ISSN 2229-5518

Rainfall Induced Landslide Hazards of Bangladesh: Challenges, Issues and Sustainable Development

Hossain A.T.M.S., Toll D.G., Shushupti O

Abstract— Bangladesh is a tropical monsoonal South Asian Country. In this research, an attempt has been made to see the influence of precipitation pattern on slope failures. Thousands of families become homeless each year due to this disaster along with causing agricultural loss. Hill cutting for urban development and settlement at the bottom hills has significantly increased the risk of landslides during monsoon. This natural disaster now turns to a humanitarian disaster and threatening the sustainable development of Bangladesh.

It is established that rainfall pattern can significantly influence on the landslide hazard events of Bangladesh. Development of pore water pressure (P.W.P) within soil mass is also evaluated and discussed. It is also observed that if small amount of antecedent rainfall for few days is added with huge amount of total rainfall for a single day, it may also contribute to the factor of safety values. Due to raining, a variation of the factor of safety (Fs) value is noted. Some numerical finite element model test results are presented in this paper to understand the impact of precipitation pattern, infiltration capacity, pore water pressure development and seepage pattern. These are some of the major concern for sustainable landslide hazards management & development in Bangladesh. The identified challenges and issues in managing landslide hazards of Bangladesh are also highlighted in this paper. Some mitigation measures and the importance of monitoring landslide hazards with geotechnical instrumentations along with the necessity of developing an early warning system to mitigate landslide hazards of Bangladesh is discussed.

Index Terms— Climate, hills, landslides, P.W.P., rainfall, sustainable & warning system.

1 Introduction

The investigated slopes of the southeastern folded part (Chittagong) of Bangladesh lies in the tropical monsoonal climatic zone (Fig.1). The rocks are mainly composed of unconsolidated to poorly consolidated sedimentary beds of sandstone, siltstone and shales. The rocks are highly fractured, jointed and faulted. Some geological formations are highly porous. More than one million people including Rohingyas repatriated from Myanmar live on the slopes and foot hills and are therefore at great risk of landslides. Hossain & Toll [1] discussed the rainfall induced slope failure mechanism in Chittagong hills. Karim et al. [2] discussed the engineering geology of the Chittagong city area. A number of authors including Fukuoka [3], Rahardjo et al. [4], Cho & Lee [5], Gasmo et al. [6], Toll [7], Tsaparas et al. [8] and Cardinali et al. [9] have carried out research on rainfall-induced slope failures and infiltration mechanism of rainwater into slopes. Three distinct seasons can be characterized in Bangladesh. It can be seen from Fig. 2 that the vast majority of annual precipitation is observed during the monsoon period (June to September). The strength parameters of the soils are listed in Table 1.

- *Hossain A.T.M.S is currently working as a Professor at Jahangirnagar University, Bangladesh, PH-+8801914897282. E-mail: shakhawathos2004@yahoo.com*
- *Toll D.G is currently working as a Professor at Durham University, UK,. Email: d.g.toll@durham.ac.uk*
- *Shushupti O is currently studying at the Department Of Soil, Water and Environment, University of Dhaka, Bangladesh. Email : olokashushupti98@gmail.com*

2 Methodology

Seepage modelling was used to investigate the seepage conditions in a slope under changing hydrological conditions. The commercial geotechnical finite element software Seep/W (2007) developed by Geoslope International Ltd., Canada was used [10]. Seep/W is capable of modelling saturated/unsaturated and transient flow in two dimensions (2D). The results of the finite element numerical model can be used to interpret the infiltration mechanism of the slope, seepage conditions, effect of hydrological conditions (including rainfall and evaporation) on the pore water pressure (PWP) changes. Groundwater flow can be considered to be either steady state or transient. In steady state conditions there is no change in the hydraulic head at any point with time. In transient flow the hydraulic head changes as a function of time. For analysing rainfall-induced landslides, where rapid changes in precipitation can be the trigger for instability, it is essential to model the problem as transient.

