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Effect of Rainfall to the Groundwater and Soil Displacement

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Abstract

Malaysia is located in Southeast Asia which received various rainfalls including heavy rainfall during Monsoon season with average yearly rainfall of 2500 millimeters. This paper presented the changes of groundwater and soil displacement affected by the various amount of rainfall at a slope under a transmission tower (pylon) which indirectly monitor the stability of the transmission tower itself. Three instruments are installed to observe the parameters under study which are rainfall, groundwater and soil displacement. Three years of hourly data are analyzed and observed during the dry and wet season. The study found that the fluctuated heavy rainfall has given no significant changes to the groundwater and displacement. However, the 15 hours of prolong rainfall has given significant effect as the groundwater increase 25 mm and soil displaced 12.65 mm. Besides, the groundwater is decreased about 2 mm during early morning to afternoon due to existing of transpiration activity done by vegetation and big trees near the slope. The shrink-swell behavior is highly affected by the sandy clayey SILT type of soil and occurred all day long depending on the amount of water stored and release gathered from rainfall and present of dew from its surroundings.

Keywords: Displacement, groundwater, rainfall, slope, monitoring

I. INTRODUCTION

Landslide is a type of natural disaster that occurs more frequently nowadays. The occurrences do not only affect the environment, but also causes loss of lives, higher goods expenses, limited supply of daily necessities, and etc. Hazardous slope requires extra level of monitoring due to the risk impact it caused on the ecosystem. It becomes riskier when the occurrence happened nearby transmission power lines. In the early ‘70s, landslide prone area was not a major concern for transmission tower construction. However, after many years, landslide became one of the major influences for transmission line construction. This incident would occur due to geological, morphological, physical or hydrogeological factors.

Rainfall is one of the hydrogeological factors that give the most impact to landslide occurrence. The study on the effect of rainfall intensity on slope instability was investigated by [1]–[5]. The study extended and focused on detail for unsaturated and saturated slope by [6]–[8]. Fluctuations of rainfall patterns will affect the flux boundary condition of the ground surface. This is due to the condition of water pressure which is highly pretentious by infiltration and evapotranspiration [5]. A permeability of the soil plays a role in the instability as the permeability indicates the capacity of the soil to allow water to pass through. However, not all unsaturated slope is critical due to rainfall pattern. [9].

This paper presented the changes of groundwater and soil displacement affected by a various amount of rainfall on an unsaturated slope for three years of observation at a studied slope located under a transmission tower (pylon).

II. STUDY AREA

The location of the study area was chosen based on three main criterions suitable for implementation of real time slope and structure monitoring technique. Those criterions considered for the study area includes limited site access which is only accessible by jungle trekking or a helicopter rather than 4WD vehicles. The site also has to be in landslide prone area with slope failure history. Fig.1 shows the location of the studied slope on the Landslide Hazard Map of Peninsula Malaysia. On top of that, in order to make the monitoring implementation worthwhile, the existing tower location should have no plan for relocation in the future. After investigating some possible towers, a particular transmission tower (pylon) which was built on a slope that has a landslide history is identified, which is located at 30 kilometres ahead from Tasik Kenyir (Kenyir Lake) main entrance. The landslide occurred closer to one of the transmission tower leg and there is no possible location near the tower that is suitable for tower relocation if the slope failed. Furthermore, the distance between access road to the site is 2 km by jungle trekking that will take around 2 to 3 hours, depending on the thick vegetation along the track. Therefore, the monitoring work will be more worthwhile and meaningful. This study is focused on a small-scale slope due to its importance in supporting transmission tower structure.

Fig.2 shows the terrain model and location of the studied slope, which is located in hilly topography, while Fig.3 shows the type of land use covering the nearby area. The scenery of the study area is clearly shown in Fig.3 and Fig.4, where the area is covered by various types of crops, including big trees nearby the slope. Knowing the land use information is very important as the type of vegetation affected the soil moisture by its transpiration activities. Different vegetation such as trees, bushes, and grasses give different wetted zone to the soil.

