Assessing on the Geotechnical Problems Which Causes for the Road Failure from Gilgel Beles to Bahir Dar Road Segment

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ABSTRACT

Geotechnical problems such as problematic soils (expansive soil, organic soil, natural collapsible soils, etc.), problematic rock (shale, weathered limestone), soil slope instability and rock slope instability or rock fall (landslide) which damaged civil engineering structures, such as roads, buildings, dams, railway, and other related structures in Ethiopia. The research was conducted by identifying the geotechnical problems and its effects on road segments in the north west part of Ethiopia, specifically along Gilgel Belles – Bahir Dar road segments. Gilgel Beles – Bahirdar road segment which passes on the hilly and mountainous terrain are characterized by variable topographical, geological, hydrological and land-use condition. The most appendant geotechnical problems that found in the road segments were slope instability, sink holes, road cracks, compressibility of soils. It was identified the causes and effects of the geotechnical problems on the road's alignment condition. Slope instability(landslide), expansive soil, and drainage problems have been a common problem along the Gilgel Beles – Bahir Dar road, especially during the rainy seasons particularly Chagni -Mandura road section. A detailed slope stability analysis and understanding the causes for independent slope sections was helpful to find a better remedial measure, because different slope sections may have different mode of failure, and may involve different engineering material. Slope instability along Chagni to Mandura road line is becoming serious problem due to the presence of loose unconsolidated materials, highly weathered and fractured basalt rocks, high relief, steep natural slopes, nature of geologic formations exposed along the road section, poor drainage conditions, occurrence of high seasonal rains, and seismically active nature of the region. In this study water content, specific gravity, Atterberg limits, density and unit weight, static direct shear test and triaxial test were done by using ASTM laboratory test procedure for getting geotechnical parameters. Remedial Measures for failure of the road were: removing material from the area driving the landslide; adding material to the area maintaining stability (counterweight berm or fill) and reducing general slope angle, surface drains to divert water from flowing onto the slide area (collecting ditches and pipes); shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics); vertical (small diameter) boreholes with pumping or self-draining; and vertical (large diameter) wells with gravity draining; gravity retaining walls; gabion walls; reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement elements; retention nets for rock slope faces, rockfall attenuation or stopping systems (rock trap ditches, benches, fences and walls) and protective rock/concrete blocks against erosion; soil nailing; anchors (prestressed or not); grouting, and vegetation planting (root strength mechanical effect)

Keywords: *causes, geotechnical problems, Gilgel Beles- Bahir Dar, road failure, remedial measure, soil slope instability,*

1. INTRODUCTION

1.2 background of the study

Many geological and geotechnical problems damage civil engineering structures such as, buildings, dams, irrigation canals, roads, railway etc. in the world [1]. One of geotechnical problems are Landslides or slope failures which are a complex natural phenomenon and a wide variety of slope movements such as falls, slides, spread, flows and creep that constitutes a serious natural hazard in many countries [2].

Other Geotechnical problems are problematic soils such as expansive soils. They have a tendency to heave during wet season and shrink during dry season. Expansive soils are a worldwide problem that possesses several challenges for civil engineers. They are considered a potential natural hazard, which can cause extensive damage to structures if not adequately treated. Expansive soils cause more damage to structures, particularly lighter buildings and pavements, than any other natural hazard, including earthquakes and floods.

Several geotechnical problems such as problematic soil (black cotton soil), soil slope instability, rock slope instability, surface flooding & soil erosion and natural geological variation (such as faults, change in geology, bedding plane, aperture etc.) damages civil engineering structures such roads, buildings, dams etc.in Ethiopia. Road development is one of the major investments in Ethiopia. Roads damaged by geotechnical and geological problems/hazards/ such as Expansive soil problem and slope instability. Landslides are common in many parts of the highlands and rift escarpment of Ethiopia. Over 700 landslide sites recorded in Ethiopia; mostly affecting rural communities. Infrastructures, farm lands, dwelling houses, etc. are frequently affected by landslides [4]. In Ethiopia, there are several roads, whose premature failures attributed to the volumetric changes of expansive clay soil [5].

The study area is a part of economically important main Assosa - Gilgel Belles - Bahir Dar-Gondar-Metema-Sudan root and Gondar-Tigray road that connects north central and north western part of the country with the capital of Benishangul Gumuz region -Assosa and port of Sudan (Kumuruk). This research was focused on geotechnical and geological problem identification, investigation of slope stability analysis parameter and remedial measure of the problem, protection from natural hazards, and continuing respect for the environment of the road segments. In the study site particularly in the Kar Mountain, along Gilgel Belles to Chagni road segment, is one of the common areas in the country where most slope instabilities are frequently observed. It is very common to see slope failure events that hinder traffic movements during the rainy season. Groundwater, uncontrolled surface run off, joints of rocks, and the presence of basaltic and shale within hard rocks are the main causes of slope instability. During the past years, landslides had damaged the road sections and farmlands [15].

In Gilgel Belles to Bahir Dar road segment, black cotton soils are predominant which are basically an expansive soil. Black cotton soil is atypical volume change soil which loses its strength on wetting due to increase in its volume and the absence of water it shows multiple cracks due to in its volume. The volume change behavior damage and causes distress when the structures located on the soil or the road pavements. Slope instability along road cuts is a common problem in many areas. This can cause damage to human beings as well as properties. Such areas have to be clearly identified including the different processes that cause the failure, mechanism of failure and the possible remedial measures for that landslide problem. In the Gilgel Belles to Bahir Dar road segment, slope movement in the form of landslides, rock falls and complex disturbances along the road segments. This research was conducted by identifying the geological & geotechnical problems and its effects on road segments in the north west part of Ethiopia: a case study on Gilgel Belles to Bahir Dar road segments. Therefore, in the present study, identified the causes and effects of the geological and geotechnical problems on the road alignment conditions, investigated the engineering properties of the study site and proposed mitigation measure of the problems in the road segment.