For the case of transient flow where the hydraulic head is no longer independent of time (i.e. the volumetric water content is changing with time) the continuity equation takes the following form known as Richard's equation. This can be expressed in the form of the governing equation of water flow through an unsaturated media as given in equation 1.

$$\frac{\delta}{\delta x}\left(k_x \frac{\delta h}{\delta x}\right) + \frac{\delta}{\delta y}\left(k_y \frac{\delta h}{\delta x}\right) + q = m_w^2 \rho_w g \frac{\delta h}{\delta t} \quad (1)$$

where k_x and k_y are the coefficients of permeability in x and y directions

h	is hydraulic head
q	is boundary flux
g	is gravitational acceleration
ρ_w	is the density of water
m_w^2	is the coefficient of volume water change with respect to a change in negative pore water pressure (suction) and is equal to the slope of the soil water retention curve

Equation 1 is highly non-linear since the hydraulic head (suction) and the coefficient of permeability with respect to water of the soil are dependent on the volumetric water content of the soil. For the numerical solution of equation 1, the soil water retention curve (relationship between the volumetric water content and the negative pore water pressures), the permeability function (relationship between water permeability and negative pore water pressure) and the boundary flux q are required [8]. The initial condition of the problem (initial hydraulic head at any point of the initial time step) must also be defined.

Fig.1. Location Map of the Study Area

In the seepage analysis, a triangular elements (1×1m) mesh was used. In total this mesh consisted of 750 nodes and 1382 elements. Along the left and right edges, head boundaries were applied in order to define the initial groundwater level and the initial pore water pressure (PWP) profile. A zero nodal flow boundary (Q=0) was applied along the base. The precipitation rate was modelled as a unit flux boundary (q) along the nodes at all surfaces of the ground. When solving, Seep/W translates the unit boundary (q) into a nodal boundary (Q) and then calculates the hydraulic head at each node. In order to avoid any ponding phenomenon, that is unlikely to take place on sloping ground, the software performs a check that every node at the ground surface has zero or negative hydraulic head. If a positive head is calculated at any surface node (which would indicate ponding), the flux boundary is changed to a head boundary, and set to zero, and then the flux is determined.

Rainfall and evaporation (2000-2007) data were collected from Bangladesh Metereological Department (BMD).

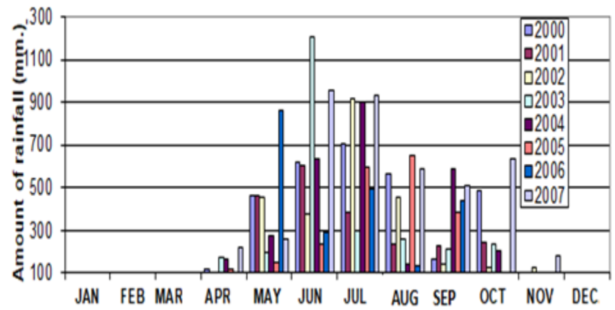


Fig.2. Total monthly variations of rainfall for the years 2000-2007

TABLE 1
MATERIAL PROPERTIES OF THE SOIL LAYERS (CHITTAGONG HILLS)

Ground type/layer	γ_{wet} (KN/m^3)	c' (kPa)	ϕ'(º)	k_{sat} (m/sec)
Sandstone (top layer)	15	1	38	1×10^{-4}, 1×10^{-5}
Sandstone, silty shale & siltstone (bottom layer)	16	3	38	1×10^{-5}, 1×10^{-7}

