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Research paper



Response of Groundwater and Soil Displacement at Slope of Electric Transmission Tower Due to Rainfall Events

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Abstract

Climate change is one of the global challenges that give high impact to the environment and societies nowadays. One of the impacts of climate change is slope failure due to fluctuations in rainfall pattern. This paper aims to investigate the response between groundwater, soil displacement to rainfall and rainfall duration. The study was conducted by site observation at three different locations located under a transmission tower at hilly topography area. All parameters are observed hourly by specified instruments installed in the studied slopes. The study found that rainfall does not cause changes to groundwater and cumulative soil displacement increased proportionally to the amount of rainfall. The analysis extended on determining the correlation between displacement to the amount of received rainfall and rainfall duration by the statistical approach and the predictive variability is 91%. The mathematical equation expressed by this study could be used in predicting soil displacement based on rainfall events, the possibility of landslide occurrence or future modelling purposes.

Keywords: *soil displacement; transmission tower; rainfall, slope, monitoring*

1. Introduction

Climate change has become one of the major issues that get into world's attention nowadays as it has affected by the earth temperature system. The wide usage of fossil fuel has increased the carbon dioxide (CO2) into the air. As the amount of CO2 increased, the temperature will increase, and more water will be evaporated from land and sea. This phenomenon causes the atmosphere to hold more moisture and produce more downpours (rainfall). The more moisture the atmosphere holds, the more rainfall will be produced and occasionally lead to heavy rainfall. Jess.F in his article published in 2017 stated that climate change will cause more rainfall in a tropical region [1]. Malaysia is one of the tropical countries that has received an average of 2500mm rainfall yearly. The rainfall pattern in Malaysia is influenced by two Monsoon Seasons, which are Southwest Monsoon (May-September) and Northeast Monsoon (November-March). However, substantial rainfall might occurs during transitional monsoon from April to October [2]. A research done by [3] found that the monsoon rainfall in Asia before the 1970s has fluctuated increment to the climate change (global temperature), while after 1970s they become proportionally correlated. Rainfall is one of the factors that cause a landslide, depending on its amount and occurrence frequency. An overview study on landslides disaster in Malaysia stated that landslides normally occurs during monsoon season which normally involving heavy rainfall and affecting hilly topography areas [4].

Landslide is triggered by rainfall through the changes that occur during penetration of water into the ground. As water seeps through the ground, the pore water pressure will increase and lower the matric suction. The increment of water content consequently will reduce the shear strength between soil particles and this phenomenon will lead to slope failure. Pore water pressure in unsaturated condition is highly depending on the variation of a climatic condition such as evaporation, infiltration and transpiration activity occurs in surroundings. Moreover, the tropical residual soils behave differently from classical saturated soil mechanics as it is normally in an unsaturated condition [5]. The increment of water content into the soil will initiate the increment of groundwater level [6]. However, the effect of rainfall on the groundwater level is also depending on the ability of soil in water absorbent. The objective of this study is to determine the response of groundwater level and soil displacement to rainfall infiltration at three unsaturated slopes located at location A, B, and C.

2. Site Location

The study was conducted at three different slopes (A, B and C) situated in two different states in Peninsula Malaysia, which is Terengganu and Kelantan. Slope A and B are in Terengganu, located between 5^o to 6_o N and 102^o to 103^o E. While, slope C is in Kelantan, located between 5^o to 6^o N and 101^o to 102^o E. The distance between A and B are 850 metres apart, while location C is 124 kilometers away from A and B. Figure 1 shows the location of the study areas and geological properties including fault line. In the geological perspective, all studied locations have Igneous activity intruded by intrusive rock, mainly granite with minor granodiorite as a bedrock. The study areas are in hilly topography, near fault lines and prone to landslide. Historical landslide incident occurred in Peninsula Malaysia has discovered by [7].

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The hard layer in Peninsula Malaysia is normally below 15 meters and for the study areas, it was found at the depth of below 18 meters under the ground. Soil type that cover the top layer of those slopes are sandy SILT, based on borehole and laboratory test. The scenery of the studied slopes as shown in Figure 2 and Figure 3. Slope A and slope C were monitored due to their historical landslide event. While slope B was monitored due to its high elevation and landslide scar that already covered by crops.

