INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 08 Issue 08 August 2025

DOI: 10.47191/ijmra/v8-i08-04, Impact Factor: 8.266

Page No. 4418-4428

Soil Instability and Prevention Countermeasures of Typical Landslide in Northwest Rwanda

Jean Pierre Ngaboyigihugu[1], Tang Aiping[2], Antoine Musengimana[3], Mbarushimana Yves [4]

[1]Assistant lecturer in civil engineering-Rwanda polytechnic-Musanze college

[2]Professor, School of Civil Engineering, Harbin Institute of Technology, Harbin, China

[3]Lecturer in civil engineering-Rwanda polytechnic- Tumba college

ABSTRACT: Landslides are one of the most common geological disasters in the world, causing massive casualties, degradation of natural resources and damage to infrastructure. In the hills and mountains of western and northern Rwanda, landslides are the most serious natural disasters that often occur, often causing huge loss of life and property. Rwanda is a mountainous, rainy country with an average annual rainfall of over 500 mm across the board, with up to around 2000 mm in some areas in the west and north. Since the minimum temperature is 14 ~ 17°C, the maximum temperature is in the range of 27 ~ 32°C, and the relative humidity is 70% ~ 77% higher, resulting in low evaporation, surface rainfall is more likely to be enriched in the rock and soil layers. This paper systematically analyses the formation instability of typical landslides in Rwanda by means of numerical simulation techniques and discusses the risk level of landslide hazards in the northwest region of Rwanda. In addition, feasible corresponding engineering prevention measures are proposed. The main research work of the paper is summarized as follows:

(1) Using numerical simulation methods, based on GTS NX software, the formation instability of landslides in different regions of Rwanda was analysed, and the influence laws of the slope, rain, fall and slope cutting on slope instability were analysed. Most parts of Northern Rwanda are above 40 degrees of slope gradient, above 30 degrees in Western parts and above 25 degrees in Southern province. The slope gradient and mass movements are the important factors that determine the distribution of landslides in Rwanda.

(2) The stability of typical slopes in Rwanda was analysed by using Bishop, spencer and strength reduction methods. The research results show that the safety factor of most multi-layer soil slopes and artificial cut slopes is less than the standard value of 1.35. These slopes are naturally unstable.

(3) Using numerical simulation technology, the feasibility of using anchor rods and H-type piles to reinforce the slope in Rwanda was analysed and the effect of reinforcement was evaluated.

Aiming at the formation instability and disaster reduction engineering measures of landslide disasters in Rwanda, this paper analyses the geological and human factors caused by landslides, and on this basis, proposes the prevention and control of natural and artificial slope disasters in Rwanda and the management of building and natural environment resources. Strategy, provides theoretical support and engineering practice guidance for Rwanda landslide disaster risk assessment and disaster reduction strategy.

KEYWORDS: Rwanda, landslide, anchor, H-shaped pile, numerical simulation

1. INTRODUCTION

Landslide is one of the most common natural hazards that has caused massive damages to infrastructure, and property as well as loss of lives around the world. The countries most affected by the landslides are China with 695 landslide-persuaded deaths, Indonesia with 465 deaths, India with 352, Nepal with 168, Bangladesh with 150, and Vietnam with 130[1]. Approximately 89.6% of the total fatalities around the world were caused by landslides set off by prolonged or intense rainfall [2].

Rwanda is prone to human-induced disasters and natural hazards. More than 80 percent of the total population of Rwanda is likely to suffer from natural hazards such as drought, floods, earthquakes, volcanic eruptions, landslides, cyclones, and storms among others[3]. Among various natural hazards, landslides are very common in the hilly region of Rwanda. Two-third of the total area of Rwanda lies in mountainous and hilly regions, one of the several reasons leading to landslides. Landslides in Rwanda causes a significant number of fatalities, and economic losses, which is one of the major restraint in development[3].

Landslides are among the global widespread geological hazards responsible for considerable human injury and death, natural resources degradation, and infrastructure damage[2]. The term landslide describes a wide process responsible for downward and outward movement of slope forming material composed of rock, soil, artificial fills, or a combination of all these down a slope[3]. The landslide occurrence depends on soil depth, soil type, slope aspects, slope curvature, elevation, vegetation cover, and other anthropogenic activities such as deforestation, road construction, and cultivation on steep slopes that change the land cover and land use patterns[4]. Landslides can also be triggered by earthquakes, volcanic activities, and heavy rainfall. Hazard is the probability of occurrence of a particular damaging phenomenon, within a specified period of time and a given area due to different existing or predicted conditions[5]. The vulnerability of Rwanda to landslides and Floods is largely due to its topographic and demographic characteristics. This is further exacerbated by the impacts of climate change such as the increasing variability in rainfall frequencies and intensity causing climatic hazards[1]. Landslides and floods have been among the major disasters in Rwanda and they have a great impact on human developments, infrastructures, properties as well as the environment in general. Landslides and floods are key disasters that frequently affect different areas of the country and most of the affected population don't have efficient countermeasures skills to fight against those hazards[6]. The hilly topography of Rwanda and annual precipitation rates, human activities such as exploitation of natural environments, deforestation, inappropriate farming, mining, and construction of new infrastructures facilitate the acceleration of disaster risks in Rwanda where every year the country loses many lives and many property damages due to those hazards. The most affected regions are located in the North-Western part such as Rubavu, Musanze, Burera, Nyabihu, Ngororero, and Gakenke[4].

2. REVIEW OF LITERATURE

2.1 CONCEPT OF LANDSLIDE

Based on knowledge and experience, the term "Landslide" has been defined in multiple ways by different researchers. Landslides can be simply defined as "the movement of a mass of rock, earth or debris down a slope," in which a large amount of soil and rock has down-slope movement under the direct influence of gravity[7]. When forces acting down-slope due to gravity exceed the strength of the earth materials that compose the slope, failures occur. Such movements result from multiple factors acting on the earth's surface which increase the effects of down-slope forces. Landslides occur on smaller scales than other natural disasters, but have higher distribution and are more dangerous in many cases. Hence, this is explained that landslides occur mostly on the slopes due to huge movement of soil due to the change in water level, stream erosion, rainfall, snowmelt, changes in ground water, disturbance by human activities earthquakes, and volcanic activity, or any combination of these factors. Landslide hazards can also be considered as the probability of occurrence of potentially damaging landslides within a specified period of time in a given area[8]. The described features for a complex slide-earth flow, which has been illustrated in the following Figure 1-1[9].