3 Results of Analyses

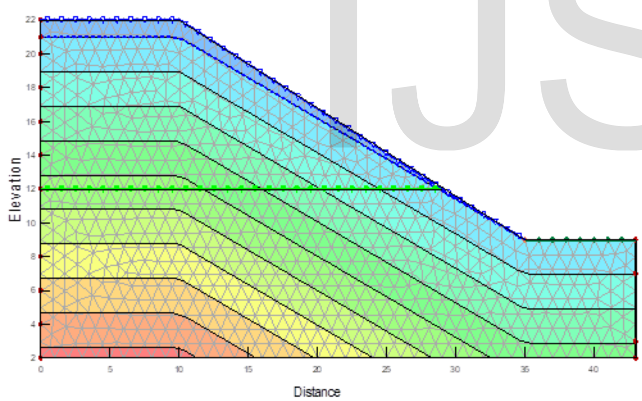
3.1 Seepage Modeling

Seepage modeling was used to investigate the seepage conditions in a slope under changing hydrological conditions to see the influence of rainfall on the selected slopes. One month rainfall (precipitation) and evaporation data (June, 2007) have been used for simulation.. Changes in pore water pressures due to rainfall were predicted. Different distributions (3 scenarios) of rainfall pattern (Table 2) were investigated

The results are presented in the following sections. The initial slope geometry assumed for the analysis is shown in Fig. 3. The initial water table was taken to be at 1m. depth below the ground at the crest and at the toe, the ground water level was taken as 1.0m. The initial pore water pressure distribution was assumed to be hydrostatic. Transient seepage and slope stability modeling were carried out to investigate the rainfall triggered landslides in different areas.

TABLE 2
DIFFERENT DISTRIBUTIONS OF RAINFALL APPLIED ON SLOPE

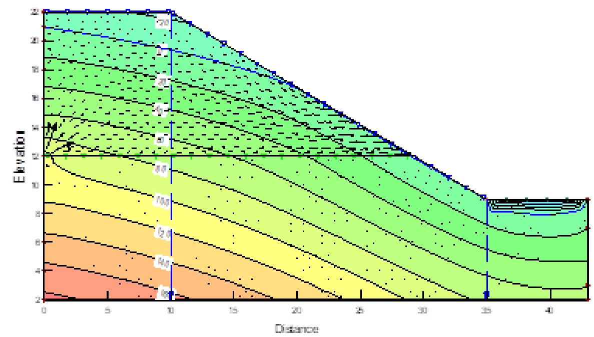
Antecedent rainfall (mm.)			**Major rainfall (mm.)**		
Scenario no.	Total amount of antecedent rainfall (mm.)	Duration (Hours) &Intensity (mm./hr,)	Total amount of major rainfall (mm.)	Duration (Hours)	Intensity (mm./hr.)
1.	185	168 (7 days) At a rate of 1.10mm./hr .			
2.		-	425	192 (8 days)	3.17
3.			425	24(1 day)	17.70



Fig,3. Initial condition of the slope

The results of the analyses for Scenarios 1-3 are shown in Figs. 4-6. These figures show contours of pore water pressure (PWP) and also vectors of ground water movement. Longer arrows indicate greater flow. The results for the different scenarios are considered in the following sections. It can be seen in all the analyses that the rate of infiltration into the bottom layer (Layer 2) is very low in comparison with top soil layer. This is due to the difference in the coefficient of permeability values of the two soil layers (Table 1). The results of the analyses show that the rainfall patterns can influence the seepage pattern, the pore water pressure development and infiltration processes.

In Scenario 1, the antecedent rainfall was distributed over 7 days (168 hours) at an intensity of 1.01mm./hr. The pore water pressure (PWP) contours calculated in the analysis are shown in Fig. 4. A negative PWP (suction) below -20 kPa is developed near the crest. In Scenario 2, the total amount of rainfall for the whole rainy period (610 mm) was distributed equally over the 8 days. Seepage condition in this case can be seen in Fig.5. A distinct variation in the generation of PWP contour profile is observed.



.Fig.4. Seepage condition for Scenario 1 (7 days antecedent rainfall at an intensity 1.10 mm./hr.).

It can be seen from Fig.5 that the zero pressure isoline has changed its position in comparison with that observed in Figure 4 with the generation of significantly less negative PWP. It can be seen that much higher pore water pressures build up at the base of layer 1, resulting in ground water flow out of the slope above the interface with the lower permeability layer 2.