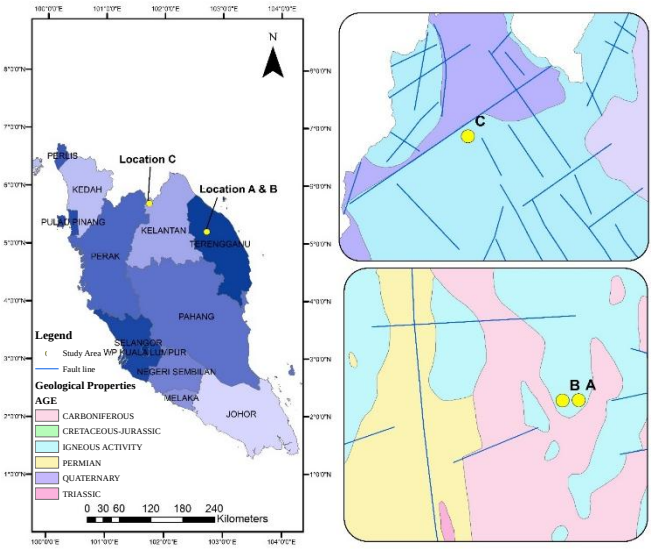


Fig. 1: The study areas, geological properties and fault line

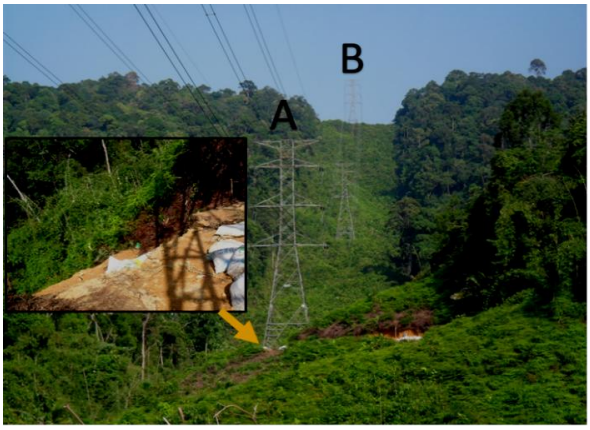


Fig 2: Scenery of location A and B



Fig 3: Scenery of location C

3. Method of Study

Three instruments were used and installed at each studied slope to hourly record the observed parameters. They are rain gauge to monitor the received rainfall, piezometer to record the groundwater level and inclinometer to observe the soil movement. 20 meters boreholes were prepared for each location to place the inclinometer and piezometer. While a data logger system records the data. Those sensors were chosen based on criteria that it can be operated near transmission tower the reading does not affect by an electromagnetic field. Therefore, the usage of tensiometer in monitoring the soil matric suction can't be done since all locations are in a remote area with hilly topography. However, the inclinometer can detect the shrinking or swelling behaviour. This study was using the similar instruments used by [8], except the soil moisture probe, as shown in Figure 4.



Fig. 4: Instruments at site. A: Inclinometer, B: Piezometer, C: Raingauge, D: Data Logger

One cycle (one year) of rainfall data recorded from each site were analyzed to identify the highest monthly received rainfall. The longest duration of rainfall event was chosen from each site to be focused on detecting the response of groundwater and soil displacement towards the amount of rainfall and its duration. This study extended by analyzing one cycle data collected to generate a mathematical function that connects the studied parameters.

4. Result and Discussion

4.1. Received Rainfall at the Study Areas

Location A and B are observed for the period of 12 months. From February 2013 to February 2014 for location A and from September 2014 to September 2015 for location B. Unfortunately, due to a technical issue, location C has only been observed for the period of four months, which is from September to December 2014. Location A recorded the highest monthly received rainfall in June 2013, which is 13,646 mm, while for location B is in December 2014, 1,986 mm. Among the 4 months of observation at Location C, the highest rainfall recorded is 378.4 mm in October 2014.

The occurrence of heavy prolong rainfall occurred in the shortest time was identified for each location, based on the ratio value for cumulative rainfall and rainfall duration. Considering of prolong

rainfall event is to make sure that the soil has received continuous rainfall and to avoid disturbance caused by other factors, such as evapotranspiration, heat by sunlight and negative changes in pore-water pressure. The rainfall event that gives the highest ratio value was chosen for each location as summarized in Table 1 and was studied into detail in determining the relationship between three parameters under study, which are rainfall, groundwater, and displacement.

Table 1: Heavy rainfall event for location A, B & C

Loc.	Highest monthly rainfall (mm/month)	Month occurred	Highest daily Rainfall (mm/day)	Rainfall duration (mins)	Ratio of cumulative rainfall to its duration
A	13,646	June 2013	6691	420	15.93
B	1,986	Dec 2014	556.6	2220	0.25
C	378.4	Oct 2014	57.2	360	0.16

4.2. Response of Groundwater to Received Rainfall

In order to determine the response between rainfall and groundwater, the data was plotted between cumulative rainfall and groundwater level with respect to its rainfall duration, as in Figure 5.

