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Influence of Seasonal Ground Water Level Fluctuations on the Stability of the Rohingya Refugee Camp Hills of Ukhiya, Teknaf, Cox's Bazar, Bangladesh—A Threat for Sustainable Development

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Abstract

Bangladesh is a south Asian Monsoonal Country and the recent precipitation pattern in the Cox's Bazar area of Bangladesh is changing and increasing the number of monsoonal slope failures and landslide hazards in the Kutubpalong & Balukhali Rohingya camp area. An attempt has been made to see the influence of seasonal variation of ground water level (G.W.L.) fluctuations on the stability of the eco hills and forests of Ukhiya Teknaf region. Ukhiya hills are in great danger because of cutting trees from the hill slopes and it is well established that due to recent change of climate, short term rainfall for few consecutive days during monsoon might show an influence on the factor of safety (Fs) values of the camp hill slopes. A clear G.W.L. variation between dry and wet seasons has an influence on the stability (Fs) values indicating that climate has a strong influence on the stability and threatening sustainable development. A stable or marginally stable slope might be unstable during raining and show a variation of ground water level (G.W.L.). The generation of pore water pressure (P.W.P.) is also influenced by seasonal variation of ground water level. During wet season negative P.W.P. called suction plays an important role to occur slope failures in the Ukhiya hills. Based on all calculated factor of safety values (Fs) at different locations, four (4) susceptible landslide risk zones are identified. They are very high risk (Fs = 0.18 to 0.46), high risk (Fs = 0.56 to 0.75), medium risk (Fs = 0.76 to 1.0) and marginally stable areas (Fs ≈ 1). Proper geo-engineering measures must be taken by the concerned authorizes to reduce P.W.P. during monsoon by installing rain water harvesting system, allowing sufficient drainage & other geotechnical measures to reduce the risk of slope failures in the Ukhiya hills. Based on the stability factor (Fs) at different slope locations of the camp hills, a risk map of the investigated area has been produced for the local community for their safety and to build up awareness & to motivate them to evacuate the site during monsoonal slope failures. The established "Risk Maps" can be used for future geological engineering works as well as for sustainable planning, design and construction purposes relating to adaptation and mitigation of landslide risks in the investigated area.

Keywords

Stability, Pore Water Pressure, Ground Water Level, Rain & Risk Map

1. Introduction

Bangladesh is a south Asian monsoonal country. Rainfall induced landslide hazards are common geo-engineering problems during monsoon in the investigated areas. In hill slopes of Ukhiya, shallow movements, slumping & debris flows in an unsaturated zone are very common. Furthermore, millions of Rohingya refugees after entering Bangladesh in 2017, had constructed temporary infrastructures for shelters and other purposes on the steep, deforested slopes of Ukhiya region, Cox's Bazar, Bangladesh. Ukhiya hill soils are very loose to loose unconsolidated granular sandy soils with silts and occasionally clays (SP, SM, SP-SM & ML) according to British Soil classification system. This research has been carried out to see the risk associated with the slope failures during raining. Based on obtained wet season factor of safety (Fs) values, a landslide risk map of the investigated area has been prepared. Some recent slope failures commonly slumping and debris flow types with loss of lives & properties during raining in the Rohingya camp area clearly justify the importance of carrying out this research. Many researchers carried out research on rainfall induced landslide hazards. Fukuoka (1980) & Rahardjo et al. (1998) discussed the influence of rainfall on the soil slope stability. Cho & Lee (2001), Gasmo et al. (2000) discussed the infiltration capacity of rain water on the stability. Guzzetti et al. (2007), Mahadi & Hossain (2014) & Toll (2001) discussed the rainfall threshold lines for the initiation of landslides. Tsaparas et al. (2002) discussed the controlling parameters of rainfall induced landslide hazards. Khatun et al. (2022) discussed the landslide susceptibility of the Rangamati area of Bangladesh. Cardinali et al. (2006) & Hossain & Toll (2013) have carried out research on the rainfall induced landslide hazards in different parts of the world. Hossain et al. (2020) discussed the rainfall induced landslide hazards of Bangladesh-challenges issues and sustainable development. Monsoonal slope failures are common in the camp area

Figure 1. Monsoonal slope failures in the camp.

(Figure 1). Rainfall induced landslide hazards in the investigated area during monsoon are increasing each year and killing many people. If seismic events occur simultaneously during rainy season, landslides in the Ukhiya hills might even destroy the makeshift shelters and other multistoried buildings constructed in Ukhiya hills and surrounding area, which might create substantial environmental as well as humanitarian disasters. The intent of this study is to highlight the landslide susceptibility risk assessment in the Ukhiya-Teknaf hills, Cox's Bazar Bangladesh. Therefore, people living in these areas are at high risk of landslide hazards. This study was actually undertaken to evaluate the rainfall induced landslide hazards in the Ukhiya and surrounding area. Previous literature suggests that the investigated area is seismically active. Unfortunately, no work has yet been carried out until 2022 to evaluate the influence of the change of Ground Water Level (G.W.L.) & pore water pressure (P.W.P.) on the stability to understand the risks. Findings from this research and prepared risk maps will eventually fill up the current research gap and give support to all concerned authorities including planners, engineers, policy makers in developing guidelines to understand risks, to build up awareness, to reduce landslide hazards, sustainable infrastructure design & development and to mitigate slope failures, which motivated us to assess the risks based on factor of safety (Fs) values for the benefit of the society. The location map of the investigated area is shown in Figure 2. Due to mass migration, more than one million Rohingyas were shifted from