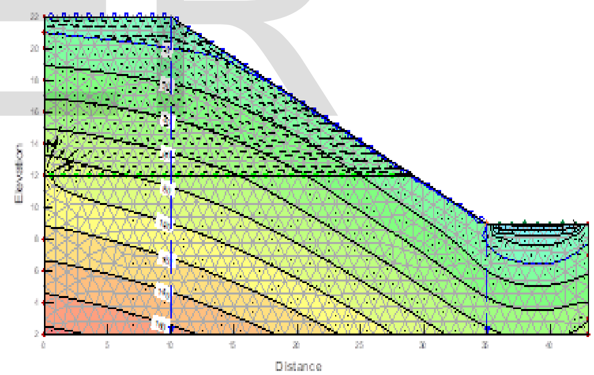


Fig.5. Seepage condition for Scenario 2 (610mm. rainfall for 8 days at an intensity 3.17 mm./hr)

In Scenario 3, the major rainfall (425 mm.) was distributed over 24 hours at 17.70 mm/h, with no antecedent rainfall. The predicted PWP contours are shown in Figure 6. Negative pore water pressures gradually diminish.

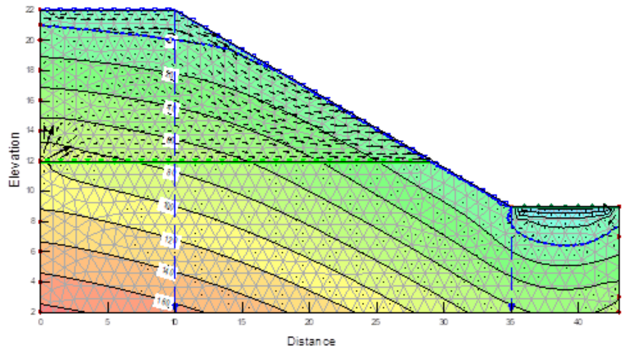


Fig.6. Seepage condition for Scenario 3

3.2 Slope Stability Modeling

The slope stability analyses were carried out to study the different seepage conditions (as predicted by Seep/W) on the factor of safety of the slopes. For the stability analyses, commercial software Slope/W (2007) developed by Geo-slope International Ltd., Canada was used.. Slope stability analyses considering the rain infiltration process were performed using limit equilibrium methods. The Morgenstern-Price method was chosen. PWP profiles generated by Seep/W for each scenario were used to evaluate the stability conditions. The results are shown in Figures 7-10 using rainfall data from 4th to 11th June, 2007. The analysis of initial slope condition before rainfall is shown in Fig.7. The initial factor of safety (Fs) was 1.105. This indicates the slope was marginally stable before raining.

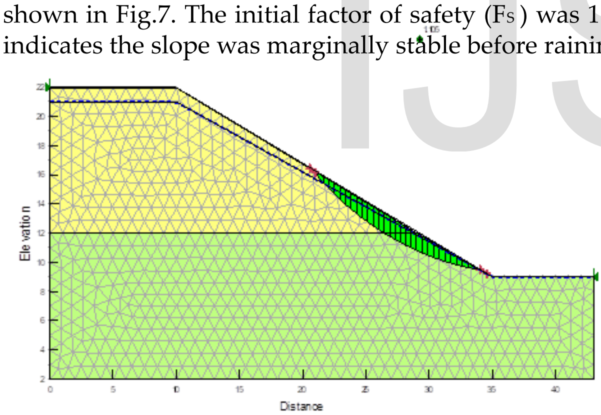


Fig. 7. Initial slope condition with hydrostatic antecedent rainfall
at an intensity 1.10mm/hr.(F_s = 1.105)

In Scenario 1, the antecedent rainfall was distributed over 7 days (168 hours) at an intensity of 1.10 mm../hr. A factor of safety of 0.727 was observed (Fig.8).