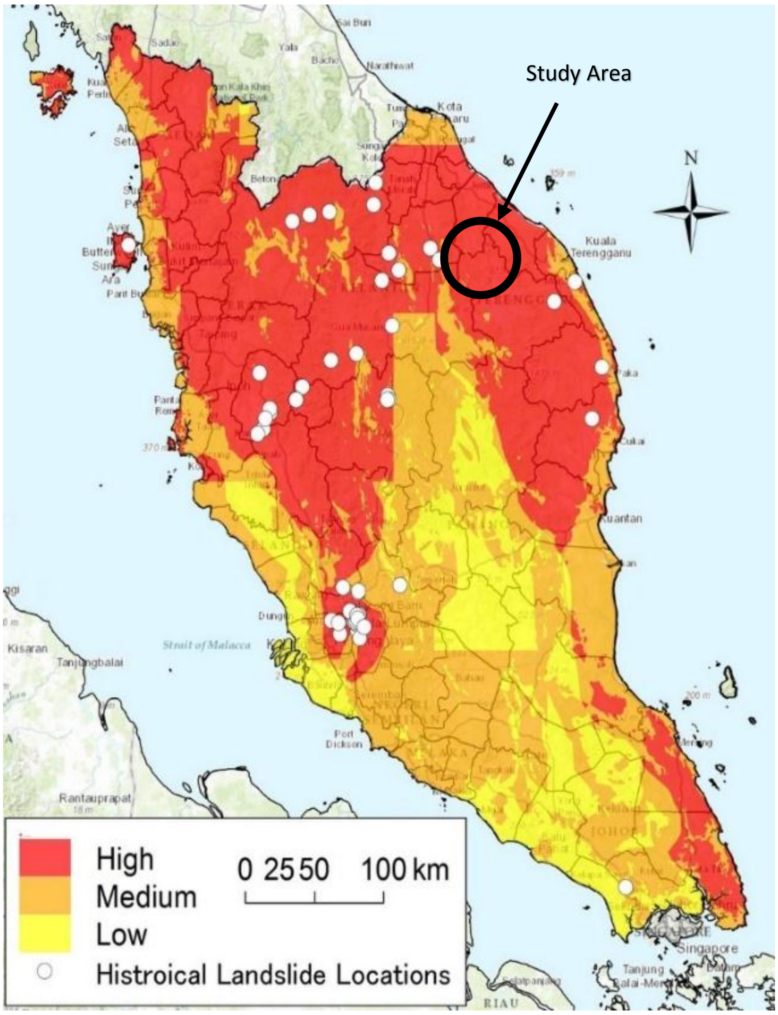

Fig.1: Landslide Hazard Map for Peninsula Malaysia [10]

