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Research Article

Landslide Risk Assessment and Preventive Measures of Selected Locations in the Rangamati District, Bangladesh

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Abstract

Detecting landslides and unstable slopes is one of the most crucial responsibilities in the emergency response to resist landslides. Having a wide range of hilly Terrain in the southeast region of Bangladesh, the risk of landslide disasters is becoming a critical issue. In Chittagong, especially in the Rangamati hill tracts, there have been several losses of life and property due to landslides in the recent past. This research attempts to evaluate the landslide risk in Rangamati hill tracts and provide suggestions to mitigate the landslide hazard by modifying the hill slope. Soil specimens from different hill locations were collected from three areas in the Rangamati district. Several laboratory experiments were conducted to determine the soil properties, and 2D slope stability analysis using Bishop's simplified method was used to evaluate the landslide potential. Different preventative measures, for example, soil nailing, anchors, and cutting slopes like stairs, are also implemented to mitigate the landslide potential by increasing the slope stability was assessed and suggested. Weighted Overlay Model (W.O.M.) was implemented for the Landslide Susceptibility Analysis in ArcGIS to confirm the potential hazard in the study areas, and hazard maps were suggested based on the slope stability results and current slopes in Rangamati. The slope stability analysis of the three spots showed that spot 3 is the most vulnerable spot, which had a low factor of safety value. Even with different mitigation techniques, spot 3 showed a lower factor of safety value, which was verified with the Weighted Overlay Method. It was also seen that among the mitigation techniques, anchoring the slopes is the most effective one that drastically increases the factor of safety value.

1. Introduction

A landslide or landslip is a sudden drift of soil particles or rock from a slope due to gravitational force [1]. A landslip is defined as an abrupt shift in the earth's surface followed by an imperceptible movement known as "creep," which occurs when the driving forces are higher than the soil's resistance and the soil's strength is weakened. The USGS defined it as the outward and downward flow of slope materials. It is one of the most devastating natural disasters, presumably the third in terms of damage to infrastructure and loss of human life [2]. A landslide will result when gravitational or other types of shear forces within a slope are more significant than the shear strength of the materials producing the slope. This disaster can be brought on by heavy rains, cyclones, floods, earthquakes, volcanic activity, snowfall, and anthropogenic developments [2]. The Hill Tracts of Bangladesh are highly susceptible to landslides due to their geological structure and soil qualities, which is a significant issue for Bangladesh. Approximately 80% of Bangladesh's geography is plain, and as a country with a subtropical monsoon climate, it has substantial seasonal changes in rainfall [3]. The average annual rainfall in Bangladesh is 2488 mm [4]. The slope is heavily influenced by rainfall [5]. The natural reasons behind landslides are soil characteristics, slope gradient, land cover, and groundwater table (G.W.T), where earthquakes and rainfall are the triggering factors. Again, different human activities such as massive deforestation of hills, unplanned development in the hills that includes hill cutting, land cover change, and soil excavation change in slope profile play an important role in slope deformation [6,7].

In Bangladesh, among all reasons, the main reason behind the significant landslides is heavy rainfall. On average, Bangladesh faces 19 landslide incidents per year, with a growth rate of 4% [8]. Bangladesh has significant slope terrain in its southern region. The typical elevation in these areas is 200 to 300 meters and can reach 500 meters [9,10]. So, in Chittagong Hilly Areas (C.H.A.) of Bangladesh, the number of fatalities and structural damage brought on by landslides has grown in recent days [11]. Over 350 individuals have died due to slides in the past 30 years [6,7]. A landslide inventory of Chittagong hill zones is included in [12]. The last significant landslides happened in 2017 in Rangamati. Due to the constant rain in June 2017, several landslides occurred in 145 locations in C.H.A., resulting in 168 fatalities and the loss of 40,000 homes [11]. An indigenous highland district called Rangamati saw its worst-ever unfavorable landslides that claimed the lives of 126 in total and severely damaged 6000 dwellings, roads, and telecommunication systems [13]. About USD 223 million was lost in economic activity overall[14–16]. Analysis of Landslide by Weighted Overlay Method in ArcGIS software can identify possible risks by analyzing different geographic characteristics of an area, which works as a triggering factor [17]. This method provides a landslide susceptibility map of an area with different levels of susceptibility, which can be quickly confirmed by analyzing past landslide history and laboratory tests of soil and numerical analysis [18]. Based on the information and literature above, the author considered the Rangamati as the highest landslide risk in Bangladesh and thought to perform some geotechnical study to evaluate the slope condition and stability analysis with some improvement.