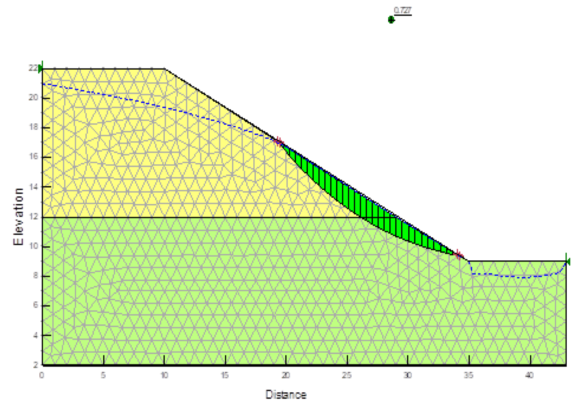


Fig.8. Slope condition for Scenario 1(.(F_s = 0.727)

In Scenario 2, the total amount of rainfall for the whole rainy period (610 mm) was distributed equally over the 8 days. It can be seen from Fig. 9 that the Fs has dropped from initial value 1.105 to 0.380. In Scenario 3, the major rainfall (425 mm.) was distributed over 24 hours at 17.70 mm/h, with no antecedent rainfall. For this condition, the factor of safety was 0.407 (Fig. 10). This clearly shows that the single day major rainstorm is sufficient to induce slope failures.

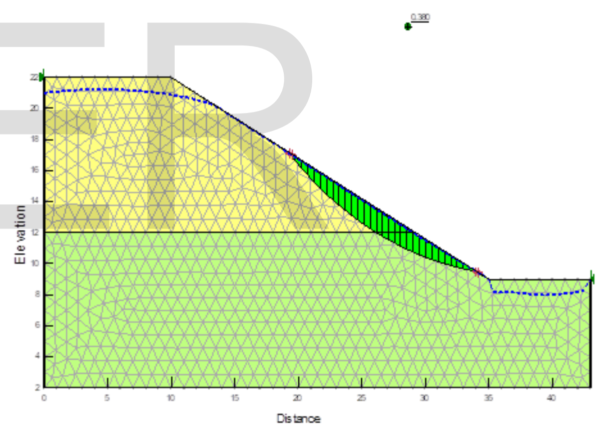


Fig.9. Slope condition for Scenario 2(.(F_s = 0.380)

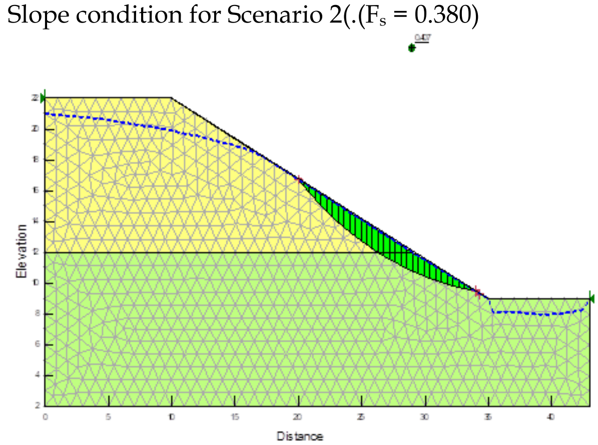


Fig.10. Slope condition for Scenario 3(.(F_s = 0.407)

The change of Fs values with different time steps (4th to 11th June, 8 days) is shown in Fig. 11. It can be clearly seen from Fig.11 how the F_s values change with time.

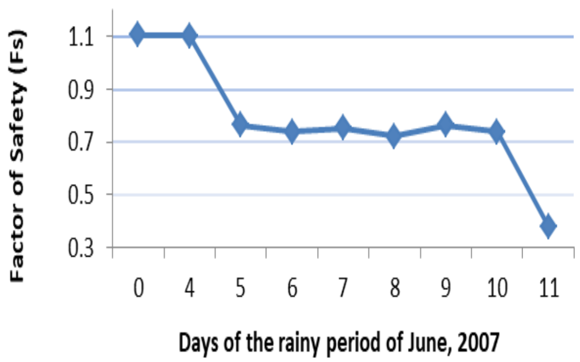


Fig.11 Variation of factor of safety values with different time stepping for 8 days.