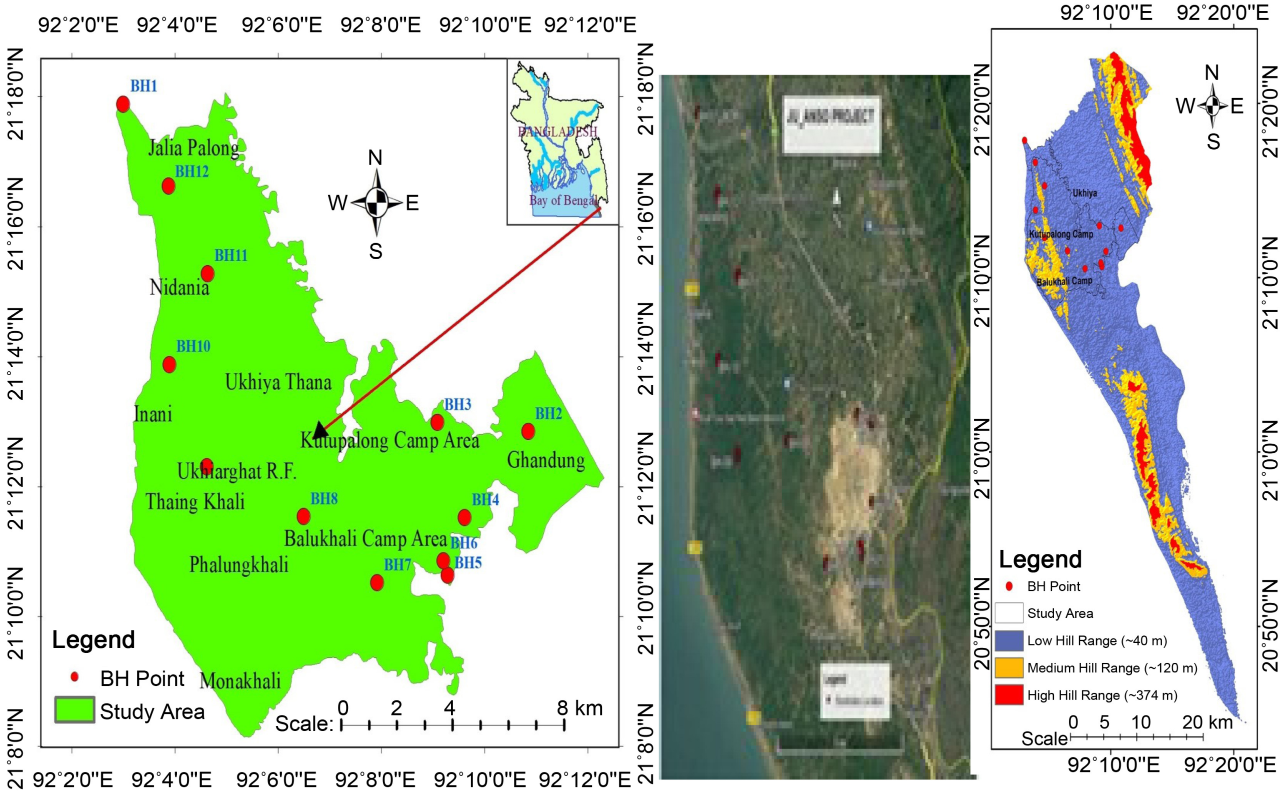

Figure 2. Location map of the investigated area.

Myanmar to the Ukhiya-Teknaf hills of Cox's Bazar district, Bangladesh. Hossain et al. (2023) discussed that Rohingyas living in an anti-humanitarian condition in the Ukhiya hills of Kutubpalong, Balukhali and the Teknaf region, where they constructed many temporary shelters by cutting down the hillslopes and trees as shown in satellite images (**Figure 3(a)** & **Figure 3(b)**) taken before and after the influx of the Rohingya refugees in the Ukhiya Hills. By destroying the green, wooded eco-forest of Ukhiya, Rohingyas constructed temporary shelters on the loose, unconsolidated sandy soils, which are at high risk of landslide events especially during monsoon. Furthermore, there is no sustainable management of forests in the camp area. Two satellite images (**Figure 3(a)** & **Figure 3(b)**) of Nov.2016 before the influx of Rohingya refugees and Dec 2017 after one year of the influx at Balukhali camp of Ukhiya hills clearly justify the destruction of trees in the hills. After one year, due to influx of Rohingya refugees, the green hills turned into naked lands by destruction of all trees and increased the risks of slope failures in the hills. This is clearly indicating the importance of carrying out this research to understand landslide risks. Many hills and infrastructures around the study area have already been affected and have caused large number of causalities & loss of properties as reported by several international and national media. Seasonal rainfall variation could potentially cause significant changes in the soil moisture regime, as well as rapid developments on hills may further deteriorate the devastating slope related hazard problems in the camp

Figure 3. Sattelite images showing destruction of eco forests before the influx of Rohingya refugees (A) Nov. 2016 & after one year (B) Dec. 2017 of influx at Balukhali hills.

area. This is clearly justifying the importance of this research work.

2. Methodology

Field site investigations were carried out in accordance with B.S. 5930 (1990). and drilled twelve (12) boreholes in the camp and surrounding area. During drilling each borehole, lithology was recorded with increasing depth up to a depth of 30 m. The SPT (Standard Penetration Test) tests with split spoon sampler were carried out in each borehole with a depth interval of 1.5 m. and the SPT (Standard Penetration Number) "N" value for each soil layer was recorded. Ground Water Level (G.W.L), Slope geometry, slope angles were also measured at different sites to establish slope models. Laboratory geotechnical testing were carried out in accordance with British Standard 1377 (1990) to evaluate the geotechnical properties. Seepage & slope stability analyses were conducted using Seep/W and Slope/W (Geoslope International Ltd., 2012) numerical finite element software using both dry & wet seasons G.W.L. data on some selected slopes to see the impacts of G.W.L. and rainfall on the Factor of safety values (Fs). Factor of safety values were calculated by considering the ratio of sum of all the driving and resisting forces as commonly used in geotechnical engineering. A Fs > 1 indicates that the slope is stable and Fs < 1 suggests that the slope is unstable. Finally, based on all obtained factor of safety results GIS based landslide risk maps before and after rain were prepared. The results were then compared and evaluated to identify risk zones in the camp area.

3. Results

3.1. Geology & Tectonics

Based on field and site investigations geology of the investigated area has been evaluated. A geological map of the investigated area has been established and compared with regional geological setting of Chittagong hill district (CHD) as discussed in Persits et al. (2001). Concerning tectonics and seismicity, Bangladesh is located in one of the most active tectonic region of the world where three plates—The Indian plate, the Tibet and the Burmese Sub plates are colliding and thrusting against each other. The whole Ukhiya hills are mainly composed of loose to very loose yellowish brown sand, medium to coarse grained soils. Some subordinate clay soils are also associated with sands (SP, SM, SC & ML). Some parts of the camp hills are composed of loose ferruginous sands, greenish and brownish grey in color. Some pebbles, cobbles, conglomeratic and shale parting are also present with sandy soils. Sandstone & siltstone with alteration of sands, silts and shales are also present. They are of Mio-Pliocene age. Persits et al. (2001) discussed the tectonic setting of the hills of the investigated area (**Figure 4**). A close consistency between the different geological units has been observed as discussed by Persits et al. (2001) & Hossain et al. (2023). The geology of the investigated area has also been evaluated and is shown in **Figure 5**. The typical

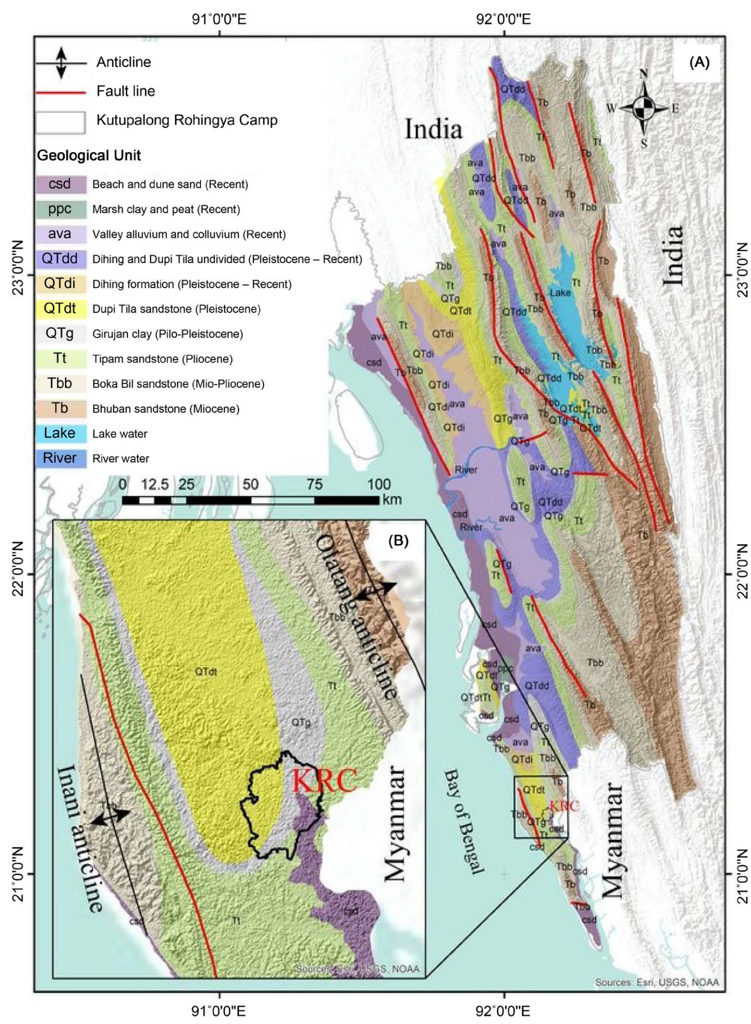

Figure 4. Tectonic setting of Hills, Persits et al. (2001).