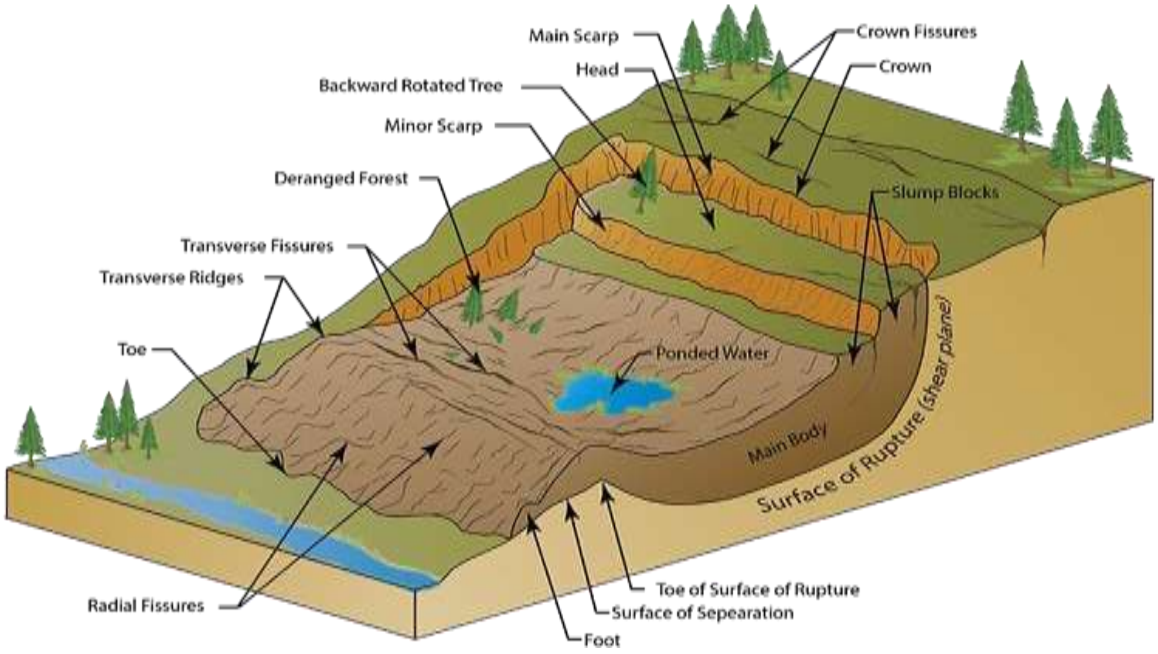

Figure 1-1 Illustration of landslide features [10]

2.2 CAUSE OF LANDSLIDE

2.2.1 General causes of landslide

Landslides can be caused by two main types which consist of Natural and human causes. In human causes, we can find more subtypes like different human activities such as construction works and mining which are the most common activities that cause the most serious landslide. Mining activities that utilize blasting techniques contribute to the landslide where vibration from the blasts can make the soil to be weaker and this weakening of soil means that anytime landslide can occur. During construction, many applied techniques can lead to the occurrence of landslides. For example, in road construction, cutting of slope, soil excavation during site clearance, and clear-cutting are required. The clear-cutting is a technique of timber harvesting that remove all old trees from the construction area especially and this technique is dangerous since it destroys the existing root structure of the area[10].

Natural causes of landslides include Earthquakes which are seismic activities that have contributed to landslides across the world. Because of the movement of tectonic plates, the soil covering them moves along with them and triggers earthquakes, which may lead to landslides if the area is with steep slopes soil. Another natural cause of landslides is long-term climate change which significantly impacts soil stability. Reduction in precipitation leads to lowering of water table and reduction in overall weight of soil mass. A significant increase in precipitation or groundwater saturation would lead to soil saturation, and therefore, when sloped areas are completely saturated with water, landslides can occur. In absence of root support, the soil runs off. Erosion caused by running water such as rivers, streams, wind, and waves spread out lateral slope trigger landslides to occur easily. Steep slopes with gravitational force can trigger a massive landslide which means that gravity also is one of the causes of landslides[10].

2.2.2 Major causes of landslides

2.2.2.1 Landslides and water

Soil congestion is the major cause of landslides. The effect of soil saturation can occur in the form of snowmelts, intense rainfalls, variation in ground-water levels, and changes in water levels along with earth dams, banks reservoirs, lakes, rivers, and canals. Water can trigger landslides and mudslides because it alters 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. Excessive water is thought to be one of the most common triggers for landslides[11].

The terms flooding and land sliding are nearly allied as both of them are related to runoff, precipitation, saturation of the soil, and ground water[12]. Flooding can be one of the effects of landslides because floods in the form of sheet flow, overland flow, groundwater ridging, etc. are connected to landslides. The landslide dams can block stream channels and valleys allowing a huge amount of stream water to back up. This can cause flooding backwater and if the dam cannot withstand the pressure of backwater flooding there would be subsequent downstream flooding. The landslides can overtop the reservoirs and reduce the potential of reservoirs and basins to store water[12].

2.2.2.2 Landslides and volcanic activity

Landslides can be caused due to volcanic activities and some of them are destructive types. The process of volcanic lava can melt snow at a high rate, causing a deluge of ash, soil, water, and rock that accumulates swiftly on the steep slopes of volcanic mountains. The most affected region is the flat area around the volcanoes. The break out of Mount St. Helens in 1980 in Washington provoked the gigantic landslide in the northern region of the volcano, which is reckoned to be the biggest landslide in recorded times[12]. Volcanic eruptions can also trigger landslides, in case an eruption occurs in a wet condition, the soil will start to move downhill initiating landslides. Weathering can be a result of landslides. In case the rocks weakness due to weathering, which is the natural procedure of rock deterioration that leads to the weakness of the material, here the slip away of rocks can cause landslides[10].

Other various reasons causing landslides are listed below[14]:

i. Geological causes: Weak or sensitive materials, sheared, jointed or fissured materials, weathered materials, contrast in permeability and or stiffness of materials, adversely oriented discontinuity (bedding, fault, unconformity, contact, and or forth).

ii. Morphological causes: Tectonic or volcanic uplift, fluvial, wave or glacial erosion of slope toe or lateral margins, glacial rebound, deposition loading slope or its crest, subterranean erosion (solution, piping), shrink-and-swell weathering, freeze-and-thaw weathering, vegetation remove (by fire, drought), thawing.

iii. Human causes: Loading of slope or its crest, excavation of slope or its toe, drawdown of reservoirs, deforestation, irrigation, artificial vibration, mining, and water leakage from the utility.

