Characterization of Site-Specific Landslide in Port Blair, Andaman and Nicobar Islands using Total Station and 2D Electrical Resistivity Tomography

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Abstract

The Andaman and Nicobar Islands (ANI) of India is well known for its strategic location in the Bay of Bengal, compressional tectonics and is a part of the Southeast Asian plate with frequent seasonal cyclones and rainfall-induced landslides. Rainfall-induced landslides are a natural phenomenon and have become more significant in recent times due to the rapid growth of the population and the development of settlements in and around the steep hillslopes. In addition, these islands are also vulnerable to other natural hazards, i.e., tsunami, storm surges, coastal floods etc. In such cases, the complete reduction of risk is difficult and co-existence with landslides is to be accepted. The capital city, Port Blair, received heavy rainfall and witnessed numerous landslides in and around the city during the great cyclone "Vardha" of 2016. The landslides that occurred during cyclone "Vardha" ranged between minor to moderate, these landslides are yet not to be neglected due to the immense loss caused to properties. Therefore, in our current study, we made a small attempt to characterize and understand a site-specific landslide using ground-based techniques, i.e. Total Station and 2-Dimensional Electrical Resistivity Tomography (2D-ERT), and with field validation. The outcome of the total station survey is presented

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in the form of a topographic profile that revealed the slope angle of the landslide i.e. 30°and the resistivity tomogram shows the presence of a slip surface at 6 meters (approx.) depth along with different lithological structure of the sub-surface, which are very crucial information for landslide hazard assessment on a wider scale.

1. Introduction

Landslides are frequently triggered by various factors, i.e., geological, geotechnical, and climatic (rainfall) (Bogoslovsky and Ogilvy, 1977; Champati Ray and Lakhera, 2004; Aleotti and Chowdhury, 1999; Kannaujiya et al., 2019). The rapid increase in the frequency of landslides has drawn global attention mainly due to their unpredictable nature of damage to human lives and enormous socio-economic impacts throughout the world, especially in developing countries like India. This phenomenon is mostly triggered by earthquakes and heavy rainfall in vulnerable seismic zones and tropical regions respectively (Champati Ray and Lakhera, 2004; Aleotti and Chowdhury, 1999; Kannaujiya et al., 2019). It is pertinent to mention that globally rainfall-induced landslides which occur during a long period of rainfall occupy the top place due to their uncountable damage to lives, the economy, and society. In India, landslides are one of the major destructive natural disasters due to its fragile geo-climatic and topographical arrangements and are covered by ~15% of the geographical area under the landslide hazard-prone area (Sarkar and Kanungo, 2004; Champati Ray and Lakhera,2004; Aleotti and Chowdhury, 1999; Kannaujiya et al., 2019;). The distribution of landslides varies from high to low scale in India i.e., the Himalayan regions, and the Eastern and Western Ghats respectively (Aleotti and Chowdhury, 1999; Kannaujiya et al., 2019; Sarkar and Kanungo, 2004). Besides, the Andaman Islands (ANI) experience frequent landslides due to continuous heavy rainfall for long periods (majorly caused by cyclones) and nonstop deformation due to its geological setup, which needs to be addressed. On 7th December 2016, India witnessed a devastating cyclone called "Vardha". During this cyclone, Port Blair received continuous heavy rainfall for three to four days and triggered minor to moderate landslides, resulting in a huge socio-economic loss. In addition, the rapid growth in population and continuous changes in land use for development activities like tourist hubs and National Security (Defence) dragged more importance and demand to the current study.

In recent decades, several landslides studies have been carried out through a multidisciplinary approach based on various significant parameters like geological, geophysical, geodetic, and meteorological data analysis, including satellite remote sensing to understand landslides characteristics (Kannaujiya et al., 2019; Sarkar and Kanungo, 2004; Yoshimatsu and Abe, 2006; Yalcin et al., 2011; Chandrasekaran et al., 2013; Suzen and Doyuran, 2004; Kritikos and Davies, 2015; Cogan and Gratchev, 2019; Chang and Chiang, 2009; Castellanos and Westen, 2008; Nourani et al., 2014; El Jazouli et al., 2019; Lee et al., 2012). Noteworthy, technological developments in subsurface studies i.e., the geophysical method using Electrical Resistivity Tomography (ERT) (Lapenna et al., 2005; Perrone et al., 2006) and geodetic survey i.e., topography profiling using Total Station (Heritage and Hetherington, 2007; Keaton and Degraff, 1996) were well established and the integration of these techniques play a crucial role in understanding and characterizing the landslides. ERT is the most common, non-invasive and cost-effective method used to study the subsurface characterization through its capability of reading the electrical properties of the subsurface and helps us to identify the slip surface of the site-specific landslide (Kannaujiya et al., 2019; Lapenna et al., 2005). On the other hand, the Total Station survey, which is a combination of theodolite and an Electronic Distance Meter, is a fundamental instrument and is frequently utilized in monitoring landslides due to its accuracy, speed, and minimal human efforts (Heritage and Hetherington, 2007; Keaton and Degraff, 1996). Both these techniques are fundamental and crucial in understanding and characterizing landslides.

In this context, the integration of total station survey and electrical resistivity tomography proved useful to acquire parameters for this study. In our current site-specific study, we employed the ERT and Total Station survey at Kamaraj landslide, to understand and map the topography and to determine the depth cum geometry of the slip surface of the landslide.