In this research, Numerical Analysis analyzed the slope condition of three distinct spots in the Rangamati area for possible slope failure and landslide incidents. Also, the obtained data was validated with Landslide susceptibility mapping by the Weighted Overlay Method.

2. Study Area

Rangamati is a hilly area in the Chittagong Hill Tracts, as shown in Figure 1. This district is also the capital of Chittagong Hill Tracts. Rangamati is 17 meters above sea level, 22°27' N and 92°33' E [19]. From Chittagong, a 77-kilometre route connects to Rangamati. Rangamati is situated on the western bank of Kaptai Lake. Its borders are the Bandarban District in the south; on the northern side, it has Tripura state; on the eastern side, it has the Chin State of Myanmar and Mizoram State of India; and at the western side, the Khagrachari and Chittagong Districts. Rangamati is the only district of Bangladesh that shares its border with two different countries: India and Myanmar. The total area of the Rangamati district is 6116 km^2 [11], of which 294.61 km^2 comprises river bodies, and 2233.84 km^2 is vegetated under reserve forest [19]. In Rangamati district, there are ten sub-districts. Rangamati Sadar, Kaptai Upazilla, and Kawkhali Upazilla are most affected by landslides [20]. For this study, three distinct spots from Rangamati Sadar were chosen, as shown in Figure 1. The spots were slope adjacent to Shahid Abdul Ali Academy (22°38'58.9'' N 92°11'47'' E), Slope adjacent to the Police Line School (22°38'28''N 92°11'42.7'' E), Hill near Prabin Park (22°38'21.4''N 92°11'39.1'' E). These locations were chosen based on previous landslide history. The nearby locations previously faced landslide incidents. The three spots have nearby buildings of great importance. The location 2 has a school on top of the slope. Location 1 has Bangladesh Shishu Academy, Rangamati Women Sports Federation, and a monument nearby. Location 3 is near a roadway that connects the Rangamati district with some tourist spots. Therefore, the chosen locations are fairly significant. Geographically, all three locations are near the Kaptai lake.