2.3 Landslides triggering factors in Rwanda

A triggering factor is an external stimulus that triggers the movement and one of the renowned triggering factors is rainfall. Rainfall is an important factor in triggering landslides in Rwanda. Precipitation conditions determine infiltration and run-off. Prolonged rains with a lower intensity result in a higher and deeper infiltration and lower run-off in sloping areas. On the other hand, in these regions, torrential rains increase run-off and result in a lower amount of infiltration in many areas of the country. Nevertheless, they promote the wetting of soil along fissures which serve as natural rainwater collectors[13]. The amount of rainfall has a considerable influence on the moisture content and the pore pressure in the soils[13].

Higher moisture content can increase the specific mass of rocks by 20 to 30% and at the same time lower their shear resistance by 50% and even more, due to increased pore-water pressure[15]. This greatly reduces shear strength and hence slope failure. Rwanda has a tropical climate characterized by its hilly landscape stretching from east to west. The country has four primary climatic regions: eastern plains, central plateau, highlands, and regions around Lake Kivu. The eastern plains receive an annual rainfall of between 700 mm and 1,100 mm, with the mean annual temperature oscillating between 20°C and 22°C. The central plateau region enjoys rainfall of between 1,100 mm and 1,300 mm, with an annual mean temperature of between 18°C and 20°C. The highlands, including the Congo-Nile Ridge and volcanic chains of Birunga, benefit from an annual rainfall of between 1,300 mm and 1,600 mm and experience annual mean temperatures between 10°C and 18°C. Regions around Lake Kivu and Bugarama plains get annual rainfall of between 1,200 mm and 1,500 mm with annual mean temperatures between 18℃ and 22℃. Overall, the country's four climactic seasons are represented through the long rainy season: March to May, and short rainy season: September to November. These seasons alternate with the long dry season: June to August, and short dry season: December to February.

The mean annual temperature for Rwanda is 19.1℃, with average monthly temperatures ranging between 19.5°C (September) and 18.5℃ (July). Annual precipitation is 1,170.2 mm. Rainfall is experienced throughout the year in Rwanda, with most significant rainfall occurring from September to May. The temperature in Rwanda, the high degree of inter-annual and inter- decadal climate variability and lack of historical records has made climate trends in the country difficult to determine. The average annual temperature ranges between 15℃ to 17℃ in high-altitude areas and up to 30℃ in lowlands in the east and southwest. Regional temperatures for central-east Africa saw average increases of 0.29°C per decade from 1985 to 2015.

Temperature increases have been experienced, 1971 to 2016 showing an increase in mean temperature of between 1.4°C and 2.6°C in the south-west and eastern regions of Rwanda. Increased inter-annual variability in recent decades was also observed, for example, average increased temperature from 2012 to 2014 increased by 0.79℃.Precipitation Rainfall trends have shown an increased occurrence of extremes since the 1960's across various regions of the country with the southern oscillation influencing precipitation trends during years. The annual rainfalls in Rwanda exhibited high fluctuations since 1961 to 2016. Over this period, mean rainfall significantly decreased in January, February, May, and June, but with a significant increase from September to December across the country. Rwanda's eastern region has experienced frequent dry episodes from September to December. In the northern and western provinces, rainy seasons are becoming shorter and more intense, which has resulted in increased erosion risk in these mountainous areas of the country [16].

3. METHODOLOGY

In this research method of slices is selected. Using this method we sliced the land mass into number of parts and individually calculated the normal and shear forces on each slice. The method used to understand the stability of soil by getting the FS. Bishop and Spencer's methods were used in this analysis because they satisfy both moment equilibrium and forces equilibrium. Bishop developed a method of slices to determine the FS, whereas Spencer's method w satisfies moment and force of equilibrium of the failure of mass. The unstable condition of the slop is determined by the factor of safety less than one. Otherwise, the slope stability is guaranteed.

3.1 Bishop and spencer method

Bishop's method is matched to most stability problems where a circular failure surface is exposed. It is easy to run and always produces a result since it considers moment equilibrium. The Spencer method is suitable for both circular and non-circular problems and is theoretically more accurate than Bishop's method. However, in practice, the Factors of Safety determined by Spencer's method and Bishop's method for circular failure surfaces are almost identical. In some situations it can be difficult to get a result when using Spencer's method since the force and moment equilibrium calculations may not always converge. In order to get good results both Bishop and Spencer methods were considered in this research and because both methods are not based on hand calculations slide software was used as Finite Element software and different simulations were done using Slide.

3.2 Soil properties

This study is carried out on real data collected from Rwandan institutions where soils samples were collected from north-western province, parent materials with 45.59 % of sand, 3.2% of clay and 51.21% of silt as a result of hydrometer test and the grain size distribution from sieve analysis test 12.9% of gravel, 68.3% of sand and 18.8% of fines. The moisture content of the soil is 12.48% with 2.666 specific gravity. Other soil properties used in this research are the unity weight of the soil which 15 kN/m3, the cohesion of the soil which is 8.39 kPa, and the friction angle of the soil which is 18.25 degrees the total area of the soil is 930m2. The water surface was not considered in some conditions and the strength type used is Mohr-Coulomb.

3.3 Construction of modal

3.3.1 Contours generation in QGIS

Using QGIS the 2D contour lines are generated from digital elevation model (DEM) data of Rwanda as shown in Figure 2-9. The contour lines' interval is 10 m. The selected area of interest is affected by landslide as it can be seen on Figure 3.1.

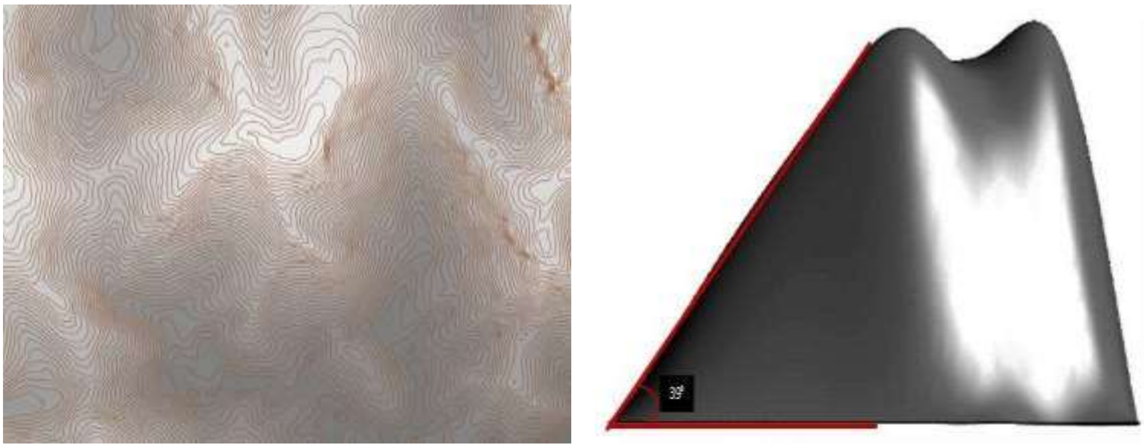

Figure 3-1 Contour generated for modelling

3.3.2 AutoCAD 3D contours generation

After generating 2D contours in QGIS the application of AutoCAD is needed to generate 3D contours, which later is used to convert contours into 3D-model. 3D-generated contours model in AutoCAD is presented in Figure 3-2.