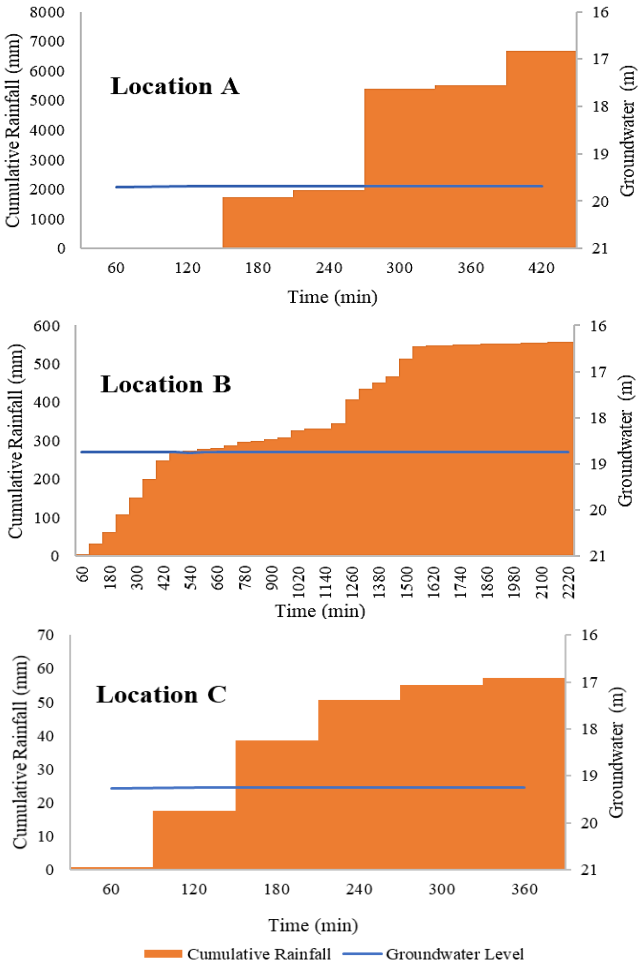


Fig. 5: Cumulative rainfall and groundwater for location A, B and C

The groundwater for location A is at 18 meters, location B is at 19 meters and location C is at 19 meters under the ground. The study found that the changes in groundwater are insignificant to the increment of rainfall. Malaysia has located in Asia, which falls under semi-arid area, who has a deep groundwater table [9]. The soil type at location A, B and C are Sandy SILT. The soil classification was based on the soil profile taken by borehole result conducted at each location. Silt is a fine-grained type of soil which has a low permeability rate due to its small individual pore-spaces. As the pore-space is small, it is very difficult for rainfall to penetrate immediately after rainfall to reach the groundwater level. According to [10], infiltration rate is greatest at the crest of a slope and higher at the beginning of the rainfall event. [11] stated that unsaturated soil with low permeability might delay the rising of the water table. This is due to the longer time taken for pore-water pressure to be equalized. For fine-grained soil such as at all studied locations, slope failure might not occur during or immediately after prolonged rainfall. However, the possibility of landslide occurrence might be some time after the end of rainfall, as explained in [12].

Since the groundwater level is very deep and does not increase even to one meter during heavy rainfall, the possibility of landslide occurrence due to arising of the water table is impossible. Moreover, the is none of the research prove that water table rise significantly and trigger shallow failure and most of the landslide occurs above the groundwater table that usually one to three meters from the surface. [12]. Hence, for these study areas, the possibility of landslide occurrence due to an increment of the groundwater table was not expected. However, landslide occurrence due to volume increment in a perched water table formed by antecedent rainfall is expected.

4.3. Response of Soil Displacement to Received Rainfall

The response of soil displacement to the received rainfall is shown in Figure 6. The displacement was taken from a summation of displacement occurred at all six sensors along the inclinometer for every 60 minutes (one displacement value for every hour). Soil layer above the groundwater level considered unsaturated and this layer is originally in negative pore-water pressure. When rainfall water seeps into the soil, the soil getting wetter and negative pore-water pressure will change towards the positive side. Changing in pore-water pressure will reduce matric suction, reduce shear strength and increase the soil volume.