2. Objectives

The general objective of this study to assess some geotechnical problems that causes for the road failure from Gilgel Belles to Bahir Dar road segment, in north west part Ethiopia. To accomplish the general objective the following specific objective were set:

1. To assess the geotechnical problems that exist in the study area
2. To identify causative factors for the road failure in the study area
3. To determine physical and engineering properties of the soil which involved in the problematic area
4. To propose remedial measures with respect to the problems that exist in the site

3.Research Methodology

3.1 The Study Area

The study area is located Gilgele Belles to Bahir Dar road segments which is found in the Amhara and Benishangul Gumuz Regional state in the northern western part of Ethiopia. The Gilgele Belles to Bahir Dar Road segment is 198 km long. The site can be accessed through Addis Ababa – Debre Markos -Injibara Asphalt Road and Assosa -Gilgel Belles -Injibara Road.

Accessibility to the road segment- The study area is a part of economically important main Addis Assosa –Gilgel Beles- Injibara-Bahar Dar-Gondar - Metema - Sudan root and Gondar -Tigray road that connects north west and northern part of the country with the capital of Benishangul Gumuz region -Assosa.

Land Use and Cover- The land use pattern along the road alignment can be defined as mostly cultivated land with the small portion covered by bushes, shrubs, eucalyptus trees, etc. Bushes cover limited part of the study area, which is used for grazing. Mostly people are dependent on the farming and cattle breeding which is main livelihood for them.

Terrain of the Study Area- The terrain of the road alignment can be generally described as rolling and flat over the large portion of the road with some sections characterized by escarpment and mountainous physiographic features.

Climate of the study Area- The climate falls under warm subtropical climate condition. The area receives rainfall twice in a year; heavy precipitation from June to September and light to moderate precipitation from mid-February to mid-March. The rainfall peaks in July or August at about 300 to 400 mm per month; about 50% of annual precipitation is within July and August. According to the Meteorological map of Ethiopia, 1979, the study area receives annual rainfall in the range of 1400 – 2000 mm with moisture index >1 which is humid and mild effective temperature varying between 14oC and 20oC which is most of the time comfortable.

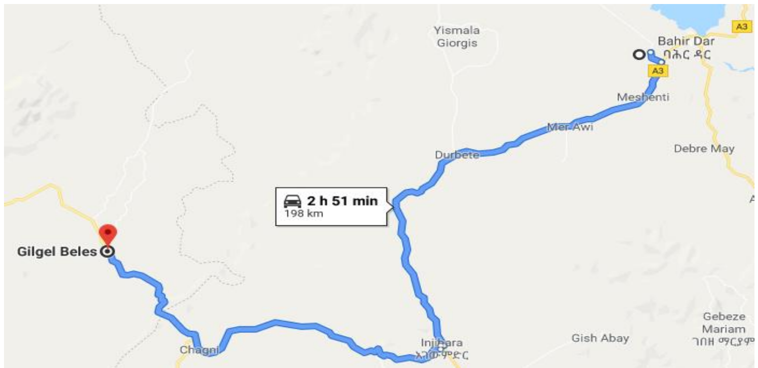

Figure 1: map of study area (Google map, 2016)

3.2 The Study Period
The study periods set for this research has been from November 2018 to June 2020

3.4 Research design
The research was conducted by using both descriptive and analytical methods. Which mean that the methodology used in the research is laboratory analysis of sample data, and was collected from the site. The data was analyzed and interpreted using both descriptive (i.e., case reports and case series, conducting experiments, field visualization, cross sectional study) and analytical methods of approach

3.5 Population
Population of this study was unstable zone /failure area/ of the road such as, weak or sensitive soil material, active slope instability area, geological discontinuities (bedding, schistosity, and fault) and rainfall was the population. Case study in Gilgel Beles – Bahir Dar road segments.

3.6 Methodology
The research objectives could only be reached if acted upon with a planned approach. The first step towards a goal always starts with knowing everything about it. A detailed literature survey about geotechnical problems including slope stability analysis and remediation methods were reviewed. As a second stage systematic field work was conducted. Samples from many sample points were collected and carefully packed and sent to the laboratory for the analysis. Various field visits were also made to know about the actual conditions that exist in the working conditions and which could be included in the study, during the analyses. The collected samples were undertaken various analysis to know about the sample properties like cohesion, angle of internal friction, unit weight, density, angle of repose etc. then these sample properties were used in the analyses during the analysis using the software. Field observations on critical slope sections were made and all pertinent data for slope stability analysis was collected. Besides, soil samples were collected which were later tested in laboratory to know the shear strength parameter of the soil and using the result as basis for sensitivity analysis. In the final stage the slope was modeled using slope stability analysis software and the most suitable stabilization technique under static and dynamic conditions were deduced.

3.6.1 Method of Investigation

The investigation was carried out to obtain information about the soils encountered at the site by means of sampled boreholes. Consequently, laboratory testing and engineering analysis was carried out to assess the overall stability of the slope.

Data collection process: The data could be collected through:

- ✓ Field data collection: observation, field investigation, etc.
- ✓ Experimental: Both Field and Laboratory test based on ASTM standard specification was used

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3.7 Field Work

3.7.1 Reconnaissance survey

In order to gather general information about the study area a reconnaissance field survey was conducted. During reconnaissance survey information on landslides and related slope instability problems in the study area was mainly obtained through visual observations and by interviewing the local respondents for collection of secondary data that is very important particularly to know about general conditions of the study area. Even though there was scarcity of secondary data such as; climate data, rainfall data, temperature data, and ground water level, still attempts were made to collect existing data/information which were relevant for the present study. Such secondary data was collected from published and unpublished sources.

3.7.2 Detailed field work (Field observations and data collection)

The detailed field work was conducted during the detailed study, emphasis was made to identify and locate the most critical slope sections in the study area. For these thorough observations were made to know the actual or potential manifestations of slope instability in the study area. After the identification of critical slope sections further field observations relevant to slope stability studies were performed. It was believed that this stage was the best opportunity to collect the exact data needed for further analysis of the present research work. The field observation in general helped in understanding the site condition and provided a clear knowledge about the geology and geomorphology of the study area in general and specific to critical slope sections, in particular. Further, all necessary field observations/ sampling was made relevant to the study. Besides, all necessary primary data pertaining to various parameters were collected, this eventually formed the basis for analysis, as per the scope of the present study.

3.7.2.1 Field observations

During the field work, efforts were made to identify the different instability manifestation features present on the slope and to identify and collect data for the probable causative factors for the slope instability. Besides, information on past slope instability activities was gathered by interviewing the local respondents. In addition to these, it was attempted to assess the damages caused by the slope instability on infrastructure.