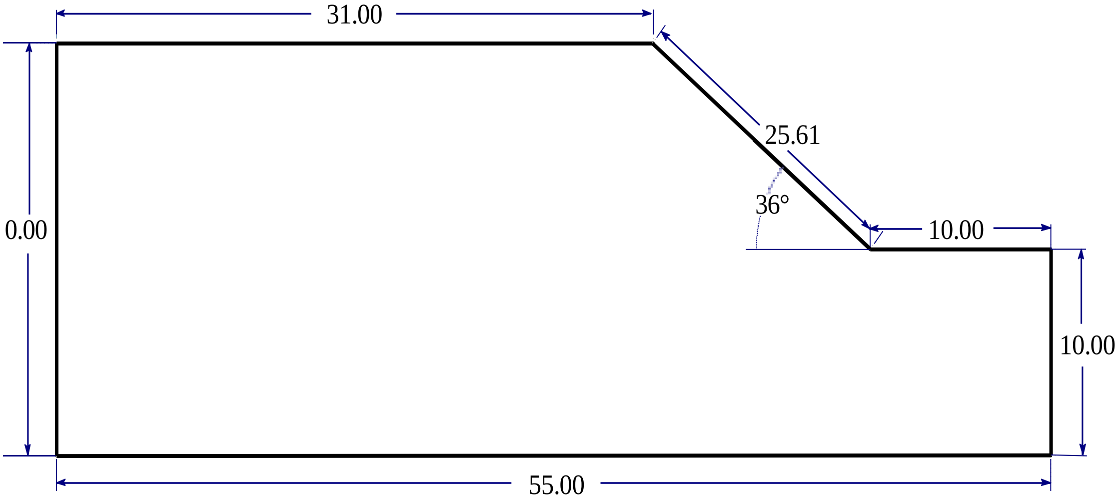

Figure 3-2 Soil modal 36 degrees

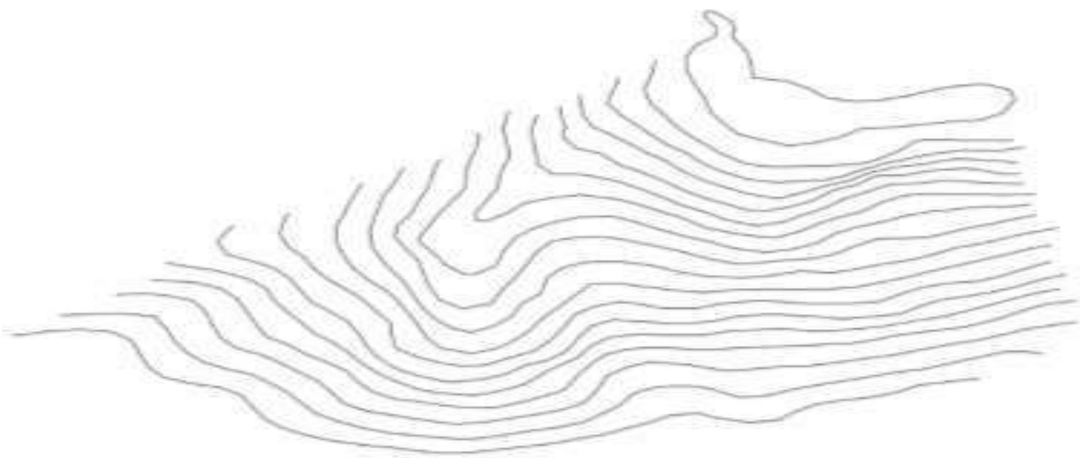

Figure 3-3 AutoCAD 3D contours generation

3.3.3 Construction of model based on angle of inclination

The final stage of construction of the model is carried out by GTS NX terrain geometry maker (for more information refer to Figure 3-4). All models used in this research are based on the model generated in GTS NX as it is shown in Figure 3-4, where 36 degrees is used to check the slope stability in safe conditions and 40 degrees for unsafe conditions, consecutively.

4. LANDSLIDE INSTABILITY

Using finite element 2D geometric model at a landslide section was constructed with specific ground conditions and materials parameters and the slope allowed to deform both failure and deformation states were modeled for better observation, this model was done base on real data counters of Rwanda in the northern part where slope inclination is in range of 30 to 45 degrees.

4.1 result of bishop simplified method of slices safe condition

The Ordinary Bishop method of slices does not favor hand calculations it requires a computational solution. Thus, another simulation software is used to find out different solutions (Slide).

The FS using Bishop Method is equal to 1.087610 in Figure 4-1. The value of the center and radius are (44.857, 29.504), and 19.444, respectively with the left and right slip surface endpoint equal to (27.895, 20.000), (44.915, 10.061), respectively.

The resisting moment is equal to 7818.44 kN-m with a driving moment equal to 7188.62 kN- m and the total slice area is 51.1296 m2.

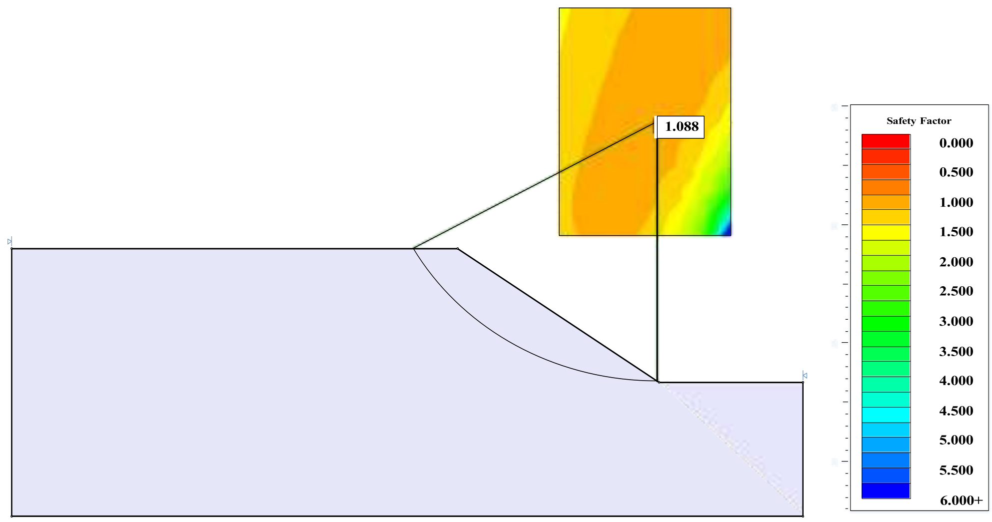

Figure 4-1 Result of Bishop simplified method at 360

Table 4-1 shows the minimum and maximum results of base normal stress, shear strength and stress, slice weight, and base normal force.