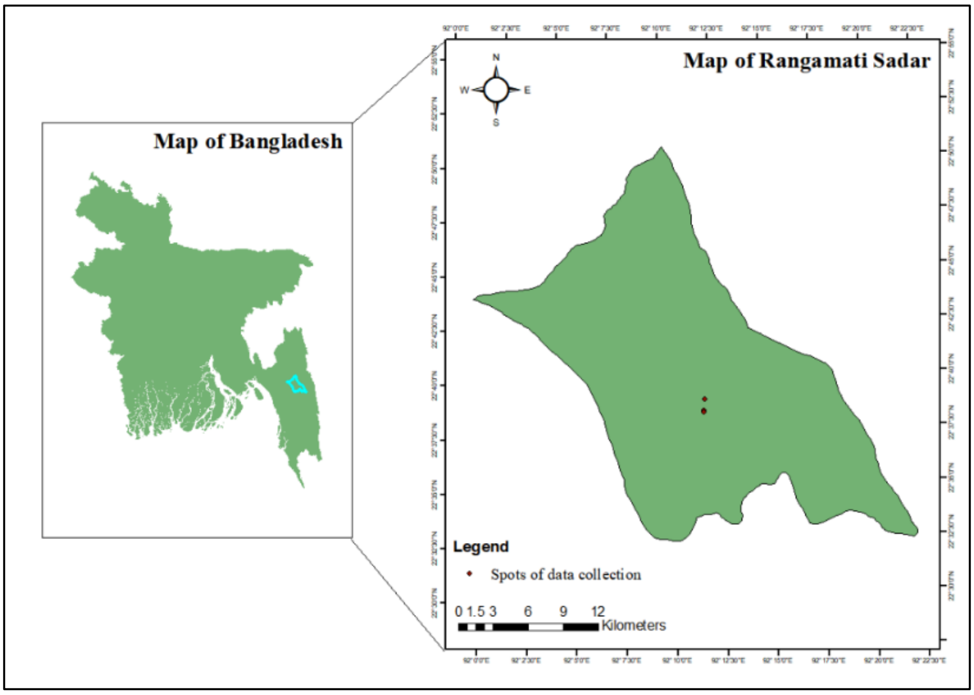


Figure 1. Study Area

3. Methodology

The methodology is divided into four major groups: Soil sample collection, Laboratory soil tests, Slope Stability assessment, and development of a risk assessment map. The flow chart is given in Figure 2.

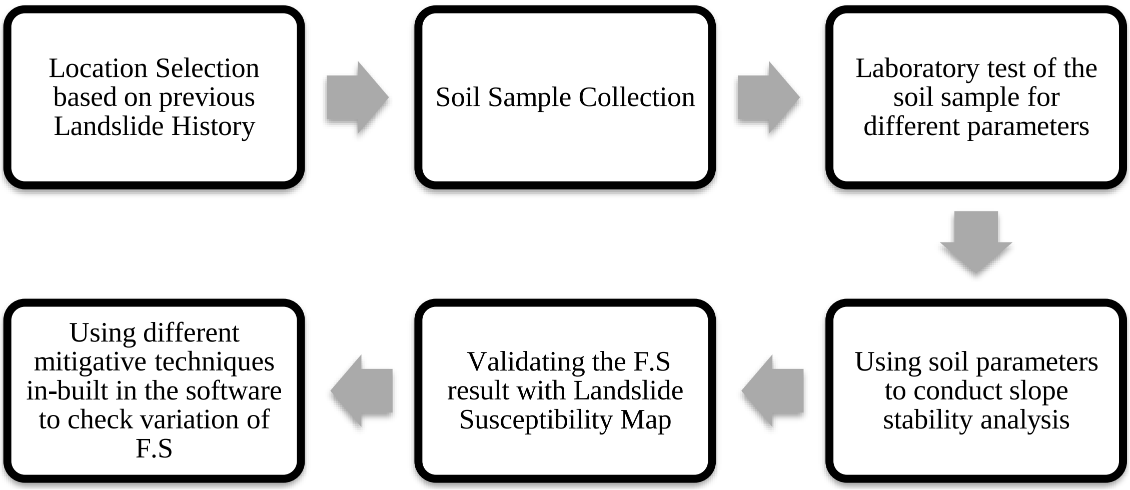


Figure 2. Methodology of this study

Depending on the soil type, soil samples were excavated from three different study area locations in disturbed and undisturbed stages. The pictures of the location of the sample collection are shown in

Figure 3. The soil samples were collected and stored in the Geotechnical Engineering Laboratory of the Ahsanullah University of Science and Technology, Dhaka, following the ASTM guidelines [21–23]. Different laboratory tests were performed to determine the index and strength properties of the collected soil presented in Table 1. These spots mainly consist of dense vegetation. This vegetation helps in reducing water infiltration and increases the shear strength of the soil.

(a)