3.7.2.2 Visual Slope Inspection

The visual slope condition assessment was carried out by the researchers. The purpose of the visual inspection was to observe/inspect the existing slope conditions, and to identify any potential areas of concern observed on the slope from a geotechnical perspective. In particular, the inspection included the examination of: evidence of slope instability; evidence of water course features; evidence of seepage on the slope; the condition of the vegetation coverage on the slope; and evidence of erosion at the slope toe. The geotechnical problems that has been exist in study area includes:

Figure 2: Expansive soil problems that causes the road failure - Cracks on the road

Chagni – Mandura Road Section

(Injibara – Bahirdar Road Section)

Figure 3: compressibility of soil/settlement problem

Figure 4: Sinkhole failure of the road due to scouring of water in the road segments

Figure 5: soil slope instability problems (Chagni – Mandura Road Section)

Figure 6: Slope failure(landslide) in the road segments (in Kar Mountain site)

Figure 7: Drainage Problems (Road failure due to scouring of water) (Injibar – Dangila road section)

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Figure 8: Sliding of Silty clay soil within constructed structure in the study road segment

Figure 9: Sedimentation problems

4. Laboratory Test Results and Discussions

4.1 Determination of Properties of Soils with Laboratory Tests

For any type of soil to be used soils in civil engineering practice, the first step is to determine the properties of soils. This includes laboratory testing to determine soil's physical, mechanical and geotechnical properties. Depending on the nature of the civil engineering problem, then other required tests can be done, under either static or dynamic loading conditions. The properties of the soil from Chagni – Mandura road segment in Karber site described blow.

Table 1: Natural moisture content, Atterberg Limit test, and Specific gravity test results for Chagni – Mandura road segment Karber sample

Test pit No.	Depth of sample (m)	Specific gravity	Natural moisture content (%)	Liquid limit, %	Plastic limit, %	Plasticity index, %	Activity (A)
TP-1	3.0	2.80	34.71	70	32	38	0.48
TP-2	3.0	2.82	37.85	80	39	41	0.57
TP-3	3.0	2.85	25.00	59	33	26	0.58

TP-4	3.0	2.84	37.70	89	30	59	0.98
TP-5	3.0	2.84	37.21	62	30	32	0.42
TP-6	3.0	2.84	45.52	85	33	52	0.94
TP-7	3.0	2.84	48.00	68	30	38	0.60
TP-8	3.0	2.82	32.51	65	37	28	0.37
TP-9	3.0	2.84	33.33	68	29	39	0.63
TP-10	3.0	2.85	31.51	82	33	49	0.75
TP-11	3.0	2.85	34.21	80	33	47	0.90

Table 2: Particle size analysis test result for study site of Chagni – Mandura road segment Karber sample

Sr.No	Test pit designation	Depth of sample (m)	Percent amount of particle size				PP40	PP200
			Gravel	Sand	Silt	Clay		
1	TP-1	3.0	0.00	0.43	23.82	75.72	99.81	99.57
2	TP-2	3.0	0.02	2.99	25.47	71.52	97.44	96.99
3	TP-3	3.0	5.52	7.90	41.42	45.16	87.96	86.58
4	TP-4	3.0	7.66	10.48	36.71	45.15	83.01	81.86
5	TP-5	3.0	0.00	0.25	26.19	73.56	99.89	99.75
6	TP-6	3.0	0.00	4.20	37.45	58.35	97.11	95.80
7	TP-7	3.0	0.09	2.19	34.05	63.66	98.79	97.72
8	TP-8	3.0	0.00	0.29	23.27	76.44	99.85	99.71
9	TP-9	3.0	0.03	9.06	38.64	52.27	92.95	90.91
10	TP-10	3.0	0.03	3.20	34.36	62.41	98.15	96.77
11	TP-10	3.0	0.38	5.24	34.36	60.02	95.54	94.38

Where: PP40 = percent passing through No. 40 sieve and PP 200 = percent passing through No. 200 sieve

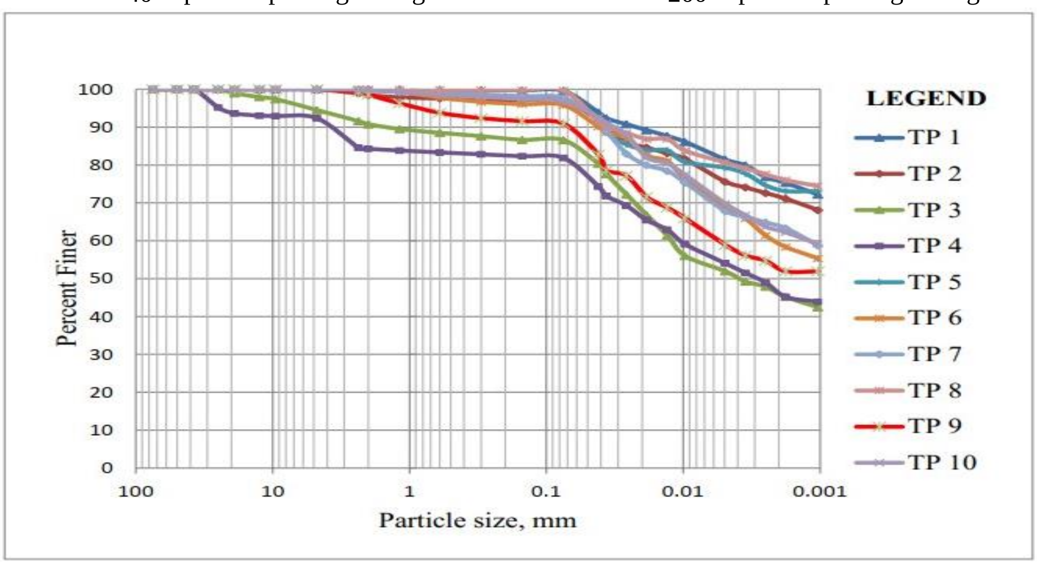


Figure 10: particle size distribution graph for study site (Karber sample)

Table 3: Shear strength parameter triaxial compressive test results for study site of Chagni – Mandura road segment Karber sample