Referring to the graphs, the cumulative displacement increased gradually as rainfall increased, for each location. The increment of displacement indicates that the soil has swelling behavior. Detail on the swelling and shrinking behavior recorded by inclinometer has been discussed in detail in [13]. According to [14], during the wetting process, which is when prolong rainfall occurred and more water added into the soil, the pore-water pressure will remain constant. Then, it will increase sharply and finally increase gradually and becomes saturated. The sharp increase can be clearly seen at Location A in Figure 10 from 180 minutes to 300 minutes. The rapid changes might also have affected by moisture condition from antecedent rainfall as these rainfall events were taken from the highest monthly received rainfall.

4.4. Statistical Estimation of the Soil Displacement

Statistical analysis was performed to estimate response of displacement of soil at the slope to amount of received rainfall and rainfall duration. Along a year of data recording there are about 340 rainfall events. The cumulative rainfall (*CR*) and the rainfall duration (*RD*) were taken as variables for deriving estimation cumulative displacement (*CD*) of the soil. In this analysis, the soil displacement represents by the cumulative displacement for each rainfall events. This paper presents only derivation of nonlinear model using data from site location A.

The descriptive statistic of the data is as in Table 2. The maximum rainfall duration recorded is 3060 minutes. The distribution of amount of received rainfall is shown in Figure 7, where it is shown that the longest duration of rainfall event was not a heavy rainfall. The maximum amount of received rainfall was recorded

more than 6000 mm in a quite short duration. This rainfall event was rarely happened.

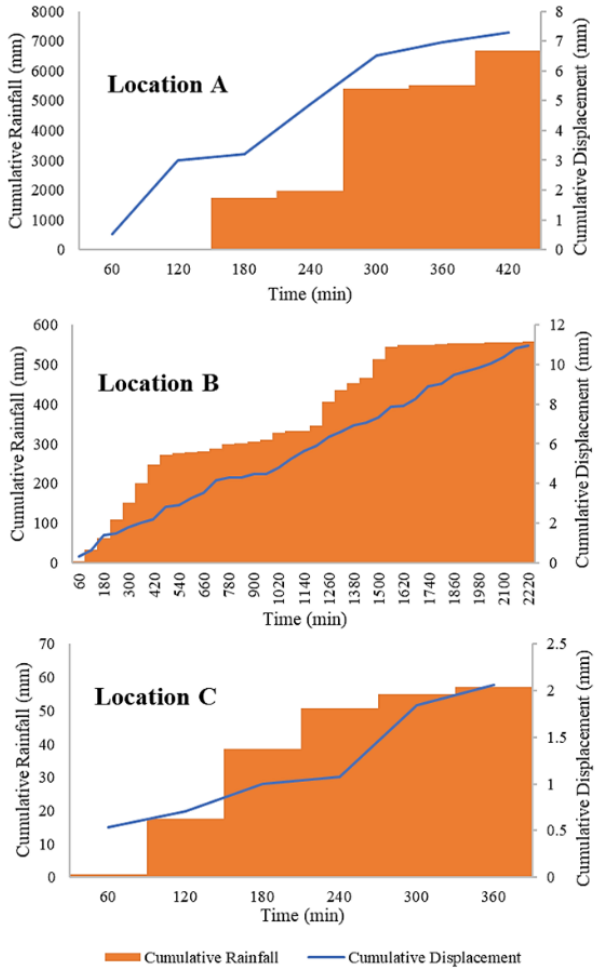


Fig. 6: Cumulative rainfall and cumulative displacement for location A, B and C

Table 2: Heavy rainfall event for location A

Variable	Valid N	Mean	Min	Max	Std.Dev.
Rainfall Duration	341	167.86	60.00	3060.00	294.46
Cumulative Rainfall	341	55.46	0.20	6691.20	441.33
Cumulative Displacement	341	5.094	0.017	98.252	9.295

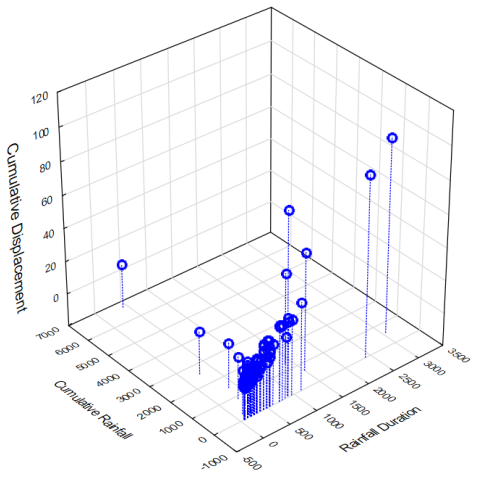


Fig. 7: 3D scatter plot of 3 variables of rainfall duration, cumulative rainfall and cumulative displacement

The correlation between *CD* and *RD* gives a good linear correlation where else *CR* expected to be a nonlinear correlation. Figure 8 shows the matrix of scatter plot between the variables. A transformation function is required to improve the estimation. A fixed nonlinear regression is conducted to derive the estimation equation using transforming equations. The *CR* gives correlation value, r = 0.905 in a linear form and the *CR* gives highest r = 0.523 in log normal form.