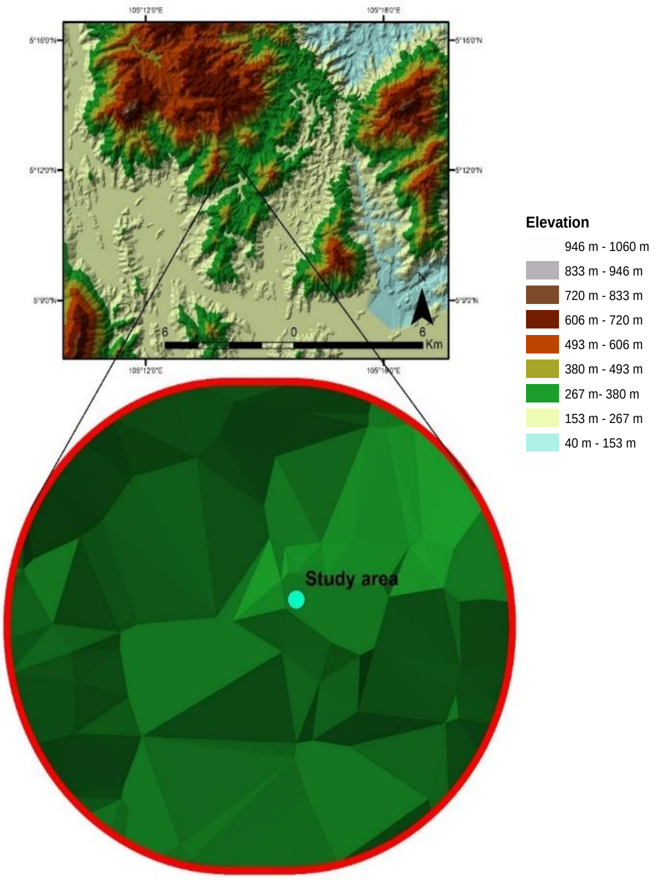

Fig.2: Digital elevation terrain model for the studied slope

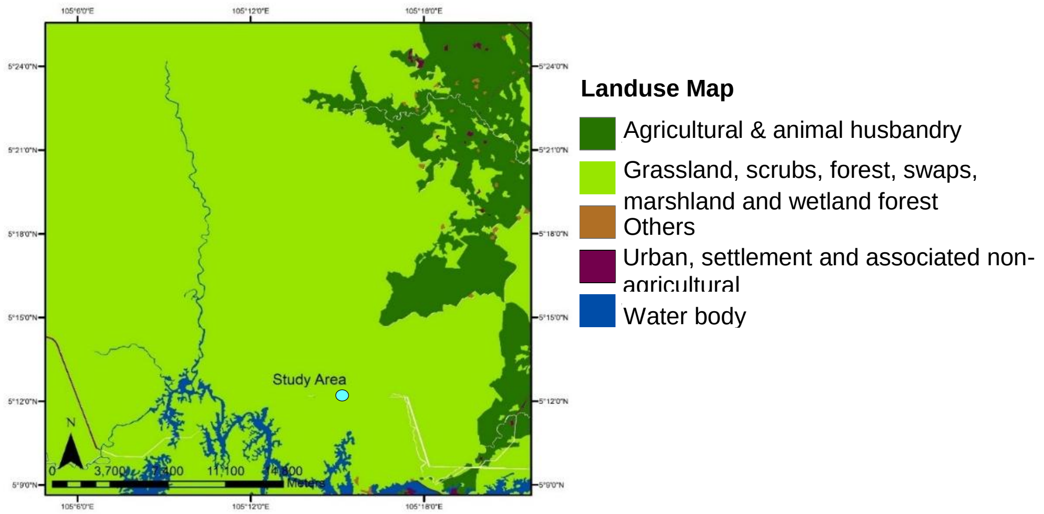

Fig.3: Landuse map of the studied slope

III. METHODOLOGY

In order to address the possibility of landslide occurrence, multiple sensors are utilised to monitor the received rainfall, groundwater level and displacement of the slope. Four types of sensors are installed at the area of study. They are tipping bucket rain gauge to record the amount of received rainfall, Vibrating wire piezometer to measure the groundwater level and In-place-Inclinometer (IPI) to detect the changes of swelling and shrinking in the slope [11], [12] [11]–[13]. Those data are recorded on an hourly basis and connected to a data logger for recording purposes. The inclinometer and piezometer are installed at the depth of 20m on the slope. The inclinometer is completed with sensors for every 3 meters, which is fitted with a pair of pivoted sprung wheels. When ground movement occurs, it displaces the inclinometer access tubing, causing the change in the tilt of the in-place inclinometer sensors. This results in change in output of the sensors, proportional to the tilt. The details on the sensors methodology used in this study was explained in [14]. The location of all sensors as shown in the aerial photo taken by a drone, as in Fig.4. In order to avoid inaccurate rainfall readings, the rain gauge is installed at a small bared area, 20 meters away from the piezometer and inclinometer due to the large trees covering the area near the slope. Moreover, in order to avoid electrocution under the power line, all sensors are located within clearance 3 meters away from the cross arm, which is a standard operating procedure to conduct any work under the transmission power line.