S.No	Name of Test Pit	Dry Density	Unit Weight	Cohesion(C') (Kpa)	Frictional Angles (Φ)

1	TP-1	15.3	17.07	40	23
2	TP-2	15.3	17.07	45	19
3	TP-3	15.3	17.07	39	24
4	TP-4	15.3	17.07	40	20
5	TP-5	15.3	17.07	45.5	7
6	TP-6	15.3	17.07	45.5	7
7	TP-7	15.3	17.07	45.5	8
8	TP-8	16.2	17.8	15	18
9	TP-9	16.2	17.8	10	20
10	TP-10	16.2	17.8	15	18
11	TP-11	15.3	17.07	45.5	7

classified based on USCS

Table 4: USCS of soils in Karber site (Chagni – Mandura road segment)

Sr. No	Test pit designation	Depth of sample	Percent amount of particle size				LL, %	PL, %	PI, %	USCS
			Gravel	Sand	Silt	Clay				
1	TP-1	3.0 m	0.00	0.43	23.82	75.72	61	32	29	CH-MH
2	TP-2	3.0 m	0.02	2.99	25.47	71.52	73	36	37	MH
3	TP-3	3.0 m	5.52	7.90	41.42	45.16	59	33	26	MH
4	TP-4	3.0 m	7.66	10.48	36.71	45.15	68	30	38	CH
5	TP-5	3.0 m	0.00	0.25	26.19	73.56	68	36	32	MH
6	TP-6	3.0 m	0.00	4.20	37.45	58.35	77	30	47	CH
7	TP-7	3.0 m	0.09	2.19	34.05	63.66	70	31	39	CH
8	TP-8	3.0 m	0.00	0.29	23.27	76.44	72	39	33	MH
9	TP-9	3.0 m	0.03	9.06	38.64	52.27	80	33	47	CH
10	TP-10	3.0 m	0.03	3.20	34.36	62.41	85	31	54	CH
11	TP-11	3.0 m	0.38	5.24	34.36	60.02	89	30	59	CH

C= Inorganic clay, M= Inorganic silt, L= Low plasticity (LL<50%) and H= High plasticity (LL>50%).

AASHTO Classification of soils

Table 5: AASHTO Classification of soils in Karber site (Chagni – Mandura road segment)

Sr. No.	Test pit designation	Depth of determination	Percent Passing					AASHTO Soil classification	GI
			No. 10	No. 40	No. 200	LL, %	PI, %		
1	TP-1	3.0 m	0.43	23.82	75.72	61	29	A-7-5	20
2	TP-2	3.0 m	2.99	25.47	71.52	73	37	A-7-5	20
3	TP-3	3.0 m	7.90	41.42	45.16	59	26	A-7-5	20
4	TP-4	3.0 m	10.48	36.71	45.15	68	38	A-7-5	20
5	TP-5	3.0 m	0.25	26.19	73.56	68	32	A-7-5	20

6	TP-6	3.0 m	4.20	37.45	58.35	77	47	A-7-5	20
7	TP-7	3.0 m	2.19	34.05	63.66	70	39	A-7-5	20
8	TP-8	3.0 m	0.29	23.27	76.44	72	33	A-7-5	20
9	TP-9	3.0 m	9.06	38.64	52.27	80	47	A-7-5	20
10	TP-10	3.0 m	3.20	34.36	62.41	85	54	A-7-5	20
11	TP-11	3.0 m	5.24	34.36	60.02	89	59	A-7-5	20

From table 5, almost all soils are classified as group A-7-5 and one soil type is group A-7-6.

5. Modelling of the road failures that exist in the study site in different cases.

5.1 Model 1: Road section is stable; upslope side is sliding

- ✓ The cases of the failure were removal of support due to road excavation has initiated instability of the upslope.
- ✓ The remedial measures are provision of proper retaining structure coupled with drainage systems (surface and sub-surface) and modification of slope geometry (removing material from the area driving the landslide and reducing general slope angle) is the solution.

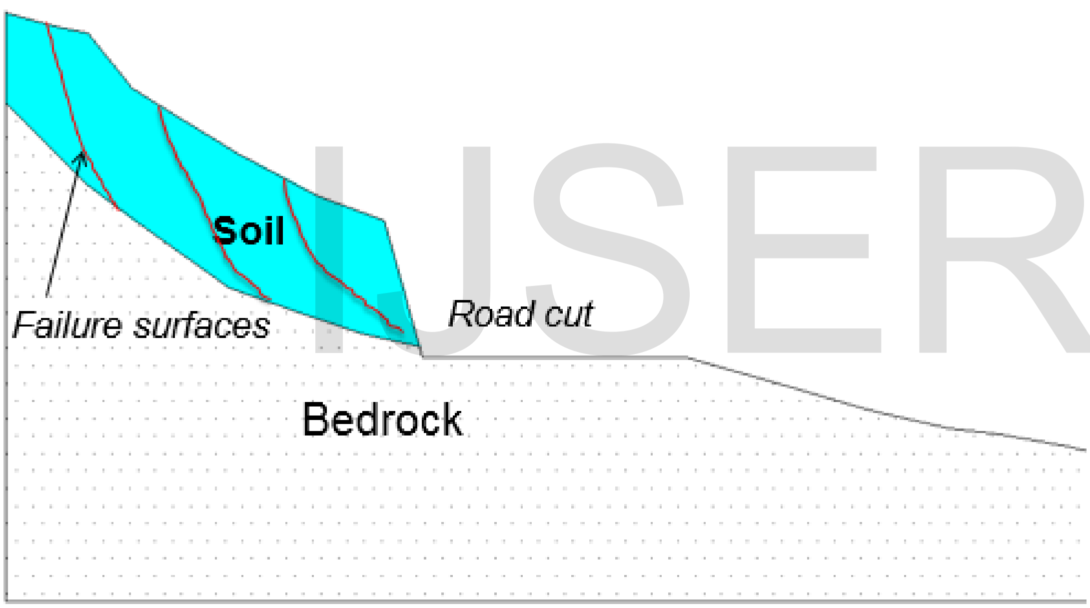


Figure 11: Model 1- road failures due to instability of slope presentation diagram and images