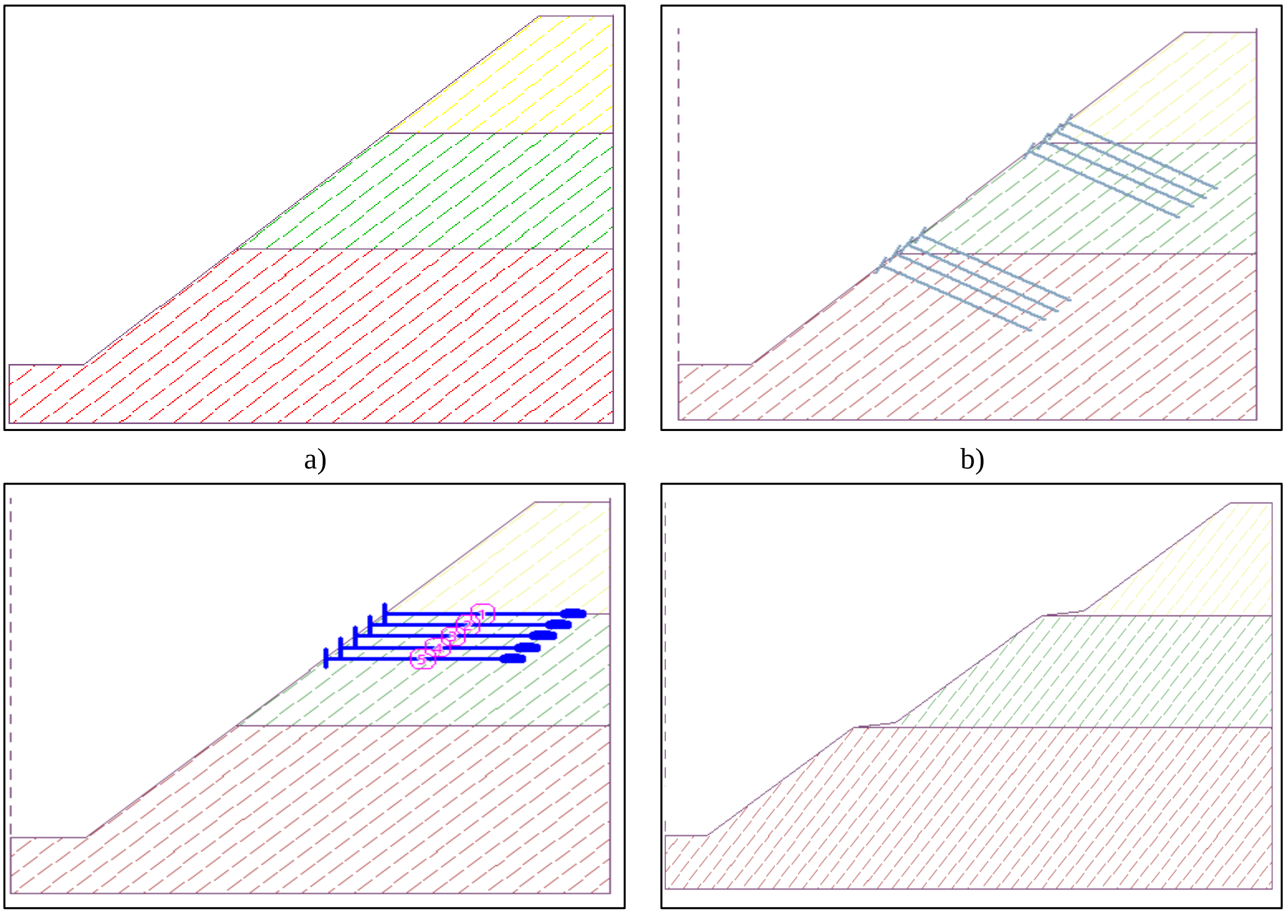
(b)

Figure 3. (a) Sample Collection Location. (b) Sample Collection Pit

Table 1. Soil parameters obtained from laboratory tests

Locations		Dry Unit weight, γ (pcf)	Saturated unit weight, γ_{sat} (pcf)	The angle of internal friction, φ (degree)	Cohesion, C (psf)
1	Top	102	122	31.55	165.62
	Middle	90	100	27.77	245.613
	Bottom	104	124	32.55	201.127
2	Top	90	100	27.83	214.49
	Middle	102	122	31.24	218.88
	Bottom	105	125	32.94	183.37
3	Top	104	124	32.2	134.71
	Middle	105	125	32.8	125.73
	Bottom	115	135	38.17	77.07