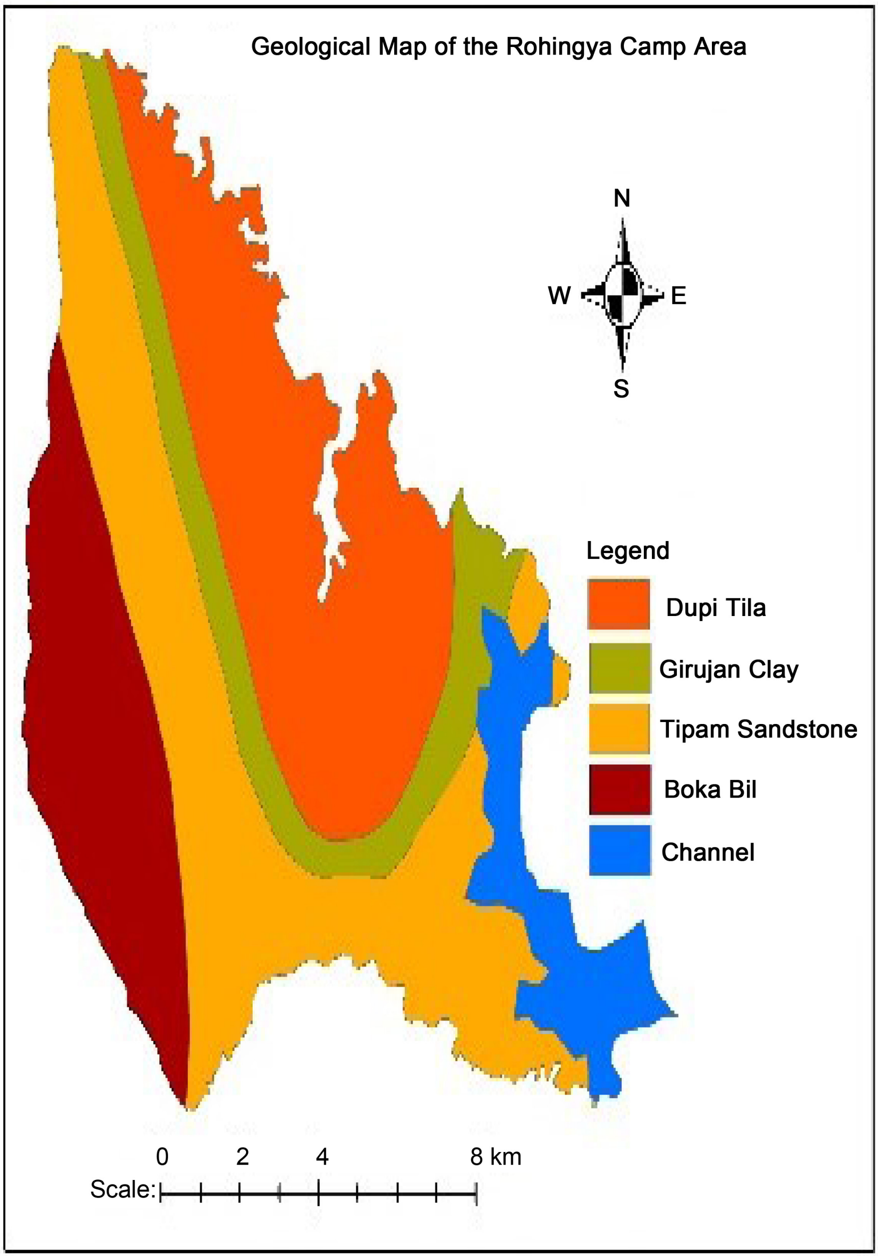

Figure 5. Geology of the camp area.

subsoil profile of Ukhiya and surrounding area consists of yellowish brown very loose to moderately dense medium to fine grained poorly graded sand (SP) & silty sand (SM) with some clay. Hossain et al. (2023) discussed the detail site characterization of the investigated area and compared the SPT results with resistivity values as shown in **Table 1**. The site resistivity images are shown in **Figure 6**. Hossain et al. (2023) discussed that the soils with higher percentages of finer particles has high plasticity value and shows lower resistivity value and soils with larger particle size has the higher resistivity and vice-versa. They established a good correlation between geophysical & geotechnical methods to identify lithology & subsurface geological materials.

Table 1. Correlation between SPT variation and electrical imaging at Kutubpalong and Balukhali sites (Hossain et al., 2023).

Drilling data	Resistivity imaging data	Lithology
Very loose sand (0 - 0.6 m), N = 2 to 5 for Kutubpalong camp area.	Low resistivity (<7 Ωm) material (0 - 0.5 m) for Kutubpalong camp	Weathered materials & very loose sands for Kutubpalong camp
Very loose sand (0 - 0.6 m), N = 2 to 5 for Balukhali camp area.	Low resistivity (<7 Ωm) material (0 - 0.6 m) for Balukhali camp	Weathered materials & very lose sands for Balukhali camp
Fine to Medium sand with cobble and pebble (0.06 - 4.11 m), N = 6 to 10 for Kutubpalong camp area.	High resistivity (14 - 250 Ωm) material (30 - >235 m) for Kutubpalong camp area.	Medium dense Sands for Kutubpalong camp area.
Fine sand with clay (0.6 - 2.13 m), N = 6 to 10 for Balukhali camp area.	Moderate resistivity (11 - 160 Ωm) material (0.6 - 2 m) for Balukhali camp area.	Fine dense sands with clay for Balukhali camp area
Very fine to fine sand with some clay (4.11 - 15.24 m.), N = 11 to 30+ for Kutubpalong camp area.	Moderate resistivity (<40 Ωm) material (>2.5 m) for Kutubpalong camp area.	Fine dense sands with silty clay for Kutubpalong camp area.
Fine to medium sand with sandy shale. (2.13 - 15.24+ m), N = 11 to 30+ for Balukhali camp area.	High resistivity (>160 Ωm) material (>2+ m) for Balukhali camp area.	Fine to medium sands with sandy shale for Balukhali camp area.

The identified main geological formations of the camp and surrounding hills are Tipam Sandstone, Bokabil & Dupi Tila formation (**Figure 5**). In the North eastern part of Balukhali camp, Dupitila Sandy formations are also identified. Most of the shallow slides and slumping have been occurred in the Tipam & Bokabil Sandy formations. Western & South eastern parts of the camp hills are mainly composed of Tipam Sandstones. Bokabil sandy formations are commonly observed in the North western part of the camp area.

Hossain et al. (2023) established DEM (Digital Elevation Modal) and slope angle map of Ukhiya hills using GIS as shown in **Figure 7** & **Figure 8**.

3.2. Site Investigations

A detailed site investigation was carried out in accordance with BS 5930 (1990).