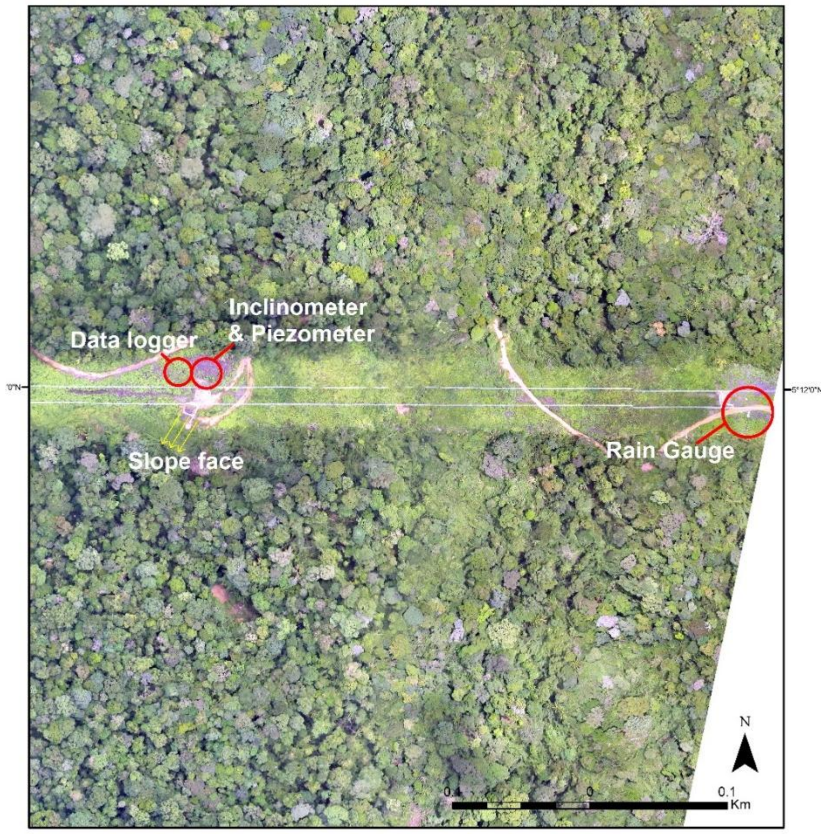

Fig.4: Location of instruments installed near the studied slope

IV. DISCUSSION

IV.I Displacement response to rainfall infiltration

Fig.5 shows the graph of rainfall and displacement pattern for three cycles of observation, based on data collected for every 30minutes starting 1st June 2012 to 10th June 2015. Along these three cycles, the normal rainfall for the study area tabulated below 200mm/h, while the highest rainfall recorded was in June 2013, which is 3427 mm/h, However, two heavy rainfall also recorded on November 2012 and February 2013, which are 491.8 mm/h and 919 mm/h. In 2013, Malaysia was experienced unusually heavy rainfall during yearly Monsoon transition on April to June. A prolong rainfall was recorded in August to December 2014 and cause big flooding in East coast area of Peninsula Malaysia on 26 December 2014.

Referring to the displacement pattern, the soil behaves in positive and negative direction, which indicates shrinking and swelling behaviour, occurred daily. This behaviour is known as "shrink-swell" behaviour. It can be clearly seen that the normal range of shrink-swell is ranging from +10mm to -10mm, respectively. After the graph is plotted, maximum points of swelling were identified in order to identify the data relevancy. This process is important due to the location of the studied slope as it is located in a jungle that has wild animals, especially elephant. Sudden swelling movement with no rainfall which recorded between 7 pm to 5 am is considered happened due to elephant activity on or near the inclinometer. From the graph, swelling due to animal activity is found two times which is on 10 October 2012 (3:30 am) and 26 September 2013 (22:30 pm). Except no rainfall, the occurrence gap is a good indicator to ignore the swelling reading because the normal cycle for an animal to come back to the same place in completing their common track cycle is between nine to twelve months.

During prolong rainfall in 2014, the soil response to unusual shrinking and swelling range. However, the physical observation found that there were no landslide or sign of landslide detected on the studied slope, except a crack on its surface. This behaviour indicates that the soil contains expansive clay minerals, that is good in water absorbent. As this mineral absorb water, it will swell and the volume will increase. This occurrence will lead the soil to swell when it is wet and shrink when it is dry. Nevertheless, this "shrink-swell" behaviour affected by water content normally occurs in 3m depth from the ground surface. If the activity occurred in the depth of more than 3m, it is influencing by the presence of tree roots in the surroundings. The clay grain size also contributes to the absorbent ability. The finer the grain size, the more quantity of water can be absorbed. When the soil is wet (more water is absorbed), it becomes sticky and when it is dry, it becomes very hard and causes shrinking. The process of shrinking in the soil can be physically detected by observing the existing of crack on the ground surface. Soil with this behaviour can be severe if it has supporting structures [15].