GEO5 software was used with a conceptual model having a height of 30ft. The model's height was maintained while the slopes' angles were changed. The model was divided into three equal layers, and 30°, 45°, 60°, and 75° slopes were taken. Different soil parameters were provided for various strata. Bishop's simplified method was chosen for analysis, and a prototype slip surface was provided as input. The analysis type was kept at "optimization" to obtain the lowest safety factor value for each slope. After assessing the bare slope, the safety factors for the nailed, anchored, and stair-like cut slopes were also calculated for the same soil properties. Different models in the analysis are shown in Figure 4.



a) b) c) d)

Figure 4. a) Bare slope model for analysis b) Nailed slope model for analysis c) Anchored slope model for analysis d) Stair-like cut slope model for analysis.

Eight nails were used for the nailing analysis driven at an angle of 30 degrees. By using the nail diameter, Yield Strength (f_y), and hole diameter as inputs, GEO5 software can determine pull-out resistance and tensile strength. Twelve-foot-long nails were assumed to have a diameter of 1.128 inches. The hole diameter was left at 1.128 inches, and the tensile strength was considered to be 60,000 psi. It was supposed that the nails were free heads. Anchor length, root length, and anchor force were given as inputs for anchoring. For this study, the anchor length was set at 12 feet, the root length at 1 foot, and the anchor force at 20 kN. The slopes were divided into three parts for stair-like slope cutting. Each stage is of the same height. The stair treads were 5 feet long and sloped at a 5-degree angle to prevent waterlogging conditions.

3.1 Landslide Susceptibility Map by WOM

The susceptibility map was done using the Weighted Overlay Model Available in ArcGIS software. In the Weighted Overlay Model, slope characteristics, plane curvature, distance of stream, road distance, land-use pattern, and NDVI were reclassified into different subclasses. Then, this data provided a landslide susceptibility map with an index value ranging from 4 to 9, where 4 means low landslide susceptibility while 9 means high vulnerability. Data necessary for this analysis were collected from USGS and hum-data.org. The NDVI index helps the user generate an image indicating a surface's greenness [24]. This index is helpful while mapping the Land-cover pattern and land-use pattern. NDVI values represent vegetation presence [25]. A high NDVI value means the surface has dense green vegetation. The NDVI value has a range of +1 to -1. The value +1 means a thick layer of vegetation. An NDVI value close to 0 or less than zero indicates no vegetation, and an NDVI value of -1 suggests the presence of a water body [26]. While doing the analysis, some factors had more impact than others. So, impact factors were also divided by analyzing the actual effect of the landslide. Figure 5 shows the impacts while analyzing,

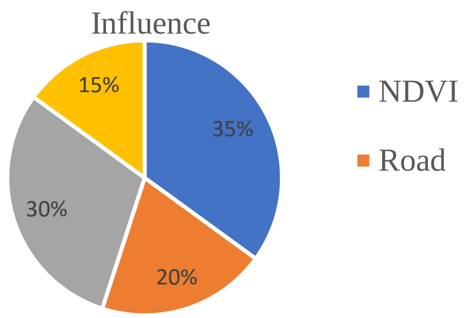
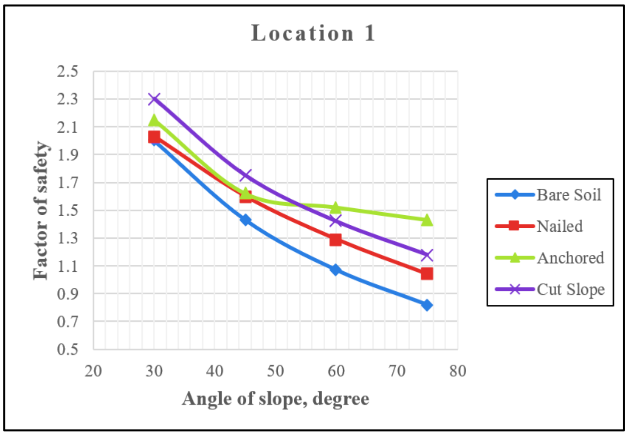