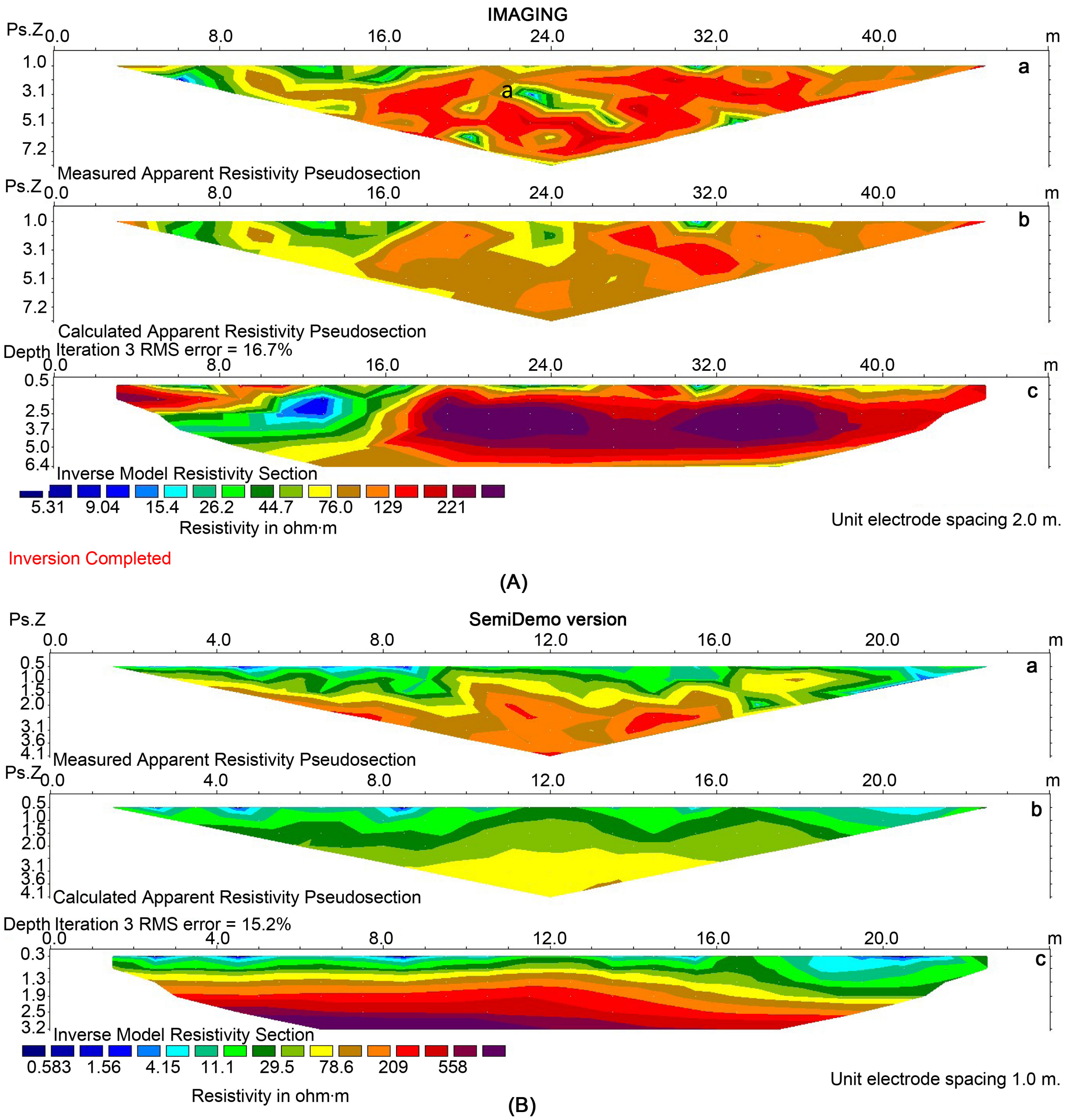

Figure 6. Electrical Resistivity Tomography of the Kutubpalong & Balukhali sites (a) Pseudo section of measured apparent resistivity (b) Pseudo section of calculated apparent resistivity (c) Inverted model (Hossain et al., 2023).

Both disturbed and undisturbed samples were collected to determine the basic geotechnical properties and shear strength.

3.3. SPT versus Depth Curves

Based on SPT values three (3) zones are identified viz. very low, medium and high as shown in **Figure 9**. Based on SPT data, it is established that SPT values are low to very low up to 4 m. at different locations and soils are very loose to

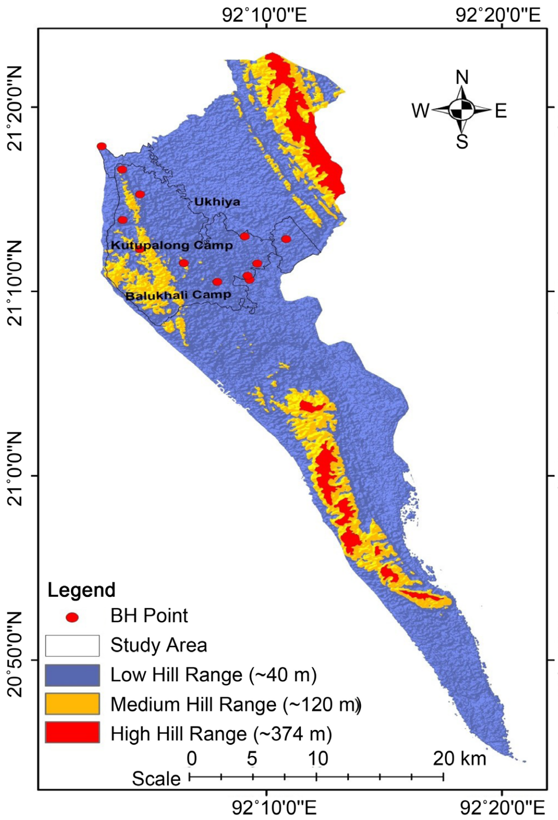

Figure 7. DEM of the investigated area.

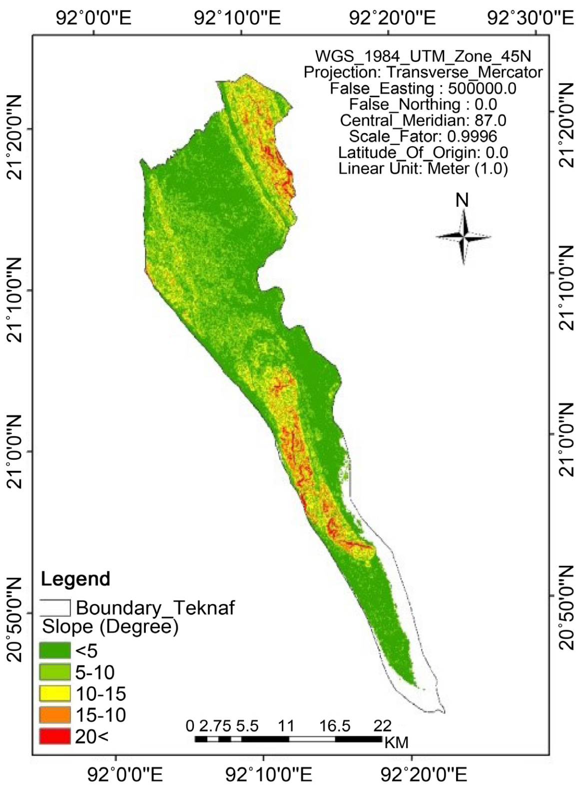

Figure 8. Slope angles of the hills.