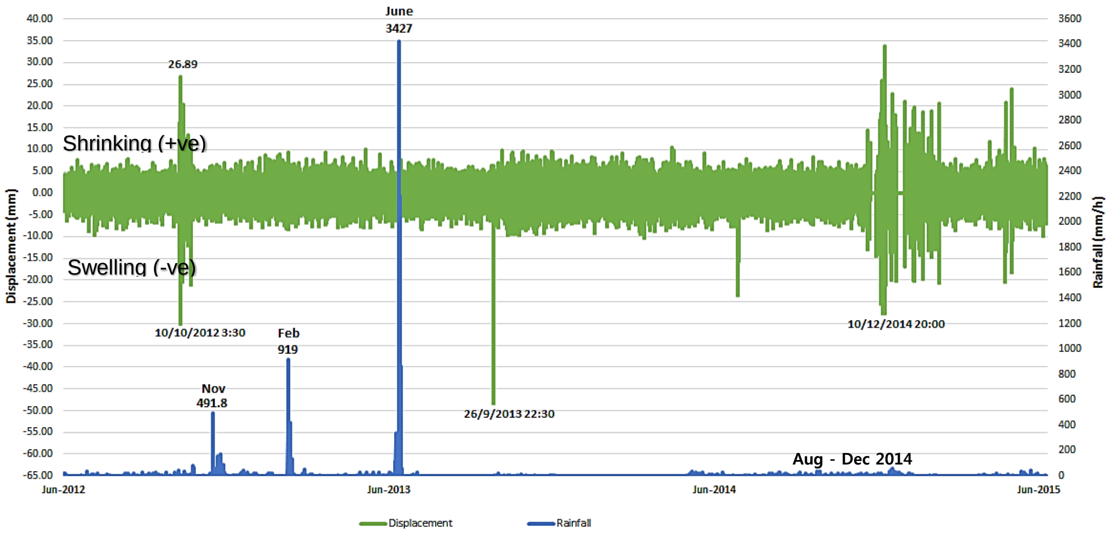

Fig.5: Rainfall and displacement pattern for 3 cycles of observation

Since the shrink-swell behaviour is affected by water, the behaviour is observed to determine the difference between two conditions, which is during wet and dry. This is to investigate on the shrink-swell range in a day. Therefore, inclinometer position is plotted based on its sensor locations, which are at 3 m, 6 m, 9 m, 15 m and 18 m. The negative side indicates swelling movement, while positive side indicates shrinking movement. Fig.6 shows the inclinometer pattern plotted for the minimum, maximum and average reading, during the day with no received rainfall (dry) and during the highest received rainfall (wet), 8034.8 mm/day. The pattern shows that the shrink-swell range during heavy rainfall is wider and inconsistent compared to during no rainfall. While during no rainfall (Fig.2(a)), the soil is still experienced its shrink-swell from the ground level, until 6-meter depth. Soil at this depth shows their ability to absorb and release water, rapidly. This happened due to the response of crops and trees in changing the soil suction which affected by rainfall, evaporation, transpiration and present of dew during night time.

Fig.7 illustrates the range of shrink-swell activity at all sensor locations, to compare the range for both conditions. Referring to Fig.7, the widest range is at 6-meter depth, with 7.42 mm in dry condition and 12.65 mm in wet condition. However, at the depth of 9 meters until 18 meters, the shrink-swell range during dry and wet show very significant changes, varies from 6 mm to 7 mm. This phenomenon indicates that soils at that depth are very good in absorbing water, compared to the upper side of the studied -slope. As the maximum groundwater level is at 16-meter, soils near the water level are considered saturated.