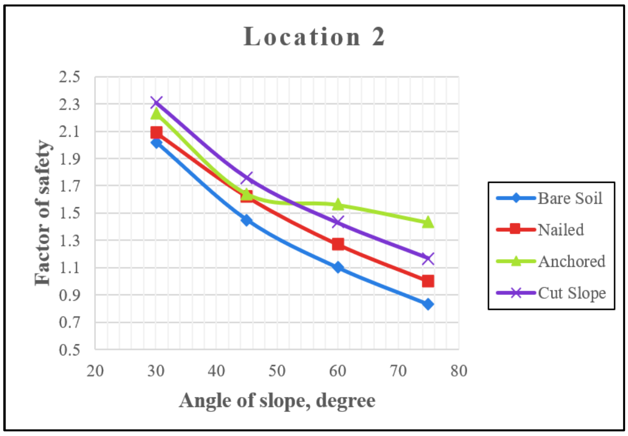
Figure 5. Parameters of WOM Analysis and their influence

4. Slope Stability Analysis Results

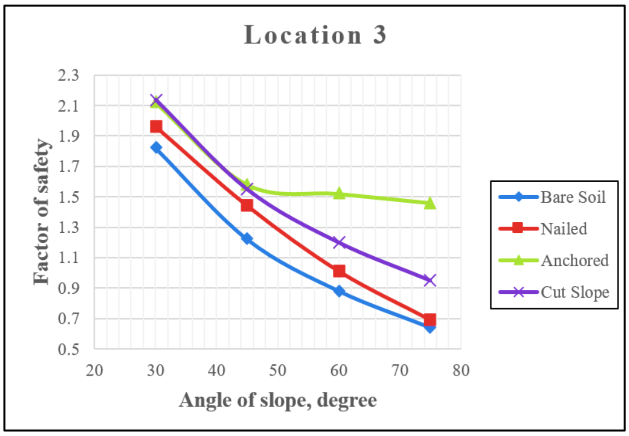
Slope stability analysis was performed for four different slope inclinations for four types of formation: bare slope, nailed slope, anchored slope, and cut slope. The slope stability analysis found that the safety factor decreases with the increase of slope angle, as expected. A bare slope angle between 35 and 40 degrees can be considered safe without maintenance. It was also found that the value of the safety factor for the three slopes greater than 60 degrees is below 1.25, which can be termed unsafe [26]. However, the introduction of nailing, anchoring, and cutting slopes like stairs increases the factor of safety rather than bare slope. These values are graphically represented in Figure 6.



(a)



(b)



(c)

Figure 6. Factor of Safety vs. Angle of Slope Curve for (a) Location 1 (b) Location 2 (c) Location 3

Compared to the bare slope, using nails can slightly increase the value of F.S. Additionally, stair-like cuts to the slope increase the F.S. value. Finally, using Anchor significantly raises F.S. The Factor of Safety is improved by nearly 15% to 20% when slopes are nailed compared to bare slopes. This change depends on the soil parameters and the angle at which the nail was driven. Again, anchoring the slopes roughly doubles the Factor of Safety.

The stability of slopes is affected when they are cut into stair-like shapes. Slope cutting like stairs nearly doubles or triples the value of F.S. The most exciting part was that dropping the safety factor after 40 degrees for the anchored slope became almost constant for all locations. It represents that anchoring will suit a slope with a higher inclination. However, again, these statistics depend on the type of soil, availability of the equipment for stabilization, project cost, etc. According to the analysis of these three spots, the F.S. values found in spot 2 are better than the rest spots.

Additionally, the F.S values of location three are lowest. Therefore, anchors are preferable to stabilize spot 3 as applying other procedures may not achieve the desired outcome. Again, while anchoring could not be cost-effective in spot 3, retaining structures with nailing or slope cutting can produce good results. Inspecting these locations revealed that using large machinery can be challenging, especially on spot 1. It would be difficult to transport those machines and work at spot 1 because it is located right next to Kaptai Lake. Simple solutions, such as modifying one slope into multiple slopes, can be used to address these types of issues. These measures can raise F.S. without hefty nailing or anchoring equipment.