5.2 Model 2: Upslope side is stable; downslope side is sliding

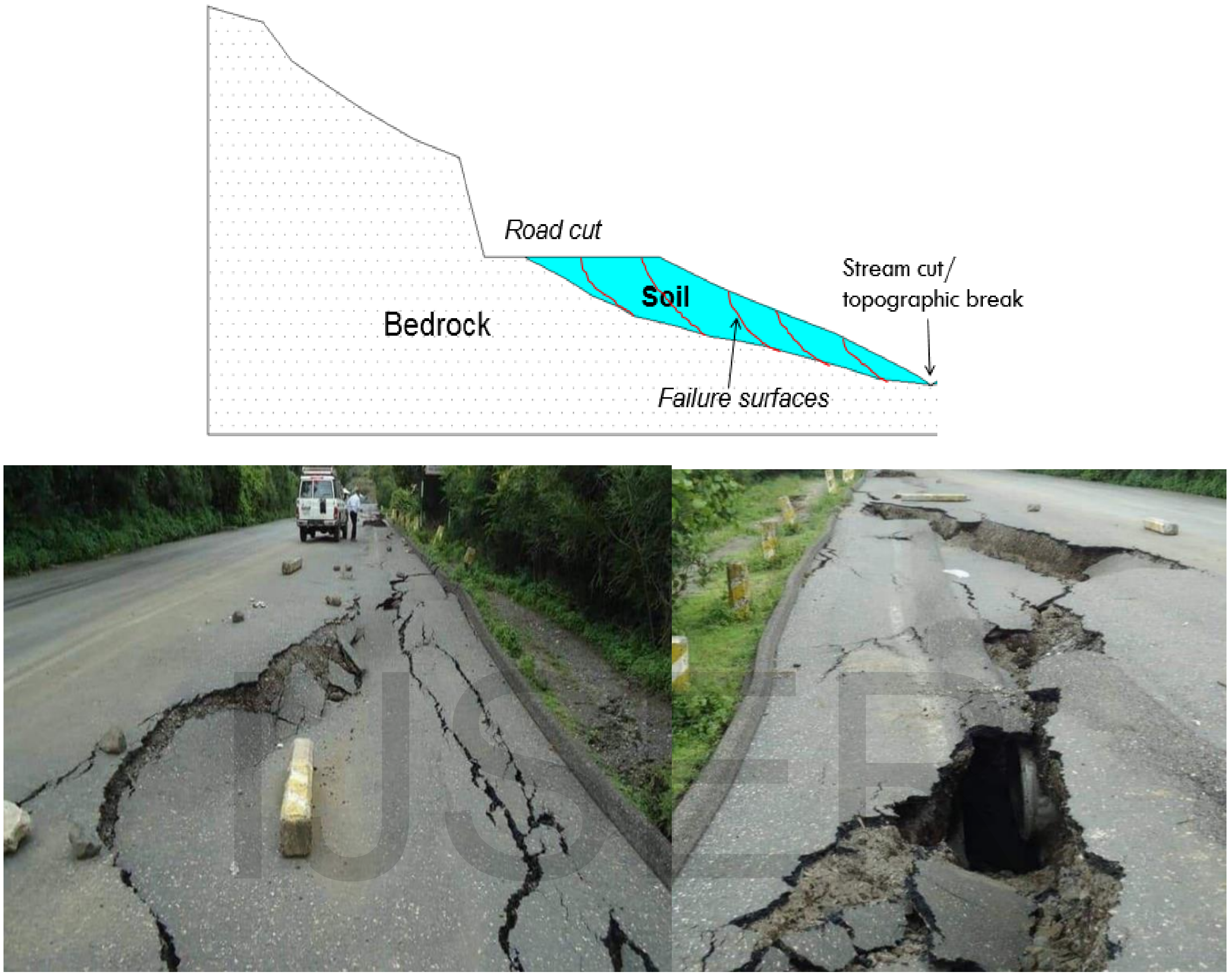


Figure 12: Model 2- road failures due to instability of slope presentation diagram and images

The causes of the road failure were additional load (due to road construction) on a slope which was already unstable or on marginally stable state is initiating instability of slopes

5. 3 Model 3: Placement of excavated material on marginally stable slope

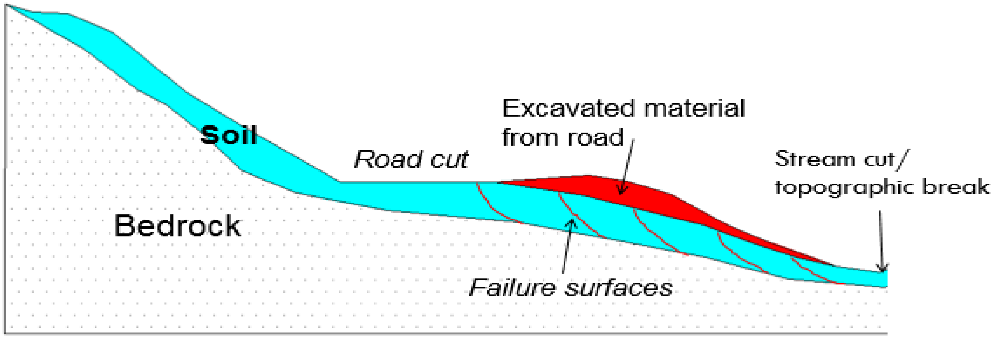


Figure 13: Model 3- road failures due to instability of slope presentation diagram

The causes of the road failure were placing excavated material from roads on marginally stable slopes or on unstable slopes is initiating instability of slopes.