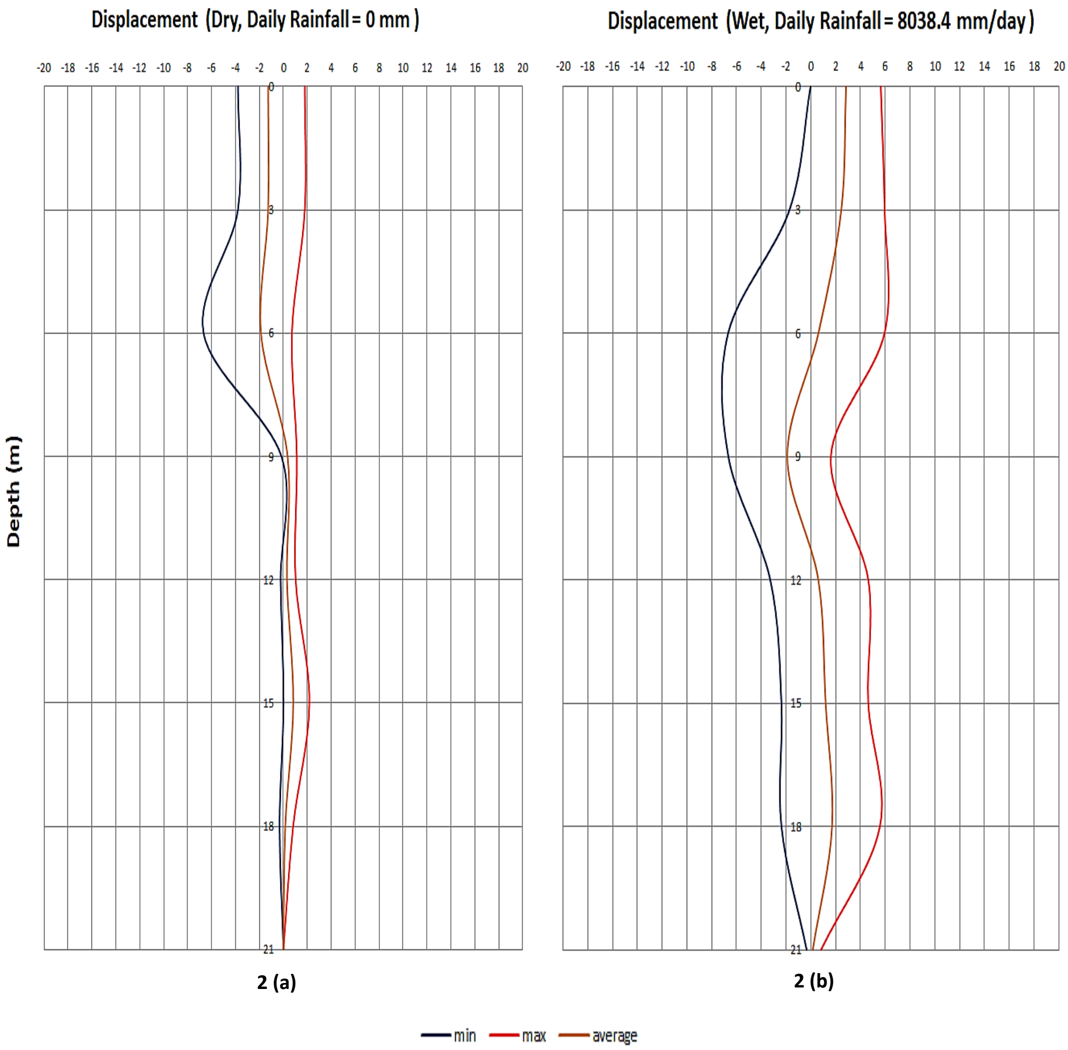

Fig. 6: Minimum, maximum and average position for every inclinometer sensors

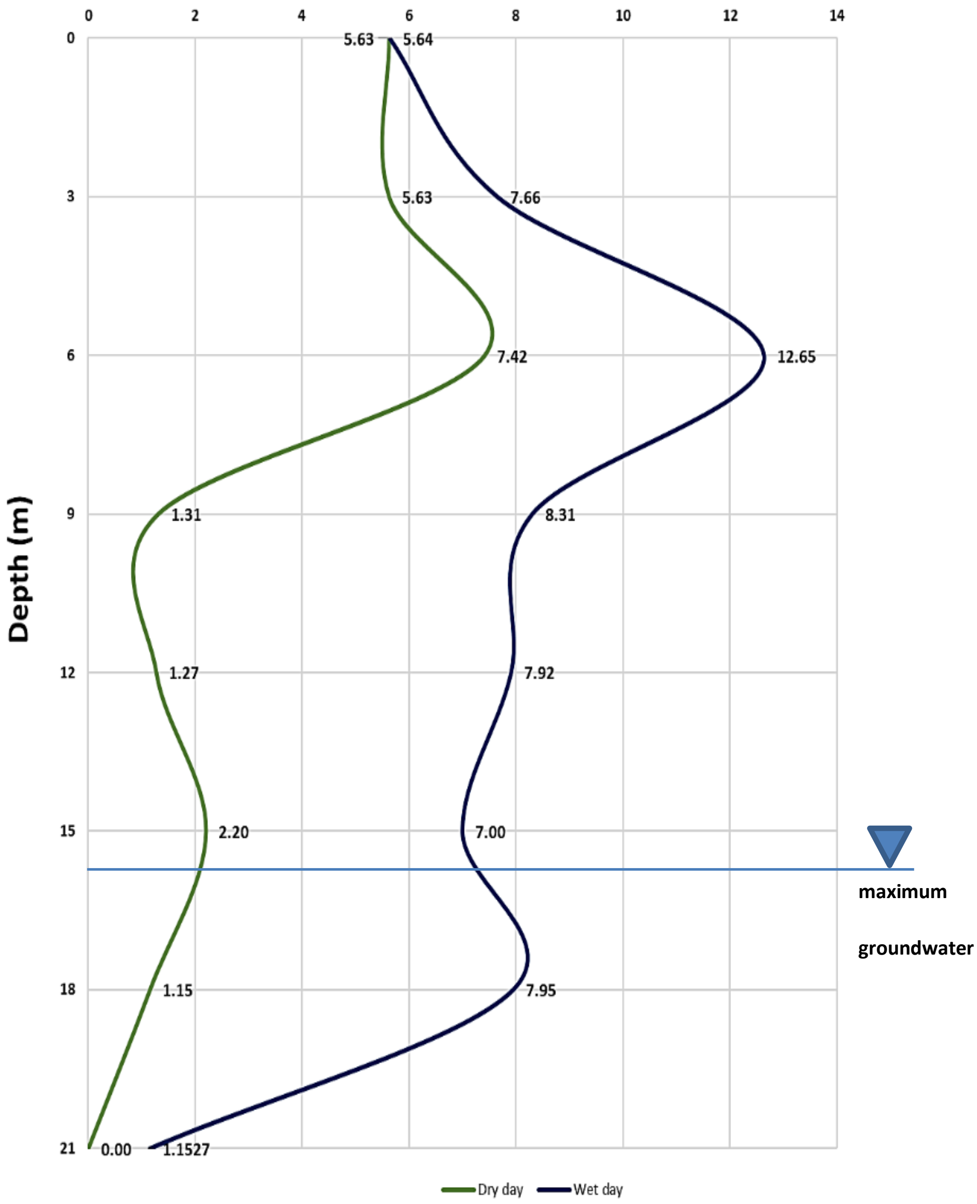

Fig. 7: Comparison of daily range for shrink-swell activity during dry and wet day

IV.II Groundwater response to rainfall infiltration

The groundwater level is recorded by piezometer installed on the studied slope. During installation, the initial groundwater level was at 18 m. During the observation, the piezometer reading is in KPa and it is converted to the meter of water (mH_2O). The graph plotted in Fig.8, shows the response of groundwater to rainfall infiltration for the three cycles of observation. Based on data collected, the groundwater level fluctuated normally in 2 m, which is between 18 m to 16 m, while the highest level is at 15.90 m.

The fluctuation shows that the groundwater affected by the rainfall, but at a very small amount and does not affect sudden changes in the water level. This is due to the response of soil (top layer) to the water, as discussed earlier. As the water already absorbed, only small amount of water is penetrated until it reaches the groundwater. However, it is good to investigate the increment during prolong rainfall. Therefore, one event of prolonging rainfall (marked in red circle) is chosen and plotted in Fig.9.