Table 4-1 all minimum and maximum slice results, Bishop Method

Slice data	Unity	Minimum values	Maximum values
Base normal stress	kPa	-1.44227	52.044
Effective normal stress	kPa	-1.44557	52.044
Shear strength	kPa	7.91441	25.5515
Shear stress	kPa	7.27287	23.4803
Base shear force	kN	7.66334	24.6463
Base Normal force	kN	-2.33894	53.1446
Slice weight	kN	3.77714	57.2223

4.2 Result of spencer method of slices safe condition

There is no big difference between the results of spencer and Bishop as shown in Figure 4-2. The FS using Spencer method is equal to 1.087090 as shown in Figure 4-2. The value of center and radius are (43.156, 25.252), and 15.325, respectively with the left and right slip surface endpoint equal to (28.759, 20.000) and (44.954, 10.033), respectively.

The resisting moment equals 6383.79 kN-m with a driving moment equals to 5872.35kN-m and the total slice area is 53.9797 m2.

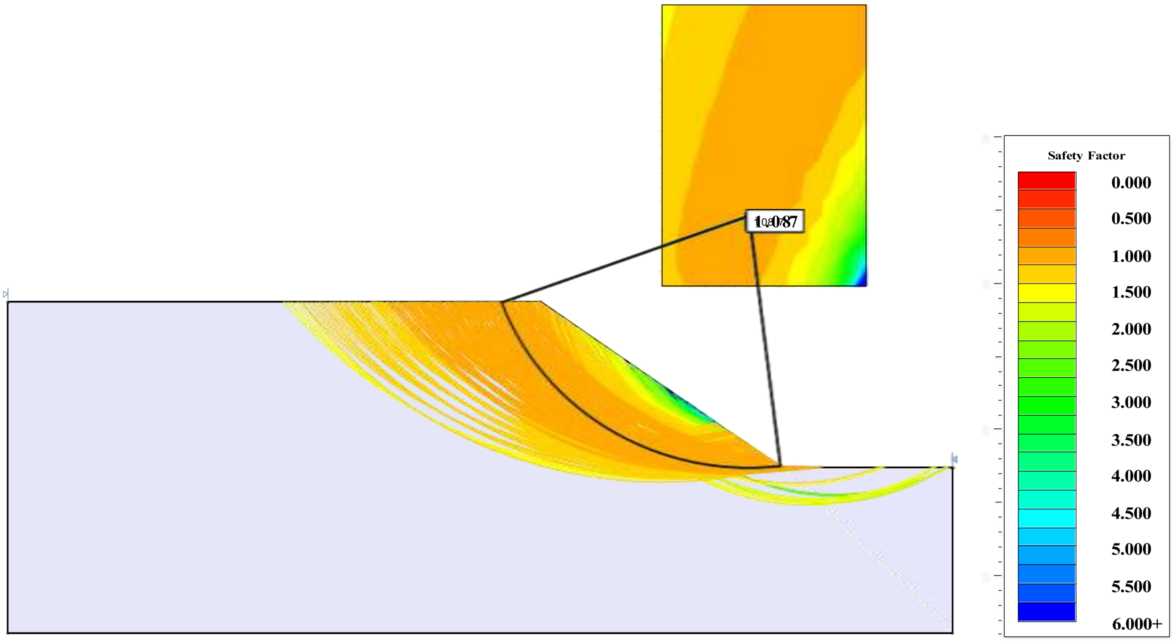

Figure 4-2 Safety factor with the minimum surfaces at slip centre grid point

Table 4-2 The minimum and maximum results of slices using Spencer method are shown

Slice data	Unity	Minimum values	Maximum values
Base normal stress	kPa	0.214983	50.2451
Effective normal stress	kPa	0.214983	50.2451
Shear strength	kPa	8.46089	24.9584
Shear stress	kPa	7.27234	22.9273
Base shear force	kN	8.94049	22.7269
Base Normal force	kN	0.34864	48.784
Slice weight	kN	3.77714	57.2223

4.3 Slope angle of inclination unsafe condition

Using finite element 2D geometric model at a landslide section was constructed with specific ground conditions and materials parameters and the slope allowed to deform both failure and deformation states are modelled for better observation, Figure 4-4 shows detailed dimensions of a model constructed in slide FE software for an unsafe condition.

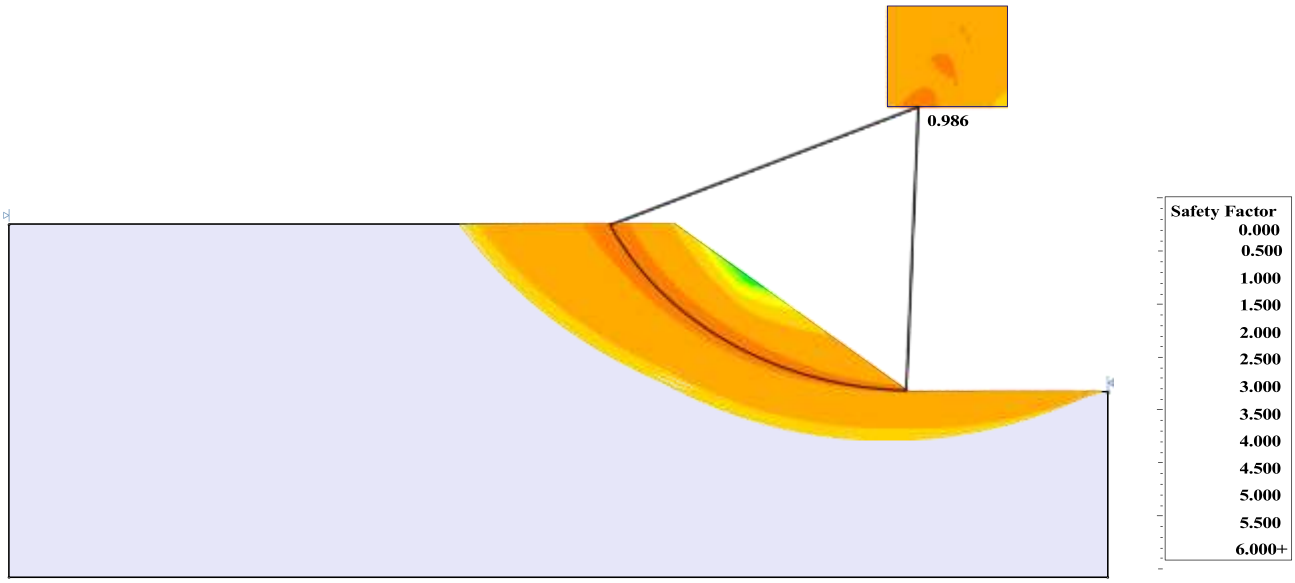

Figure 4-4 Soil modal 40 degrees

In this analysis of checking the failure of slope due to the slope angle of inclination, Bishop and Spencer methods are used in order to compare the results. 25 is considered as a number of