5. 4 Model 4: Whole road section is on a sliding mass

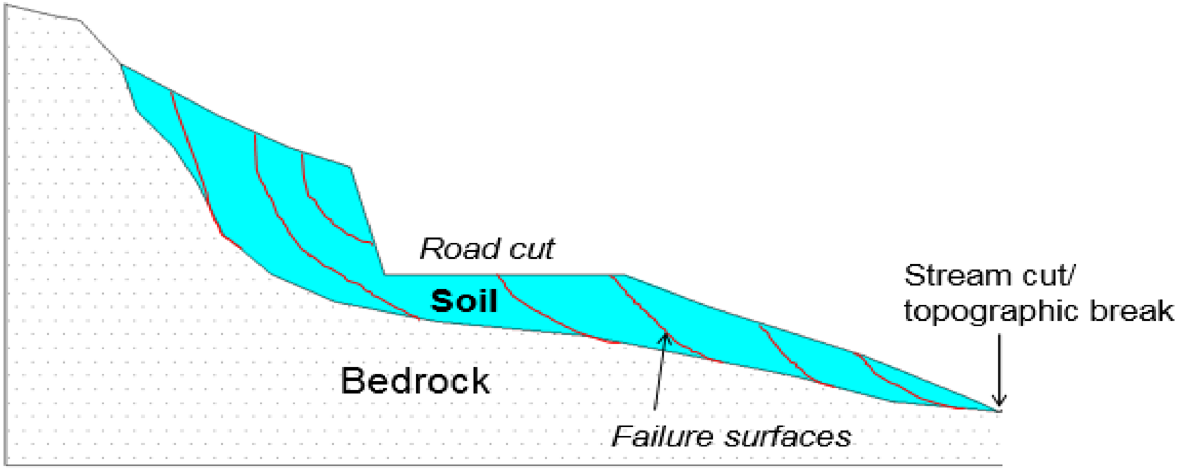
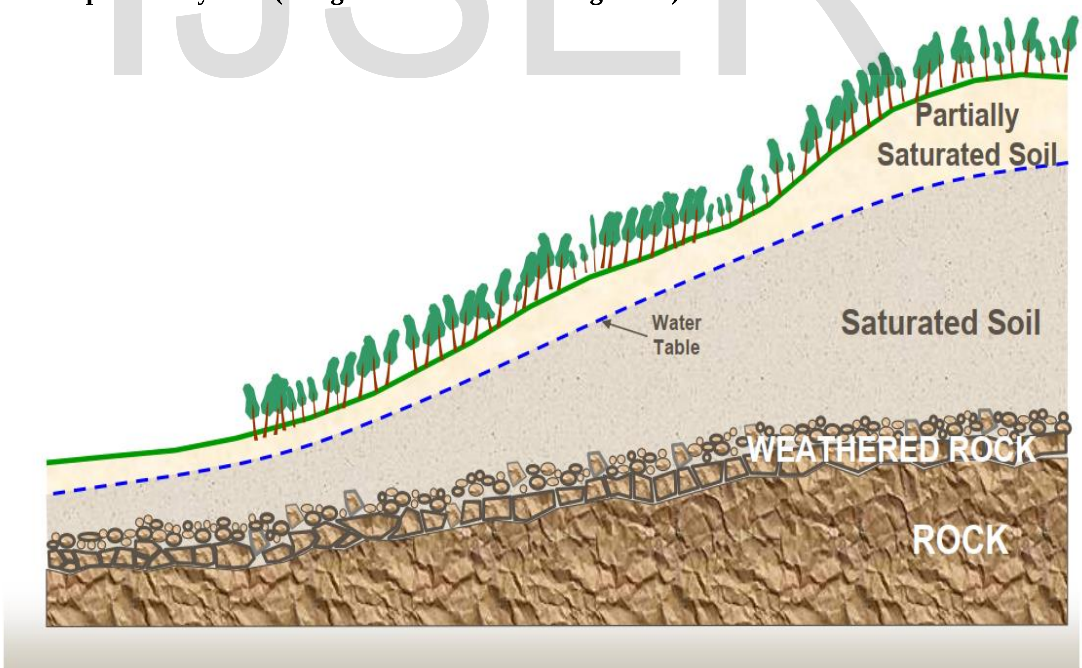


Figure 14 : Model 4- road failures due to instability of slope presentation diagram & images

The causes of the road failure were excavation and placement of additional load on already unstable slope or on marginally stable slope is initiating instability of slopes.

5.5 Anatomy of the slope in study area (Chagni – Mandura road segments)



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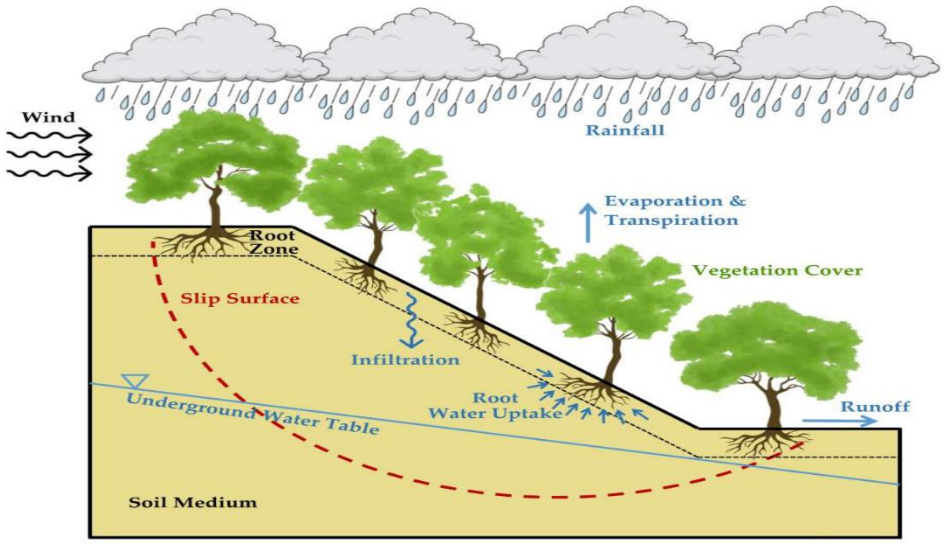
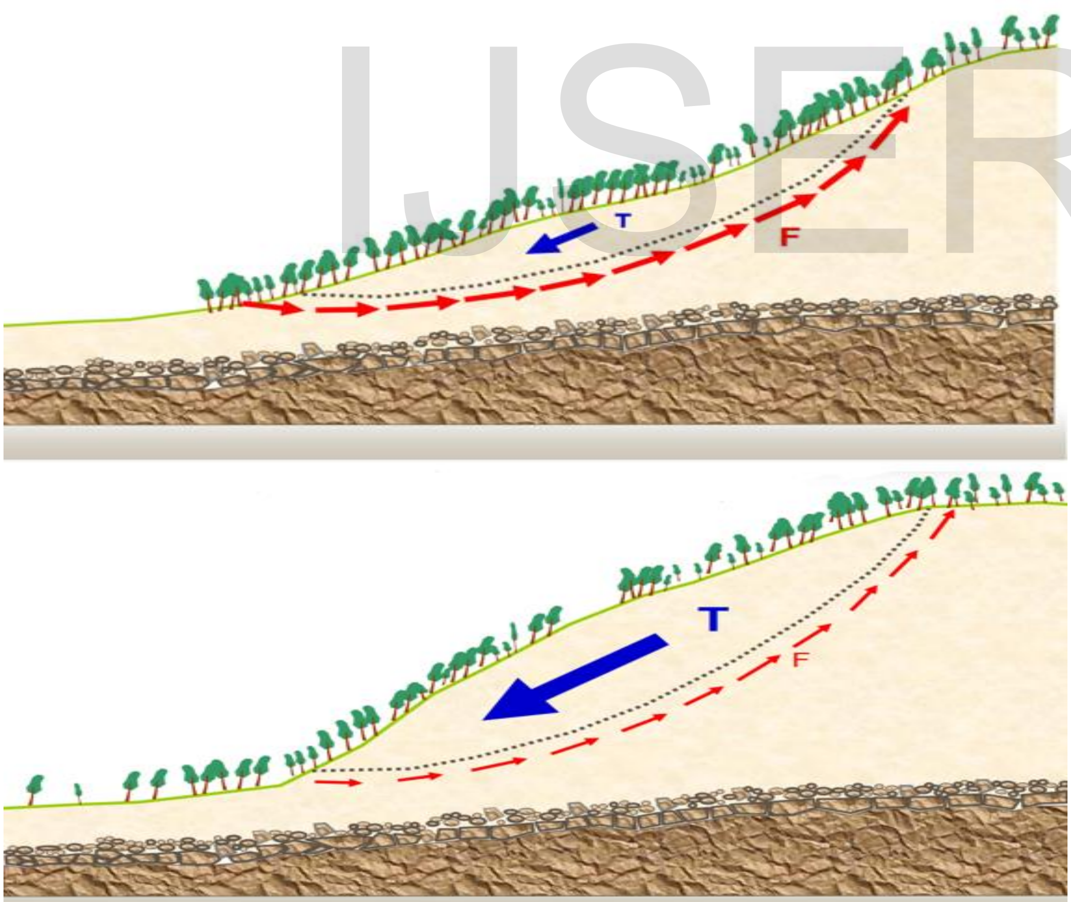