From the analyses it is also established that the seven days of antecedent rainfall would reduce the factor of safety from 1.1to 0.76 which might causes some local failures and a further significant drop of factor of safety from 0.746 to 0.38 occurred when the single day major rainfall was applied. The sequence of dropping factor of safety values from initial value 1.105 to 0.380 for 8 days clearly infer that both the antecedent and major rainfall event played role in reducing the stability values to occur landslide hazards in the investigated area. From the presented results, it is clearly observed that changing precipitation pattern & increase in extreme rain events, short term heavy major rainfall and antecedent rainfall during summer monsoon are big challenges for sustainable hill management & development of Bangladesh, Due to recent change of precipitation pattern, risk of landslides can jeopardize the current development. Seepage analyses show that during raining, negative P.W.P.(pore water pressures i.e. .suction) gradually reduced resulting in a loss of strength and increases risk in the hill slopes of Bangladesh. Heavy rain in February, 2019 also destroyed 273 Rohingya shelters in the hilly slopes of Cox's Bazar. In the hills of Chittagong, due to the low permeability of the underlying layer, infiltration was low and P.W.P.. built up in the upper layer. This combined effect helped to move water towards the slope surface & shallow failures occurred which then mobilized into catastrophic debris flows. Mahadi &Hossain (2014) [11] established a rainfall threshold line for the risky slopes of Chittagong hills, Bangladesh. They noted that a rainfall amount of 215 mm. to 450 mm. is sufficient to occur any landlside hazard in the hills of Chittagong and Cox's bazar, which might threaten sustainability. This clearly justify the impotance of establishing an early warning system & monitoring rainfall and landslide hazards in the hills of Bangladesh.

Every year the loss due to slope failures during monsoon is billion dollars including destruction of homes, property and loss of lives. It also comprises destruction of agricultural land used for subsistence and commercial farming and the agricultural produce of the hills ultimately threatening food security of the affected population. In managing slope failures & landslide hazards, the balance between social, economical and environmental aspects is therefore essential for sustainable development of Bangladesh. Analysis of Climate data variability & Geotechnical Modeling can give sustainable solutions to these issues driven hazard problems including soil slope failures & landslide hazards. Sufficient surface drainage facilities including drainage piping need to be installed on slopes to reduce P.W.P. during raining. Retaining wall construction can also help to minimize risks of soil slope failures. Group of bored piles installation can be selected as a suitable solution to control slope hazards in the hilly slopes. Community based motivation approaches are also recommended. From mitigation point of view field Monitoring of soil P.W.P. & soil slope movement with geo-technical instruments.& monitoring is essential. Piezometers that can measure positive and negative pore water pressures, extensometers at the top of the slope., inclinometers and extensometers near the toe of the slope need to be installed and development of early warning system is also essential in addition to the other approaches. To minimize the rainfall induced landslide hazards, these should be taken into account for sustainable development of Bangladesh.

Sustainable development is now a constitutional obligation in Bangladesh. Bangladesh has achieved significant progress in respect of all three pillars of sustainable development, especially the social front. Bangladesh needs more investment on urban facilities development, technology transfer as well as capacity enhancement support towards the goal of sustainable development by managing hazards and disasters. Monsoonal rainwater harvesting system in the hills of Bangladesh is an efficient way to achieve a sustainable source of water. Mathematical and physical model study can give sustainable solutions to these issues driven hazard problems. These need to be considered during national development & hazard and resources management. Finally, from the overall monsoonal rainfall data analysis, it is established that monsoonal rainfall can significantly influence on the factor of safety values in the hilly slopes of Bangladesh and which might threaten the current growth and sustainability of Bangladesh. Establishment of landslide hazard monitoring system in the Chittagong hills can also give sustainable solutions to these issues driven hazard problems.We must have to organize ourselves at all levels to meet the new challenges of the 21st century and to attain sustainable development of Bangladesh.