4.3.1 Bishop simplified method unsafe condition results

For unsafe conditions, the overall results are reduced where the factor of safety using the Bishop method equals to 0.999382 as in Figure 4-5. The value of the center and radius are (45.855, 27.093) and 17.046, respectively with the left and right slip surface endpoint equal to (30.355, 20.000) and (44.912, 10.073), respectively. The resisting moment equals to 5761.56 kN- m with a driving moment equal to 5765.12 kN-m and the total slice area of 42.3239 m2.

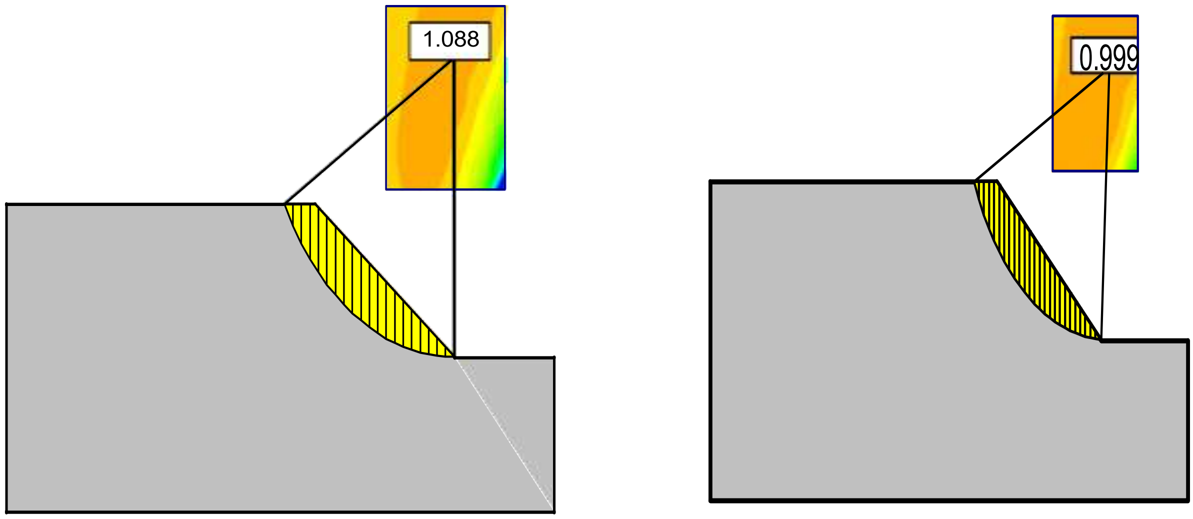

Figure 4-5 Global Minimum Query (bishop simplified)

4.3.2 Spencer method unsafe condition results

For unsafe conditions, the overall results are reduced where the factor of safety using the Spencer method becomes 0.996930. The value of the center and radius are (45.855, 27.093) and 17.046, respectively with the left and right slip surface endpoint equal to (30.355, 20.000) and (44.912, 10.073), respectively. The resisting moment equals to 5747.42 kN-m with a driving moment equals to 5765.12kN-m and the total slice area becomes 46.4184 m2.

4.4 Factors affecting slope stability failure in Rwandan soil

The main external factors that can trigger a landslide include breaking down or dissolving of rock strata; the increase of pore water pressure, the infiltration of rainwater or rise of groundwater surface, the increase of loadings, and the supporting forces due to human activities. In Rwanda also rainfall is an among the main triggering of landslides as well as human activities like construction works, some legal and illegal mining, and the unregulated cutting of hills. Here are results of factors affecting slope failure in Rwanda

4.4.1 Geometry of the slope

In this research it is obvious that the slope which is greater or equal to 40 degrees, Figure 4- 6 (b) is under failure according to the results of simulation which was done using Bishop method where the value is of FS is less than one comparing to the slope of 36 degrees Figure 4-6 (a).

(a) safety of factor at 36 degrees (b) safety factor at 40 degrees

When the slope angle increases the safety factor decreases gradually for a particular soil properties, values of seismic acceleration coefficients, and landslide effects. The slope gradient and mass movements are the important factors that determine the distribution of landslides in Rwanda. According to the soil samples used in this research, landslides occur on slopes with angle equal and greater than 40 degrees. Most parts of northern Rwanda are above 40 degrees of slope gradient, above 30 degrees in western parts and above 25 degrees in southern province as it is shown in Figure 4-7.

Figure 4-6 Rwanda has a steep topography with an altitude between 915m and about 4500m