Figure 15: anatomical presentation of the slope

Engineering analysis of slopes



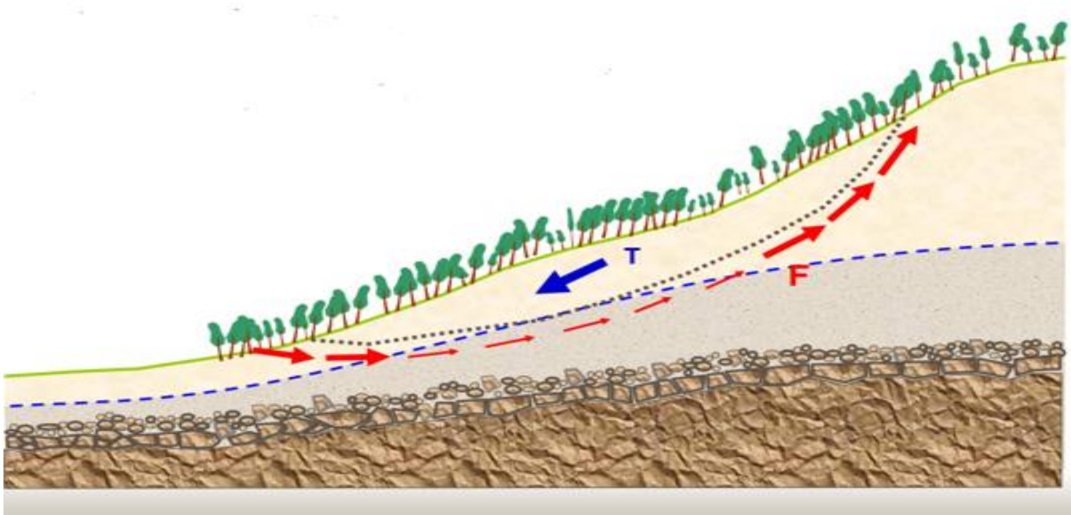


Figure 16: Diagrammatic representation of slope failure mechanisms in the study site

"T" less than "F" i.e. slope will not fail (T =driving actions and F = resisting actions)

"T" greater than "F" i.e. slope will fail (T =driving actions and F = resisting actions)

Water reduce "F" i.e. slope may slide (T =driving actions and F = resisting actions)

Engineering analysis of slopes

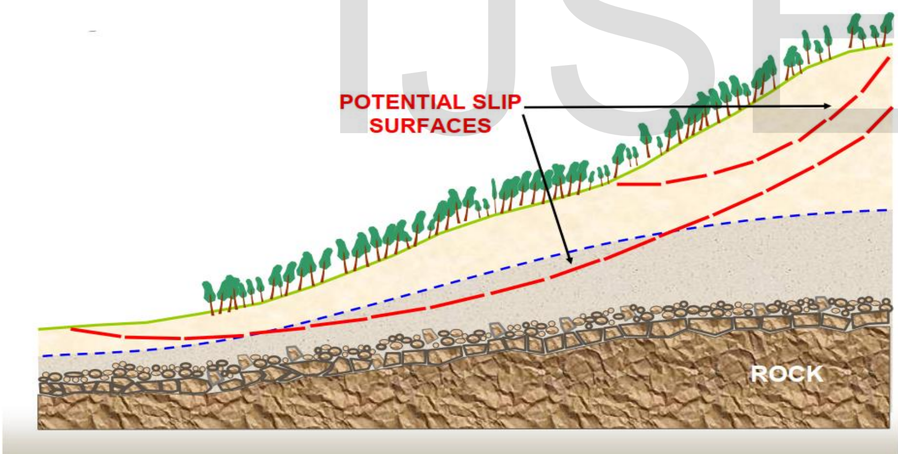


Figure 17 : Diagrammatic representation of Engineering analysis of slopes

6. General Causes of Landslides in our study site (Gilgel Beles - Chagni – Injibara- Bahir Dar road segment)

A famous soil engineer once said, "The major causes of landslides in order of importance are water, water and more water." This is no exaggeration. we interpret this as meaning surface water, subsurface water and inherent water in the soil or its natural moisture content. Water actually affects some of the additional causes which follow later. In every slope there are forces which tend to promote downslope movement and opposing forces which tend to resist movement. Causal Factors of the road failures were:

- Intense rainfall
- Excavation of slope or its toe
- Use of unstable earth fills, for construction
- Pore Water pressure
- Dynamic load Traffic
- Construction activities such as road cutes
- Improper slope maintenance
- Incomplete earthworks
- Incomplete slope strengthening works
- Incomplete drainage works
- No slope maintenance

- Ground Conditions (Plastic weak material, Sensitive material and Collapsible material)

7. A Brief List and Short Comments on Remedial Measures for failure of the road

I. Pre-failure stage, this stage is mostly controlled by progressive failure.
II. Onset of failure characterized by the formation of a continuous shear surface through the entire soil or rock mass;
III. Post-failure stage which includes movement of the soil or rock mass involved in the landslide, from just after failure until it essentially stops;
IV. Reactivation stage when the soil or rock mass slides along one or several pre-existing shear surfaces. This reactivation can be occasional or continuous with seasonal variations of the rate of movement.

7.1 A brief list of slope instability remedial measures

Modification of Slope Geometry- removing material from the area driving the landslide (with possible substitution by lightweight fill); adding material to the area maintaining stability (counterweight berm or fill) and reducing general slope angle.

Drainage- surface drains to divert water from flowing onto the slide area (collecting ditches and pipes); shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics); vertical (small diameter) boreholes with pumping or self-draining; and vertical (large diameter) wells with gravity draining.

Retaining Structures- gravity retaining walls; gabion walls; reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement elements; retention nets for rock slope faces, rockfall attenuation or stopping systems (rock trap ditches, benches, fences and walls) and protective rock/concrete blocks against erosion.

Internal Slope Reinforcement- soil nailing; anchors (prestressed or not); grouting, and vegetation planting (root strength mechanical effect)

8. Conclusion

The conclusions of this research report are:

- ✓ Gilgel Beles – Bahirdar road segment which passes on the hilly and mountainous terrain are characterized by variable topographical, geological, hydrological and land-use condition. Slope instability(landslide), expansive soil, and drainage problems have been a common problem along the Gilgel Beles – Bahir Dar road, especially during the rainy seasons. The most common problems for the road sediment are landslide. Detailed investigation of the type of landslides and the materials involved in the slope instability and identification of the causes of the slope instability are necessary for the developmental works in the area. A detailed slope stability analysis and understanding the causes for independent slope sections was helpful to find a better remedial measure, because different slope sections may have different mode of failure, and may involve different engineering material.
- ✓ Slope instability along Chagni to Mandura road line is becoming serious problem due to the presence of loose unconsolidated materials, highly weathered and fractured basalt rocks, high relief, steep natural slopes, nature of geologic formations exposed along the road section, poor drainage conditions, occurrence of high seasonal rains, and seismically active nature of the region.
- ✓ Causal factors of the road failures were: intense rainfall; excavation of slope or its toe; use of unstable earth fills, for construction, pore water pressure, dynamic load traffic; construction activities such as road cutes; improper slope maintenance ; incomplete earthworks; incomplete slope strengthening works; incomplete drainage works ; no slope maintenance and ground conditions (plastic weak material, sensitive material and collapsible material)
- ✓ Remedial Measures for failure of the road were: removing material from the area driving the landslide (with possible substitution by lightweight fill); adding material to the area maintaining stability (counterweight berm or fill) and reducing general slope angle, surface drains to divert water from flowing onto the slide area (collecting ditches and pipes); shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics); vertical (small diameter) boreholes with pumping or self-draining; and vertical (large diameter) wells with gravity draining; gravity retaining walls; gabion walls; reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement elements; retention nets for rock slope faces, rockfall attenuation or stopping systems (rock trap ditches, benches, fences and walls) and protective rock/concrete blocks against erosion; soil nailing; anchors (prestressed or not); grouting, and vegetation planting (root strength mechanical effect)
- ✓ Soil tests do not show that the slope is safe and also, erosion could lead to slope failure and un engineering retaining walls will fail.

9. Recommendation

Slope instability along Gilgel Beles to Bahirdar road are triggered by natural factors including the presence of unconsolidated deposits, high relief and steep natural slopes, nature of geologic formations exposed along the road section, poor drainage conditions, occurrence

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of seasonal rains, and seismically active nature of the region. These factors suggest that slope instability in the area will continue to occur and pose hazard to the road despite the remedial measures.

The main aim of this study was to assess, identify and to suggest remedial measures to control and minimize the potential hazard associated with geotechnical problems. Thus, it was intended to suggest the most suitable remedial measures, based on analysis and site conditions. Although the hazards associated with slope failure cannot be completely eliminated, they can be significantly minimized by employing a variety of protective and remedial measures. In addition to remedial measures, continual maintenance of the highway is essential for smooth and safe flow of traffic.
The general recommendations based on the present study are;

- ✓ Although there are numerous occurrences of slope instability along the road segment, many steep slopes have reached their natural state of equilibrium. Excavating the toes of these slopes for the purpose of widening the highway can result in instability, triggering new failure. This will be particularly true for the areas where unconsolidated materials are prevalent. Therefore, the best approach for widening the road would be to consider fill embankments supported by retaining structures before undertaking any excavations to gain the required width of the road.
- ✓ From the present study it was deduced that the poor drainage condition on critical slopes have played a significant role in inducing instability of slopes therefore, improvement in drainage condition will be an effective measure to stabilize the slopes in the area.
- ✓ The magnitude of the slope instability problems along the road is so massive that in certain instances, the hazard has to be accepted and to be learnt as how to best live with the problem.
- ✓ Before implementing any remedial measure suggested through present study more detailed studies would be required to work out specific cost-effective remedial measures for individual critical slopes.
- ✓ In order to evaluate better influence of critical factors for slope instability, further detailed geotechnical investigations, geophysical and topographic survey should be performed.
- ✓ The conclusions derived from this work should serve as a basis for further research, extending issues already dealt with in previous studies and contributing new information on slope instability in the study area.

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