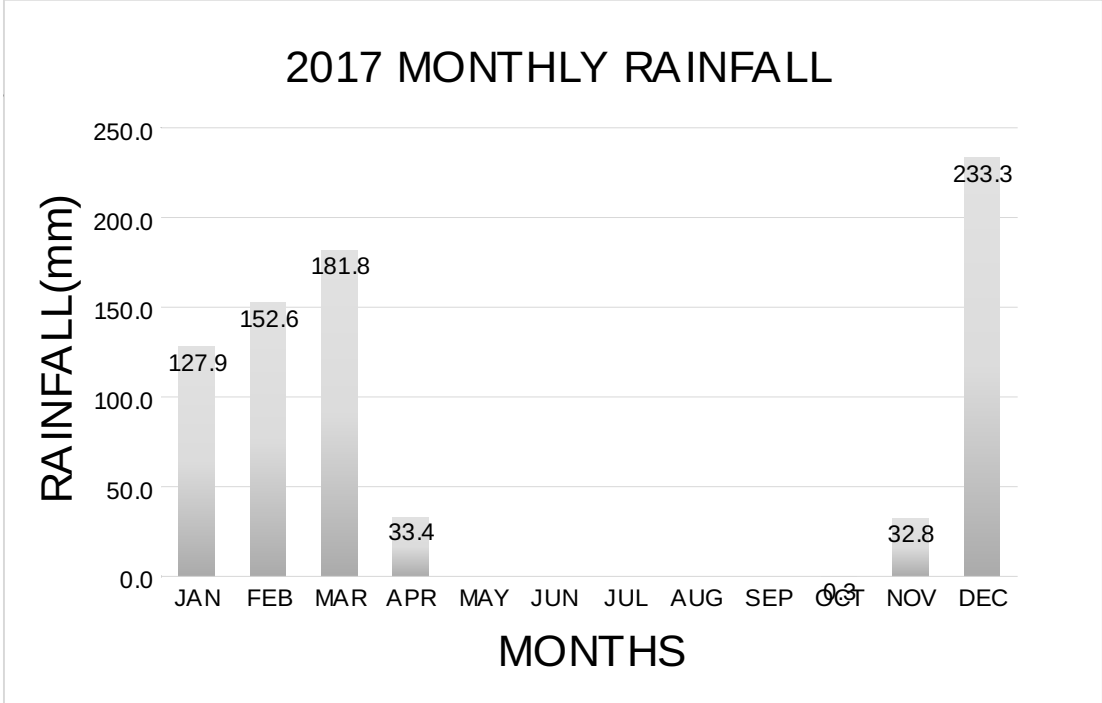


Figure 23: 2017 rainfall graph

Table 10: Chozoli annual rainfall

YEAR	Total Rainfall (mm)
2010	747.8
2011	526
2012	860.4
2013	639.4

2014	777.7
2015	661.3
2016	697.2
2017	762.1
2018	559.3
2019	700.6
2020	645

Table 11: The area of each land cover class measured in square kilometers

Class Name	**2000**	**2009**	**2019**
Agricultural area	69.1398 Km^2	72.5103 Km^2	79.4052Km^2
Bare Soil	161.348 Km^2	125.555 Km^2	88.3665 Km^2
Built-up area	72.8676 Km^2	110.324 Km^2	124.169 Km^2
Forest (tree covered areas)	53.4105 Km^2	48.4866 Km^2	34.8243 Km^2

Table 12: Slope values

Slope (Degrees)	Slope (percentage)
0-4.95	4.71%
4.95-10.75	10.59%
10.75-17.58	16.47%
17.58-25.64	23.53%
25.64-74.31	100%