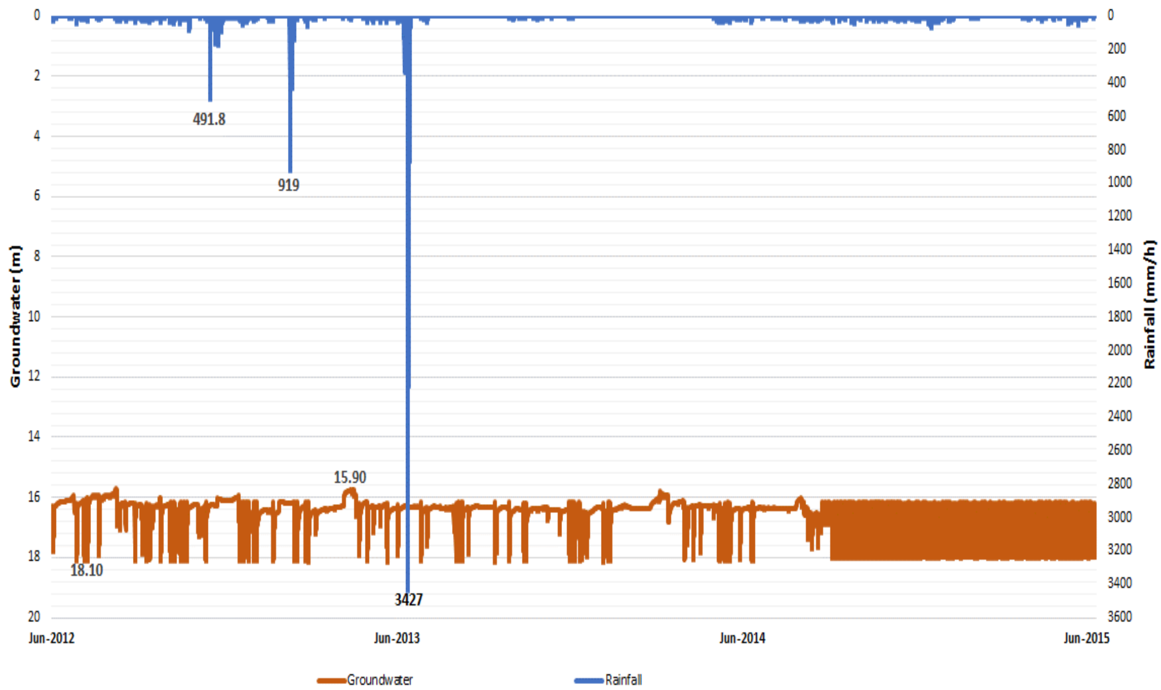

Fig.8: Rainfall and groundwater pattern for 3 cycles of observation

Fig.9 shows the groundwater fluctuation condition during 15 hours of prolong heavy rainfall. The rainfall gives significant effect to the groundwater as the groundwater increase significantly to the amount of rainfall. The increment can be considered as small, since the groundwater fluctuate between 1.8250 m to 1.8275 m, which the changes is at 25 mm. Even though during heavy rainfall, the groundwater suddenly drops about 2 mm starting 5:30 am to 1:00 pm. This occurrence clearly shows that the groundwater is highly affected by evaporation and transpiration activities done by its surroundings.

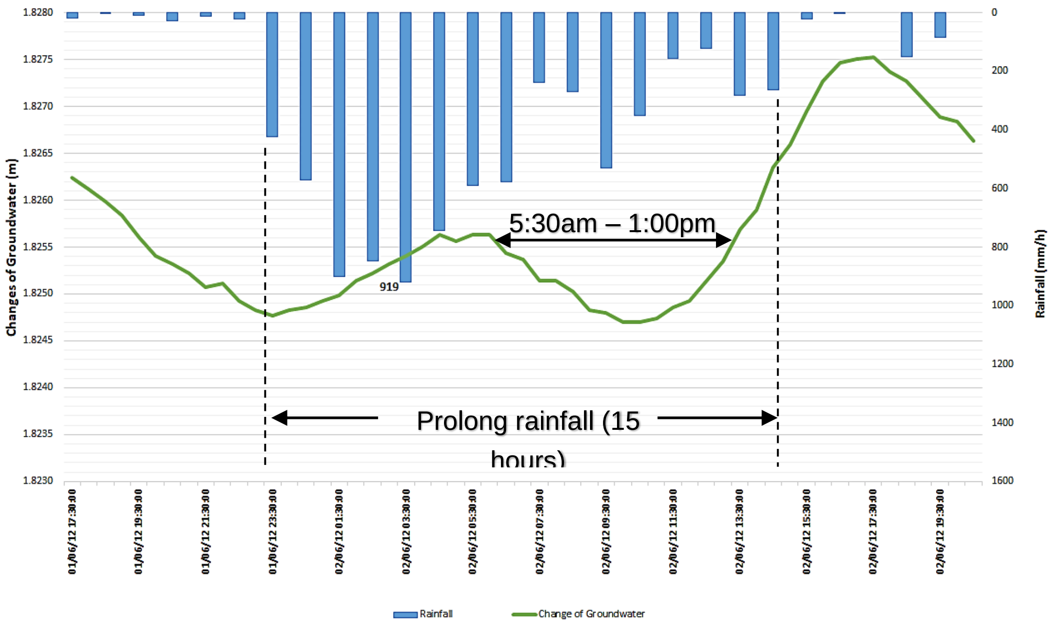

Fig.9: Groundwater fluctuation condition during 15 hours of prolong heavy rainfall

V. CONCLUSION

Three parameters under study which are rainfall, groundwater, and displacement have been monitored by specific sensors for 3 years in order to complete the 3 cycles of site observation. Data collected has been analyzed to identify the response of groundwater and displacement towards received rainfall. The site has experienced fluctuated and prolonged rainfall with the highest rainfall recorded is 3427 mm/h. The fine-grained of sandy clayey SILT makes rainfall slowly seep into the slope and cause shrink-swell activities and fluctuated of groundwater level. Furthermore, the evapotranspiration activities are done by its environment also give effects to the slope behavior. The normal range of shrink-swell is -10mm to +10mm, while the normal range of groundwater is between 16m to 18 m from the ground surface. The shrink-swell behavior occurred differently during the dry and wet season at every depth of the slope. This is caused by the presence of different amount of clay that controls the water absorbent ability. However, possible sliding might occur at the depth of 6 m as the soil is more swell during wet condition.

This method can be applied in monitoring slopes that carry a structure. For future research, it is suggested to compare the response of displacement and groundwater to the amount of rainfall for different types of soil. Moreover, this research can be extended in developing displacement index based on the type of soil and rainfall precipitation, including prediction of its failure possibility.

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