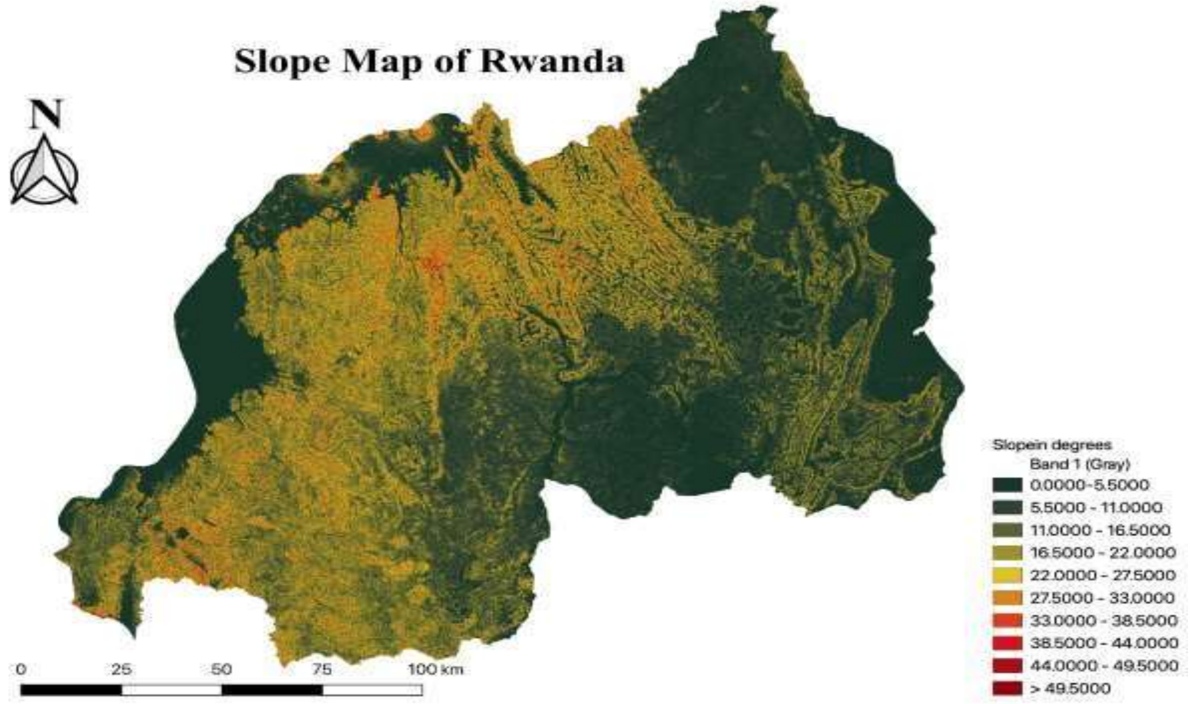

Figure 4-6 Slope failure due to the angle of inclination

5. LANDSLIDE COUNTERMEASURES

5.1 Anchors and H-Pile Design

H-Piles are structural beam elements. Anchors play a very important role in slope stability, its main function is to support the soil mass that may collapse and prevent slope deformation. Anchors and H-Pile, see Figure 5-1.

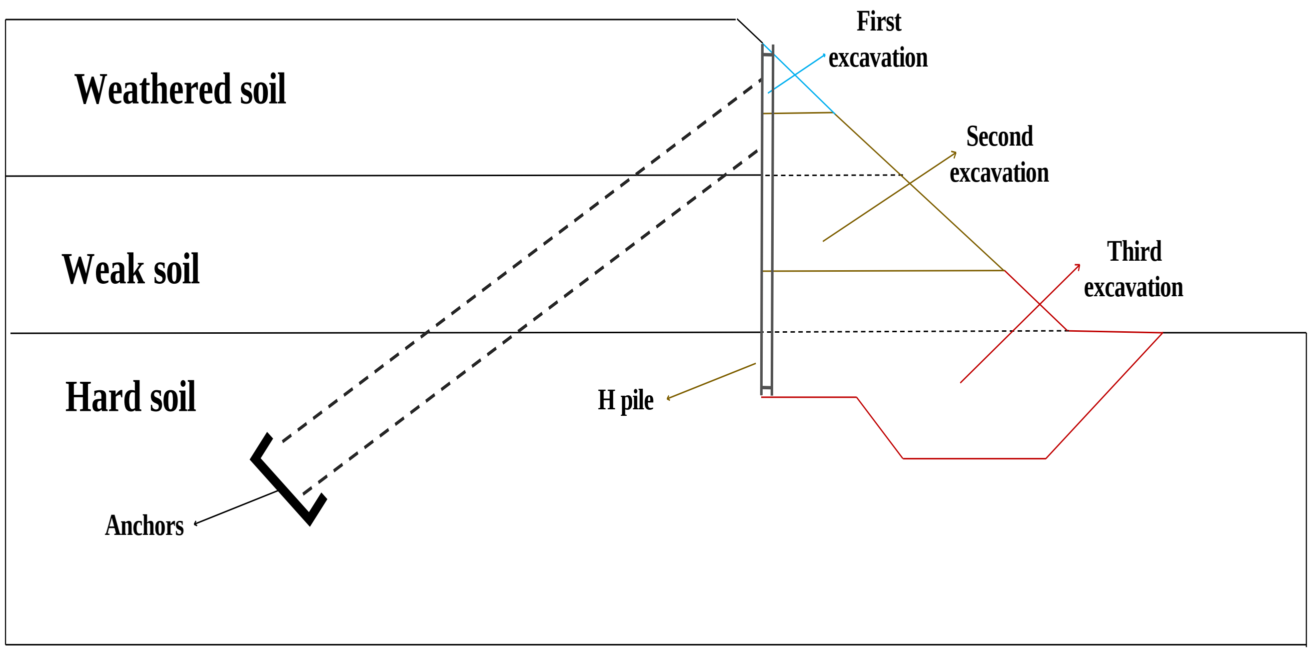

Figure 5-1 Supported model with anchors and H-Pile

The values of both anchors and H-Pile cross-section areas, torsional stress coefficients, both area of moment of inertia and both effective shear area are shown in Table 5-1 and Table 5-2 consecutively.

5.1.1 material properties

Using Midas GTS NX to establish a two-dimensional model of the anchors and H-piles, it is assumed that each layer is an isotropic body that satisfies the Mohr-coulomb criteria. By meshing the model, in the generated 2D model there are 102 elements and 116 nodes.

The meshing of the model, in the generated 2D model is shown in Table 5-1 and the result of boundary condition is shown in Figure 5-1. All cross-section used in this research for anchors and H-Piles are the same.

Table 5-1 H-Pile beam element design

Name	Anchor	unity
Cross section Area (A)	0.00031	m^2
Torsional Constant	1.57E-08	m^4
Torsional Stress Coefficient		0.01

Table 5-2 Anchor truss element design

Name	H Pile	Unity
Cross section Area (A)	0.0198	m^2
Torsional Constant (Ix)	4.12E-06	m^4
Torsional Stress Coeff	0.04999 7	

5.2 Analysis of calculation results

According to the construction needs, the strength reduction method is used in this research to analyze and calculate the slope after cutting the slope, and it is concluded that the safety factor is 1.12969, which is less than the standard value of 1.35, and there is the most dangerous sliding