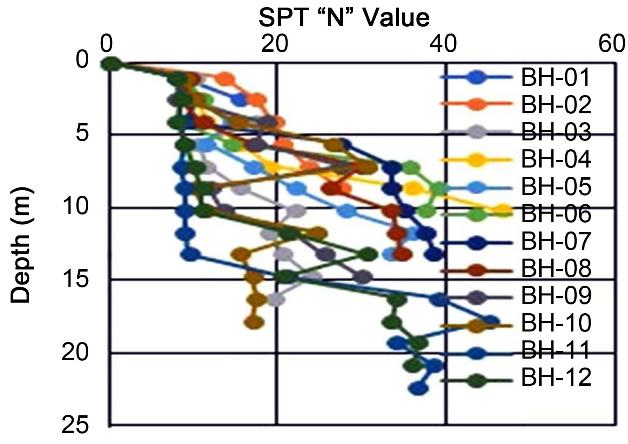

Figure 9. SPT (N) versus depth curves.

loose in nature, The obtained SPT values from a depth of 4 m to 10 m. indicating medium dense soils and at higher depths SPT values are very high indicating dense soils. A wide variation of SPT values with respect to depth at different locations was also observed (**Figure 9**). The determined SPT values are in consistent with the established lithology of resistivity method as discussed by Hossain et al. (2023).

3.4. Basic Geotechnical Properties

Hossain et al. (2023) discussed the grain size results as shown in **Figure 10**. From the grain size analysis results it is established that these soils are sand dominated soils (more than 82% to 98% sand) with silty clay, uniformly graded and fall within range of 0.01 to 1 mm. Moisture Content values of the camp soils are highly variable from 9.18% to 37.01%. The specific gravity values range from 2.53 to 2.89. The liquid limit value of silty clay soils of Kutupalong Camp ranges from 32% to 40% and Balukhali camp ranges from 42% to 51%. The plastic limit values of silty clay soils of the Kutubpalong camp ranges from 12% to 22%, whereas plastic limit values for Balukhali camp range from 13% to 24%. Plasticity index values of Kutubpalong camp soils range from 18 to 25 and 13% to 24% for Balukhali camp. According to BS 5930 (1990), Kutubpalong camp soils are Low to Medium Plasticity Inorganic Clay soil and Balukhali camp soils are Medium to High Plasticity Inorganic Clay soil. They are normally to over consolidated and medium to low compressible soils. The cohesion (c) of these soils is less than 10 with an angle of internal friction (φ˚) value range from 16 to 36 degrees.

Some other determined geotechnical parameters of the shallow landslide hazard site soils of the investigated area are listed in **Table 2**.

4. Monthly Rainfall Data Analysis

From the 13 years (2008 to 2020) monthly rainfall data analyses, it is established that May to August of each year, the area has experienced highest amount of

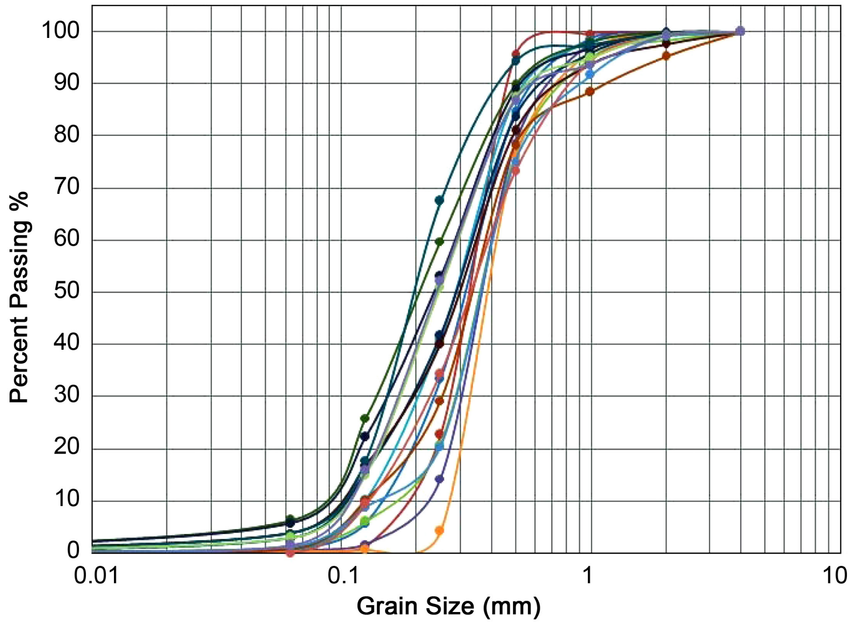

Figure 10. Grain Size distribution curves.

Table 2. Geotechnical properties of shallow landslide hazard site Soils.

Camp Name	Depth (m.)	Sample No	Grain Size (%)			Grading Properties		Moisture Content	Speciifc Gravity (Gs)	Cohesion (c) kPa	Angle of Internal Friction
			Gravel	Sand	Silt-Clay	Cu	Cg	(%)	Gs	(c) kPa	Degrees (˚)
Kutupalong Rohingya Camp	0.60 - 1.06	D1	0.56	98.41	1.03	2.05	1.10	25.45	-	-	-
	2.14 - 2.59	D2	10.03	88.95	1.02	5.06	1.32	29.39	2.59	7.04	26.38
	3.65 - 4.11	D3	17.11	82.09	0.80	4,30	1.14	18.53	2.56	-	-
	5.18 - 5.63	D4	4.69	94.70	0.61	2.92	1.26	18.87	2.60	9.92	27.79
	6.24 - 6.71	D5	1.20	92.74	1.06	1.93	1.07	19.26	2.53	13.95	26.76
Balukhali Rohingya Camp	0.60 - 1.06	D1	0.48	98.88	0.64	2,41	1.09	13.96	2.59	-	-
	2.14 - 2.59	D2	0.18	99.48	0.34	1.92	1.11	13.19	2.56	4.48	34.29
	3.65 - 4.11	D3	1.63	97.37	1.00	2.41	1.21	13.04	2.55	17.40	16.75
	5.18 - 5.63	D4	0.38	99.04	0.58	1.78	1.02	24.04	2.60	-	-
	6.70 - 7.16	D5	0.77	98.65	0.58	2.64	0.97	20.07	2.53	13.43	23.46
	8.22 - 8.68	D6	0.53	99.35	0.12	1.56	0.96	25.02	2.55	-	-

rainfall. Highest number of slope failures is also reported during this monsoonal period with huge loss of lives and properties. This monsoonal rainfall might influence on the fluctuations of Ground Water Level (G.W.L.) & stability values. Monthly rainfall variations clearly showing that highest amount of rainfall obserevad during monsoon (**Figure 11**).

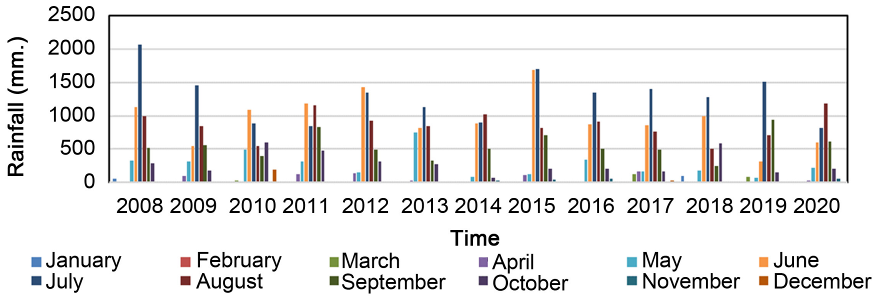

Figure 11. Monthly variations of rainfall from 2008 to 2020.