5. The Landslide Susceptibility Mapping

The Landslide Susceptibility Analysis was done by the Weighted Overlay Method, and a map was developed based on the slope stability analysis results and available field data of current slopes in Rangamati. The present slopes of and the potential risk zones of the Rangamati Sadar area are shown in the following Figure 7 and Figure 8. This map shows that the three spots fall in zones with a susceptibility index 7. As the number is high, it indicates a high chance of slope failure. Also, a slope map was created from the Digital Elevation Map (DEM) of Bangladesh collected from USGS. The portion of Rangamati Sadar was extracted from the DEM using the Mask tool in ArcGIS 10.7. For the analysis, the data from the website of USGS and others were obtained in February 2023, and the resolution was 30m×30m [27]. This slope map also shows that the existing slopes in the study area are considerably steep.

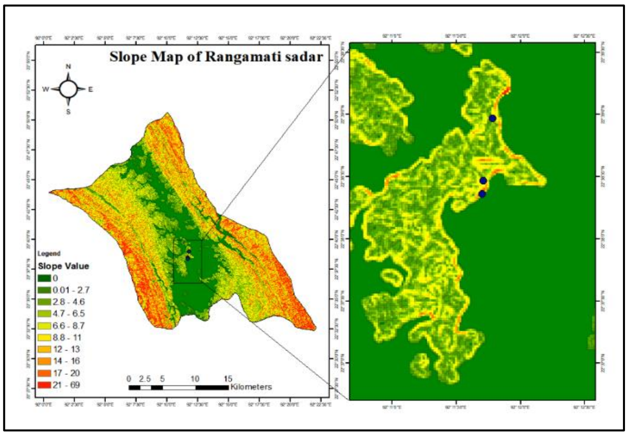


Figure 7. Slope Map of Rangamati Sadar

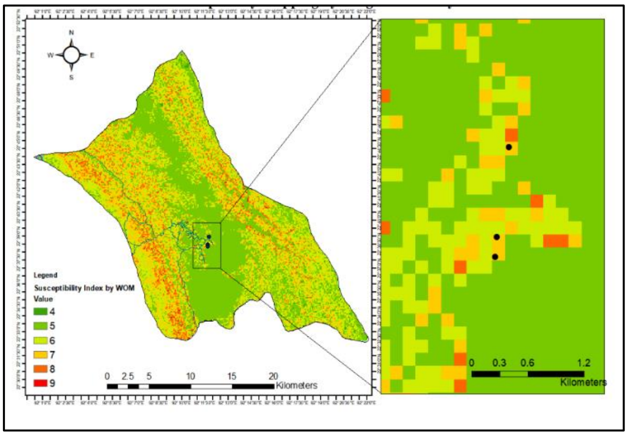


Figure 8. Landslide Susceptibility Map of Rangamati Hill tracts

6. Conclusion

An effort was made to evaluate the landslide risk determination and prevention in the Rangamati hill tracts. The slope stability and GIS-based analysis show that the existing slopes have a high risk of potential landslide incidents in the Rangamati hill tracts. The safety factor values of the slope having higher than 60 degrees obtained in the slope stability analysis show a lower value than the margin. The potential mechanisms that might be used to stabilize a slope are also suggested by this study. Based on the current slope data and slope stability analysis results, the potential landslide hazard map was developed for the Rangamati hill tracts. Also, some slope stabilization methods were suggested by supporting the slope stability analysis. When choosing the stabilizing slopes in the actual world, factors like economy, quality, accessory availability, working facilities, etc., should be considered. By considering additional factors, two or more solutions can be implemented to stabilize slopes in significant locations, such as those next to roadways. The anchoring may be used for any slope with a higher inclination based on other stabilization factors. The future recommendation of this study is to utilize further vigorous analysis with sophisticated technology, remote sensing, and 3D numerical analysis to get a more precise idea of slope stability and feasibility.

Declaration of Competing Interest: The authors declare that they have no known competing of interest.

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