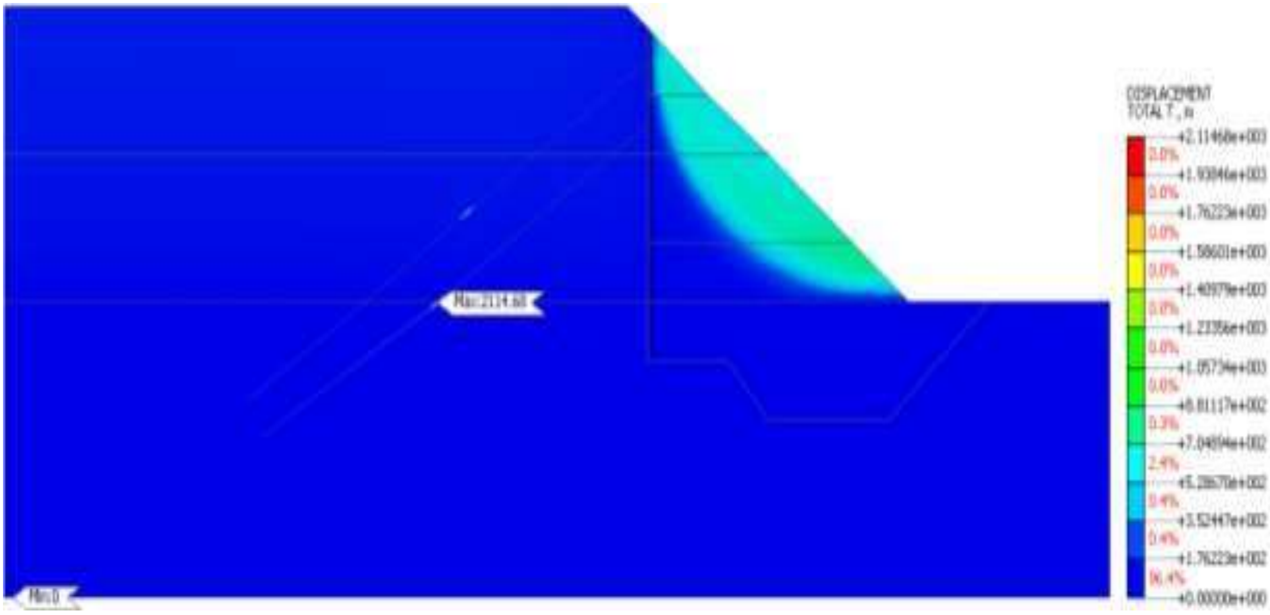

Figure 5-1 Total displacement t, m results

surface passing through the toe of the slope, indicating that in the natural state the slope is unstable and needs to be reinforced. By adopting the measures of anchors + H-Pile support to reinforce the slope after cutting, the safety factor of the slope is calculated to be 1.35469, which is greater than 1.35, and the slope is in a stable state. The maximum displacement in the X-direction of the slope decreased by 2 m, and the displacement in the Y-axis direction and X-direction decreased significantly, indicating that the soil anchors combined with H-Pile supports can ensure the safety of the slope.

6. CONCLUSION

The aim of this study was to understand the landslide instability and try to provide adequate countermeasures related to landslides. According to the previous research, the northern, southern, and western provinces of Rwanda are highly exposed to landslides hazard due to high elevation, slope, rainfall, and poor land management.

In this research, slope stability analysis was performed using different methods in order to understand the phenomena of slope instability, where Bishop, Spencer, and Strength Reduction methods (SRM) were used and different conditions were applied to the same model. Here, among the influencing factors of the slope failure, we can mention the slope inclination, human activities and heavy rainfall. Different simulation softwares such as Slide for two dimensions Bishop and Spencer method and GTS NX for SRM are used. Then, the landslide instability is evaluated based on comparative study of the factor of safety of the slope (FS) from different softwares mentioned above. The simulation results show that the areas, which have slope inclination greater than 40 degrees have FS less than 1. This explains the unsafness of the slope. In addition to that human activities can accellarate the slope failure even in the areas where the slop is stable based on the slop inclination indicator.

According to the slope stability analysis carried out in this research, it has been proposed different methods for reducing landslides hazard effects in Rwanda. The proposed method use a combination of anchors and H-Piles to reinforce the slope. Using the developed model of north- werstern region of Rwanda, the reinforncing anchors and H-Piles were applied to verify the correctness of the proposed method. As result, the FS increased from 1.12969 to 1.35469, which is greater than the critical FS of 1.35 required to maintain the slope stability. Since the FS is increased, the slope deformation significantly deacrease in response. Different simulation results are provided by considering different influencing factors on the slope instability in Rwanda to comfirm the analysis performed.

REFERENCES

1) Long N T. Landslide susceptibility mapping of the mountainous area in a Luoi district, Thua Thien Hue province, Vietnam[D]. Vrije Universiteit Brussel, Faculty of Engineering, Department of Hydrology and Hydraulic, 2007.
2) Petley D. On the occurrence of fatal landslides[M]. 2008, 11: 9030.
3) Nahayo L. Landslides Hazard Mapping in Rwanda Using Bivariate Statistical Index Method[J]. Environmental Engineering Science, 2019.
4) Moeyerson J. Complex nature of creep movements on steeply sloping ground in southern Rwanda [J]. Earth Surfa Processes and Landforms, 1988, 13(6): 511-524.
5) Bizimana H, Sonmez O. Landslide Occurrences in The Hilly Areas of Rwanda, Their Causes and Protection Measures[M]. 2015.
6) Ayalew L. The effect of seasonal rainfall on landslides in the highlands of Ethiopia[J]. Bulletin of Engineering Geology and the Environment, 1999, 58: 9-19.
7) Cruden D M. A simple definition of a landslide[M]. Bulletin of the International Association of Engineering Geology-Bulletin de l'Association Internationale de Géologie de l'Ingénieur, 1991, 43: 27-29.
8) David J V. Landslide Hazard Zonation: A Review of Principles and Practice, Natural Hazards[M]. Paris, UNESCO, 1984.
9) Varnes D J. Landslides: Analysis and Control[M]. Washington, DC, Transportation Research Board, 1978.
10) Eclipse E. Causes of landslide[Z]. [2021, 05/12/21]. Available https://eartheclipse.com/natural-disaster/causes-effects-and-types-of-landslides.html.
11) Conners D. What causes landslides and mudslides?[Z]. [2019, 10/04/19]. Available: https://earthsky.org/human-world/what-causes-landslides/.
12) Khanh N Q. Landslide hazard assessment in muonglay, Vietnam applying GIS and remote sensing[D]. University Greifswald, Faculty of Mathematics and Natural Sciences ErnstMoritz, 2010.
13) Nyamulinda F. D. K. Soil erosion and mass wasting risk in the highland area of Rwanda, Mountain Research and Development[J]. N0s, 1989, 8(2/3): 173-182.
14) Varnes D. J. Landslide Types and Processes. Landslides and Engineering Practice[J]. Journal of Geoscience and Environment Protection, 1958, 24: 20-47.
15) Poesen J. The environmental significance of the remobilization of ancient mass movements in the Atbara-Tekeze headwaters near Hagere Selam, Tigray, Northern Ethiopia, Geomorphology[J]. Geomorphology, 2003, 49(3-4): 303-322.
16) Rembco. Ground rocks and soil anchors[Z]. [2022, 19-04-2022]; Available: https://www.rembco.com/portfolio/anchors/.