4.1. Seasonal Variations of G.W.L.

Variations of G.W.L. in both wet and dry seasons can be seen in Figure 12. It is clearly observed that at all locations dry season G.W.L. is lower in comparison with wet season G.W.L. These variations of G.W.L. might be due to the infiltration of rain water into the ground, hence attempts have been made to see the variation of G.W.L. on the stability.

4.2. Seasonal Variations of Ground Water Level on the Slope Stability

Hossain et al. (2023) noted that a rainfall amount of 140 mm. to 280 mm. is sufficient to occur any landslide in the hills of Ukhiya, Bangladesh. Changing precipitation pattern & increase in extreme rains, extreme events, short term heavy rainfall for few days during summer monsoon are big challenges for sustainable community living & development in the Rohingya camp area. Monsoonal Heavy rain in 2021 has destroyed 273 Rohingya shelters in Cox's Bazar area. More than 200,000 Rohingyas camp residents are categorized as vulnerable during monsoon. Therefore, an attempt has been made to see the impacts of seasonal variations of Ground Water Level (G.W.L.) during dry and wet season on the camp hill slopes stability. Two individual case studies result are presented here to show the effects of G.W.L. on the stability at Balukhali & Kutubpalong camp area. The seasonal variations of G.W.L. can be seen in Figure 12. Dry & wet seasons seepage and stability analysis results are presented here in Figure 13 & Figure 14. At Balukhali camp, the slope was initially stable with a Factor of safety (Fs) = 1.332 (Figure 13), when G.W.L. was at 1.5 m. When the same slope was analyzed with a different G.W.L. (1.0 m.) for rainy season, the Fs value has dropped (Figure 14). The distinct variation of Fs values with two different G.W.L. values clearly indicates that G.W.L. condition has significantly influence on the stability (Fs) values. A similar variation of Fs values due to variation of G.W.L. at Kutubpalong camp (Figure 15 & Figure 16) was also observed with a drop of Fs from 1.221 to 1.05, At Balukhali 3, a drop of Fs from 1.40 to 0.46 also indicates that G.W.L. variation due to monsoonal rain has a strong influence on the camp hills stability. All the analyzed results are summarized in Table 2. It is also established that monsoonal rain water has also infiltrated into the ground and has an influence on the change in Pore Water Pressure (P.W.P.) values. A clear variation

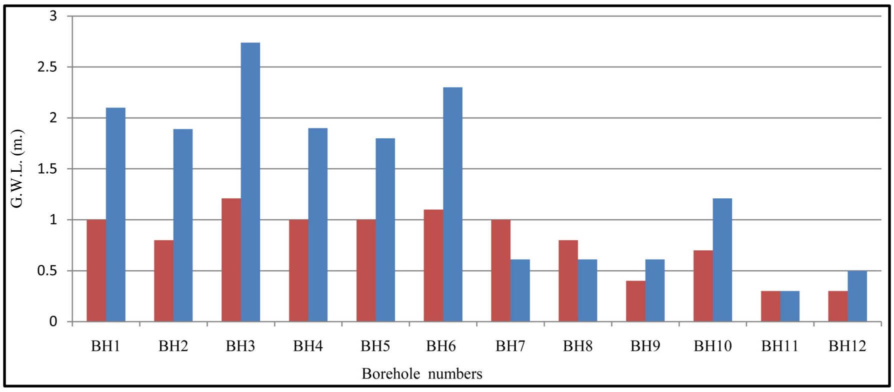

Figure 12. Seasonal variations of G.W.L.

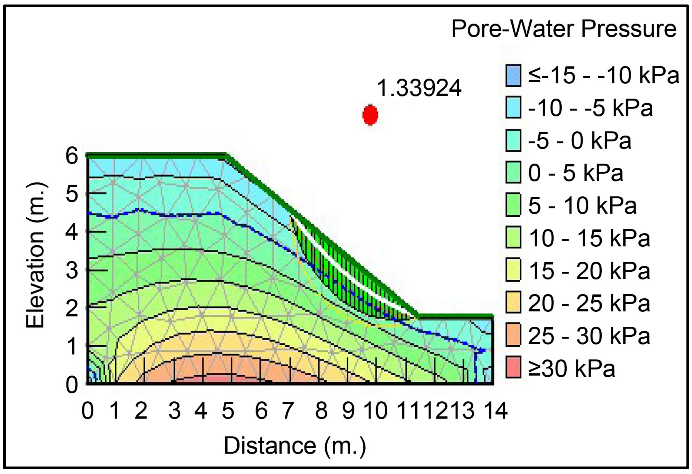

Figure 13. Stability at Balukhali (G.W.L. at 1.5 m.).

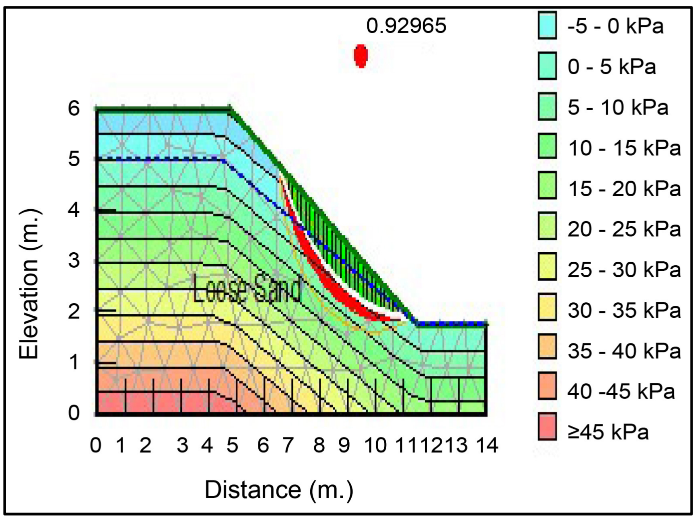

Figure 14. Stability when G.W.L. at 1.0 m.

of negative P.W.P. (which is called suction) was also observed between wet and dry season stability modal. The highest amount of suction (−15 kPa) values was observed during dry season in comparison with wet season suction (−5 kPa)

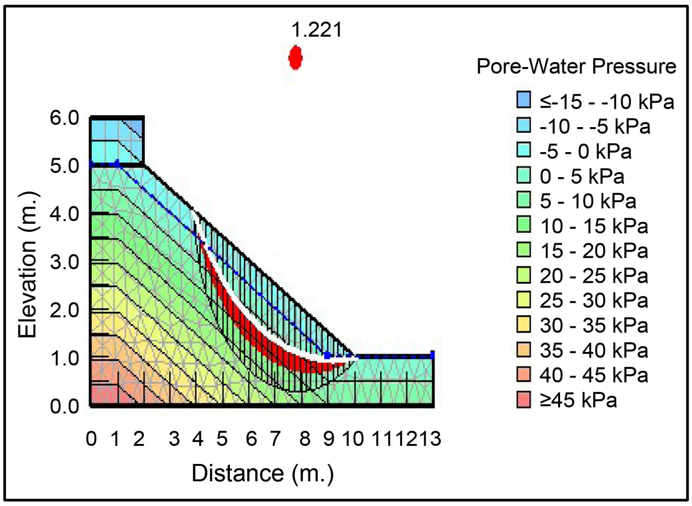

Figure 15. Stability at Kutubpalong (G.W.L. at 1.0 m.).