4 Conclusion

It is clearly established that changing precipitation pattern & increase in extreme rain events, short term heavy rainfall, small amount of rainfall for longer period, intensity of rainfall and antecedent rainfall during summer monsoon are big challenges for sustainable hill management & development of Bangladesh. From the analyses, it is also established that both the antecedent and major rainfall events play an important role in reducing the stability of the slope. The first drop of F_s value might be responsible for local failures and significant dropping of F_s value at the end of rainy period might be responsible for the catastrophic landslide hazards in Chittagong. The seepage analyses results suggest that during raining negative pore water pressures gradually reduced and hence the soil loses its strength. As a result shallow failures might occur in the hills of Chittagong. Drainage provision on the slope, structural measures including retaining wall construction, bio-engineering measures, rain water harvesting in the hills, grass and tree planting, gabion-netting, geo-engineering instrumentation viz. installation of AWS (Automated Weather Station) stations, extensometers, P.W.P. device and installation of low cost real time landslide monitoring equipment in the south eastern folded part of Bangladesh with international technical and research collaborations will certainly help to develop an early warning system in the hilly areas to help the disaster victims by preparing them beforehand and for sustainable development of Bangladesh.

ACKNOWLEDGMENT

The authors wish to thank Durham University, UK for providing softwares and other lab facilities to complete this research work.

REFERENCES

[1] Hossain, A. T. M. S. & Toll. D.G. (2013) Climatic Scenario & Suction controlled Rainfall Induced Landslide Hazards in some Unsaturated Soils of Chittagong, Bangladesh, I3CIA-2013 Conference Proceedings 851-859.SBN: 978-984-33.7884-2.

[2] Karim, M.F., Shawkat, A & Olsen, H.W.(1990) Engineering Geology Of Chittagong city Bangladesh, Report of the Geological Survey of Bangladesh.

[3] Fukuoka, M. (1980) Landslides associated with rainfall. Geotechnical Engineering Journal of Southeast Asia Society of Soil Engineering, 11: 44-72.

[4] Rahardjo, H and Leong, E.C and Gasmo, J.M and Tang, S.K. (1998) Assessment of rainfall effects on stability of residual soil slopes. Proceedings of 2nd International Conference on Unsaturated Soils, Beijing, P.R.China. Vol. 1: 280-285.

[5] Cho, S.E & Lee, S.R. Instability of unsaturated soil slopes due to infiltration. Computers & Geotechnics. 2001, 28: 185-208.

[6] Gasmo, J.M and Rahardjo, H and Leong, E.C. (2000) Infiltration effects on stability of a residual soil slope. Computers & Geotechnics, 26(02).

[7] Toll, D.G. (2001) Rainfall induced landslides in Singapore. Proceedings of the Institute of Civil Engineers, Geotechnical Engineering, 149(4): 211-216.

[8] Tsaparas, I and Rahardjo, H and Toll, D.G and Leong, E.C. (2002) Controlling parameters for rainfall -induced landslides. Computers & Geotechnics. 29(1): 1-27.

[9] Cardinali, M and Galli,M and Guzzetti,F and Ardizzone, F and Reichenbach, P and Bartoccini, P. Rainfall induced landslides in December 2004 in South-Western Umbria, Central Italy: types, extent, damage and risk assessment. Natural Hazards and Earth System Sciences. 2006(6): 237-260.

[10] Geoslope International Ltd (2007) Seep/w for finite element seepage & Slope/W analysis, vol.4.Users Manual. Calgary, Alberta, Canada,

[11] Mahadi, A.A. and Hossain, A.T.M.S.(2014).Climatic Variations and Rainfall Induced Landslide Hazards of Cox's Bazar District,Chittagong, Bangladesh, Bangladesh Geoscience Journal, Vol. 20, pp. 1-18, ISSN 10286845.