The derived equation of nonlinear regression for estimating the cumulative displacement induced by the rainfall is based on result of analysis in Table 3. The equation can be writes as in (1).

$$CD = 0.9856RD - 0.0596\ logCR - 0.0935 \quad (1)$$

After the nonlinear transform, the model fits the data better, with roughly 91% of the variability in prediction of the cumulative displacement (*CD*) as shown in the value of the adjusted R^2. The scatter plot of the observed values and the predicted values is shown in Figure 9.

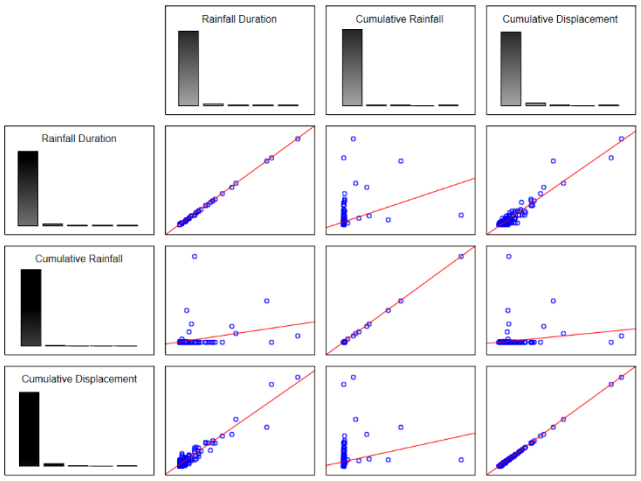


Fig.8: Matrix correlation of 3 variables of rainfall duration, cumulative rainfall and cumulative displacement

Table 3: Nonlinear regression summary for *CD*

N = 341	Regression Summary for Dependent Variable: *CD* R = 0.95162705; R² = 0.90559403; Adjusted R² = 0.90503542 p<0.0000 Std.Error of estimate: 2.8644				
	b*	Std.Err.	b	Std.Err.	p-value
Intercept			-0.0935	0.1863	0.6159
RD	0.9856	0.0207	0.0311	0.0007	0.0000
ln*CR*	-0.0596	0.0207	-0.2837	0.0987	0.0043

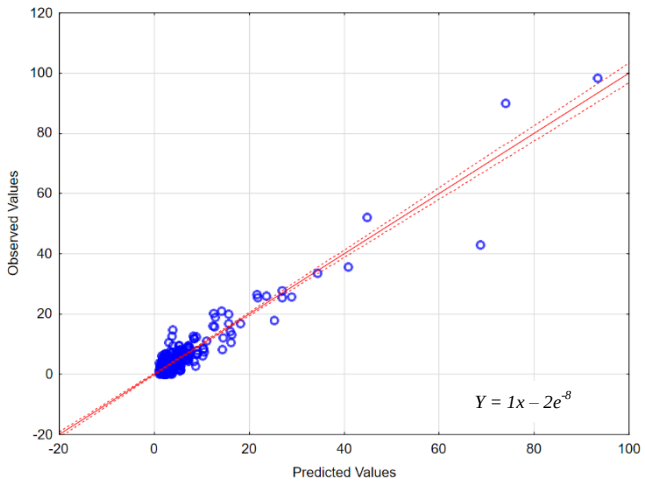


Fig. 9: Scatter plot of predicted values and observed values

5. Conclusion

The response of groundwater and displacement to the rainfall was analysed and the study discovered that the groundwater does not affect by rainfall event, while cumulative displacement increased as the rainfall amount increase. The highest rainfall event was taken from the month with the highest rainfall recorded. The proportional increment in displacement towards rainfall events might be due to additional effect caused by forming of perched water comes from antecedent rainfall events. The analysis continued to find the correlation between displacement, rainfall, and its duration. The correlation value of 91% was obtained after a transformation function was applied to improve the estimation. The relationship functions produced by this study can be used in further prediction analysis.

Acknowledgement

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