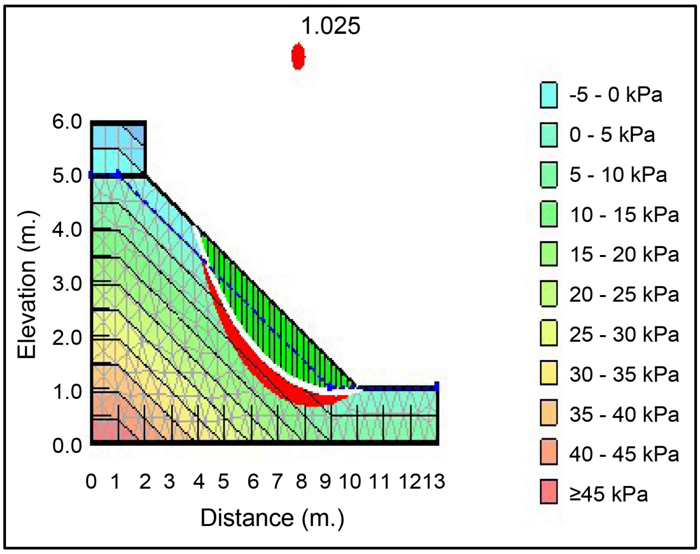

Figure 16. Stability at Kutubpalong (G.W.L. at 0.8 m.)

value, which might also be due to the variation of G.W.L. Suction values gradually diminished during raining with the increase of G.W.L. and increases the risk of slope failures in the camp area during wet season. Proper actions must be taken by the concerned authorities to reduce the slope failures especially during monsoon to reduce loss of lives and properties by taking sustainable geo-engineering measures. Before raining Fs values more than 1 indicates stable slope. After raining in some cases, low Fs values close to 1 indicating marginally stable slope. In case of high and very high risk slopes a significant drop of Fs was observed after raining due to increase in G.W.L. It infers that when rain water infiltrates into the ground, a stable slope might be marginally stable or unstable due to the variation of G.W.L. This can also be justified by the variation of suction values before and after raining. As suction values gradually diminished during wet season raining due to the variation of G.W.L., it is possible to conclude that G.W.L.

has an influence on the stability. The obtained Fs (Factor of safety) values based on wet season G.W.L. data range from 0.91 to 0.41. Fs values based on dry season G.W.L. data are higher in all cases in comparison with wet season Fs. Lower Fs values at all locations during wet season also indicate that these soils are susceptible to failure. A drop of factor of safety value less than one (Fs < 1) at all locations due to higher G.W.L. clearly indicates that G.W.L. has a strong influence on the stability and slope failure in the camp area. It is also established that wet season Fs values are lower in comparison with dry season Fs values (Table 3) due to seasonal fluctuations of G.W.L. and monsoonal raining. The variation of factor of safety (Fs) values between dry and wet season is shown in Figure 17.

4.3. Landslide Risk Map of the Investigated Area

Based on all calculated factor of safety values (Fs) at different locations, four (4) landslide hazard prone risk areas are identified as shown in Figure 18. They are very high risk (Fs = 0.18 to 0.46), high risk (Fs = 0.56 to 0.75), medium risk (Fs = 0.76 to 1.0) and marginally stable areas (Fs ≈ 1). A distinct variation between the dry (before raining) and wet season (after raining) Factor of safety (Fs) values due to raining clearly justifies the influence of climate and Ground water level on the stability (Figures 13-16). The established landslide risk maps will eventually help the all concerned authorities including planners, policy makers and engineers in developing guidelines for awareness build up, sustainable infrastructure development, site specific mitigation measures to control and mitigate

Table 3. Variation of Fs due to seasonal variation of G.W.L.

Slope ID	Latitude & Longitude	Dry Season G.W.L. (m.)	Wet Season G.W.L. (m.)	Fs (Factor of Safety) Dry Season	Fs (Factor of Safety) Wet Season
Balukhali Camp 12, Block J1	Latitude: N21˚10'50.63" Longitude: E92˚9'12.50"	1.5	1.0	1.338	0.928
Kutubpalong Camp, West 1, Block B3	Latitude: N21˚12'59" Longitude: E92˚9'05"	1.0	0.8	1.221	1.05
Balukhali 3	Latitude: N21˚11'23.8117" Longitude: E92˚9'14.401.26"	1.3	0.6	1.40	0.46
Kutubpalong 3	Latitude: N21˚12'14.9550" Longitude: E92˚9'53.2704"	1.2	0.5	1.42	0.41

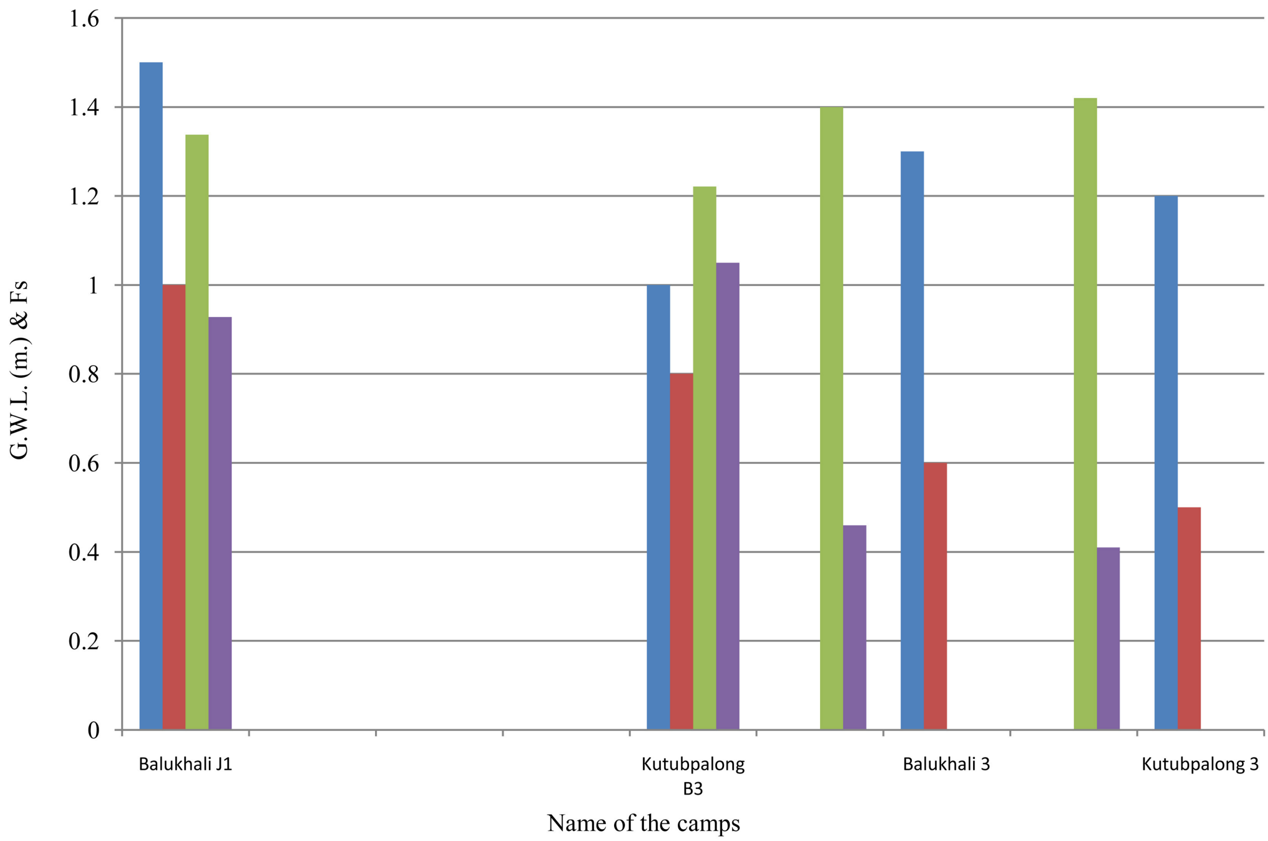

Figure 17. Variation of factor of safety (Fs) with seasonal variation of G.W.L.

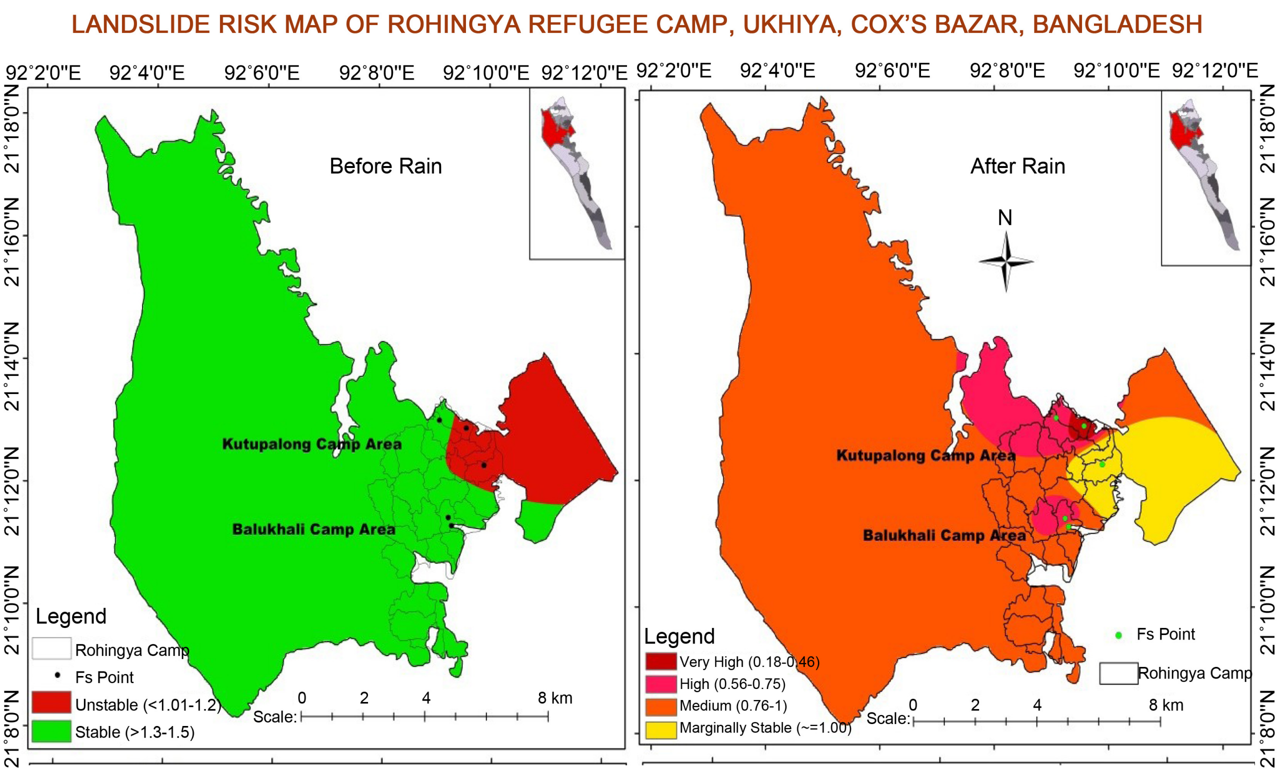

Figure 18. Landslide Risk map (based on Factor of safety values) of the investigated area.

the landslide risks in the investigated area.

5. Conclusion

It is established that most of the shallow landslides and slumping during monsoon in the Rohingya refugee camp hills have occurred in the Tipam, Dupi Tila & Bokabil formations. Based on SPT data, it is established that SPT values are low to very low up to 4 m at different locations and soils are very loose to loose in nature. The obtained SPT values from a depth of 4 m to 10 m indicate medium dense soils and at higher depths SPT values are very high indicating dense soils. A wide variation of SPT values with respect to depth & at different locations was also observed. SPT results are in consistent with the resistivity results. Grain size analysis results suggest that these soils are mainly sand dominated (SC-SM, SP & ML), which contains more than 82% to 98% sand, uniformly graded and fall within range of 0.01 to 1 mm and consistent with the criteria of liquefiable soils. The cohesion of these soils is almost zero with an angle of internal friction (φ˚) value ranging from 23 to 27 degrees.

A distinct variation between dry and wet seasons G.W.L. was observed. It is established that G.W.L. might influence the stability (Fs) value due to the seasonal variation of G.W.L. The observed Fs values during dry season in all cases are higher in comparison with wet season Fs values in all cases. A stable or marginally stable slope might be unstable during raining due to the rise of water level. Variation of G.W.L. also has an influence on suction (i.e. the negative pore water pressure). It is also observed that seasonal variation of G.W.L. might also has an influence on suction values. Based on the determined Factor of safety (Fs) values, four (4) susceptible landslide potential risk zones are identified in the Rohingya refugee camp hills and surrounding area of Ukhiya, Cox's Bazar, Bangladesh. They are very high risk (Fs = 0.18 to 0.46), high risk (Fs = 0.56 to 0.75), medium risk (Fs = 0.76 to 1.0) and marginally stable areas (Fs ≈ 1). These must be taken into account for sustainable community living & infrastructure development in the camp and surrounding area.

Sustainable development is a constitutional obligation in Bangladesh. There is no proper balance between the three (3) pillars (social, economic and environmental) of sustainable development in the camp area to manage hills as per the United Nations (UN), 2015 sustainable development goals (SDGs). Lack of resilient infrastructures, lack of a peaceful society, drainage system, healthy lives, scarcity of drinking water and sanitation, lack of landslide monitoring system during monsoon and loss of biodiversity, wetlands and forests in the camp area threaten the overall sustainability of the camp and surrounding hills. The hidden risks especially during the rainy season might create big environmental as well as humanitarian disasters and crises in the investigated area. The established landslide risk maps will eventually help all concerned authorities including planners, policy makers and engineers in developing guidelines for awareness build-up, sustainable infrastructure development, site specific slope failure risk assessment, site characterization and to mitigate the risks of landslides in the investigated area. All the concerned authorities including the UN, UNHCR, non-governmental organizations (NGOs) and the Government of Bangladesh (GoB), must be taken into account the importance of geoscience to evaluate the rainfall induced potential landslide risks in the hill slopes of the investigated area during future development in order to save lives and properties and to achieve sustainability in the Ukhiya-Teknaf hilly regions of Cox's Bazar, Bangladesh.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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