2. Study Area and Geology

“Kamaraj landslide” (named after the Kamaraj School), the present investigating site, is located at Brookshabad, Port Blair, in South Andaman. It is bounded by 11°38’15.33” N latitude and 92°44’23.08” E longitude (Figure.1) and is surrounded by human settlements. This area is also situated within the vicinity of several active faults, such as the Carbyn thrust and Bathubasti fault (Dasgupta and Mukhopadhyay, 1993; Curray, 2005; Ortiz and Bilham, 2003; Malik et al., 2006; Bhat et al., 2019) and also receives an annual rainfall of >3000 mm. Most of the landslides in this area took place owing to the steep slopes, which consist of weak materials and high rainfall during the monsoon season. The eastern section of the South Andaman Islands is comprised of extremely distorted rocks (ophiolites from the oceanic floor) which are made up of Cretaceous-early Eocene ultrabasic/pelagic/volcanic deposits together with metamorphic and the western section is covered by Eocene-Oligocene siltstone/flysch-sandstone with conglomerates in combination with Mio-Pliocene calcareous sediments (Dasgupta and Mukhopadhyay,1993; Curray, 2005; Ortiz and Bilham, 2003; Malik et al., 2006).

3. Materials and Methods

In our current study, we employed two techniques i.e., total station and electrical resistivity tomography, for site-specific landslide investigation.

Total station instrument PENTAX-V321 was used for generating the 2D and 3D Topographic profiling (scarp profiling) across the landslide site to measure the slope elevation and angle of the Kamaraj landslide. We generated several profiles across the site and selected the most accurate profiles for further processing. The selected profile of total station data is systematically processed by following standard processing techniques in Surfer software (version 11). In addition, the data is carried through several procedures to generate 2D and 3D topographic sections (Figure.2a & 2b).

Consequently, we also performed the Electrical Resistivity Tomography (ERT) survey along (M- M1) and across (P-P1) the landslide to obtain the subsurface geometry based on their electrical resistivity values (Figure.3). The ERT technique allows us to acquire two dimensional high- resolution images of the subsurface earth materials having inhomogeneous resistivity by combining the capacities of profiling and sounding prospecting procedures for data inversion with the help of cutting-edge algorithms based on the electrical resistivity properties of the subsurface material (Sharma, 1997; Bichler et al., 2004; Meric et al., 2005). In the current study, we adopted the Wenner array configuration for 2D imaging using Aquameter CRM 500 coupled with a multicore cable to obtain information from different depths of landslide subsurface for two profiles. The first profile (M-M1) is parallel and the second (P-P1) is perpendicular to the landslide. The acquired data is methodically processed using Res2D.INV software to produce the

2D resistivity pseudo-section. The Res2D.INV software generates the pseudo section for the calculated model from the inverted model and then utilizes the least square algorithms to decrease the Root Mean Square Error (RMS) (Godio et al., 2006; Loke and Barker, 1996). Then, the resultant ERT images were used to characterize the lithological features and to trace the possible slip surface of the landslide. In addition to that, we also collected field evidence during the cyclone "Vardha" which helped us while interpreting the data (Figure.6).

4. Results and Discussion

4.1 Total Station

The large-scale topographic map has a contour value that varies between 5 meters to 27 meters from the mean sea level across the Kamaraj Landslide (Figure.2a & 2b). Similarly, the slope length and slope angle of the landslide surface are also found from the obtained value of the total station i.e. 47 meters and 30˚, respectively (Table.1). These resultant parameters have an important connection with the landslides.

4.2 2D-ERT Profile M-M1

The acquired Electrical Resistivity Tomography (ERT) with a covered distance of 57 meters along the profile M-M1, which is parallel to the landslide from head (M) to toe (M1) in the North-South direction (Figure.4) usually has a resistivity range that varies from 10.8 to > 133 Ωm. Different colors demarcate the inhomogeneity of the resistivity as per the in situ true resistivity value of subsurface materials. A layer of very low resistivity in the range of 10 to 30 Ωm is detected in the upper and middle part of the profile that extended to a shallow depth of 6 meters from the top of the surface indicating the clay and very loose saturated sediments (layer 'A'). Similarly, another layer having a resistivity range of 30 to 65 Ωm can be noticed on the middle and lower part of the profile that extends up to 4 meters depth from the top of the surface is a possible indication of the depleted landslide masses of unconsolidated sediments and rock fragments with high water content (layer 'B'). In the same way, one more layer (layer 'C') in the deeper part is spotted that shows fractured or weathered ophiolite formation displays increasing values of electrical resistivity (>133 Ωm) which is the potential sign of the parent rock of this site. This profile (M-M1) revealed that the thickness of the overburden material is quite thin (up to 6 meters) and it needs less amount of water to get saturated easily leading to landslides. The vertical extension of overburdened materials at the landslide scarp is having highly saturated unconsolidated sediments that allow water seepage which causes landslides to occur.

4.3 2D-ERT Profile P-P1

The ERT along the P-P1 (Figure.5) that is perpendicular to the landslide direction was conducted on the toe region and it provides better insight into lithology variation with respect to depth and actually, it has a resistivity range from 0.264 to 353 Ωm. Like profile M-M1, a very low resistivity zone is also observed here. In P-P1, the zone of low resistivity is at a greater depth than the M-M1 profile and the thickness of the same is also higher here. There are four lithological layers (i.e. A, B, C, & D) have been demarcated in P-P1 as per their respective resistivity range. Layer “A” is having resistivity value ranging between 0.264 and 40 Ωm that extends from 4 meters to -2 meters downwards, which possibly would be high clay content with water saturated zone due to the influence of heavy leaching activity in this area. Similarly, layer “B” has a resistivity range between 40 and 120 Ωm indicating the presence of loose saturated unconsolidated sediments with sand, which extends from the surface top to around 4.5 meters depth. A small and isolated pocket layer of “C” and “D” with resistivity greater than 120 to ~353Ωm indicates the concrete structure and hard rock block, respectively, which occur from the surface to 2 meters depth.

The Electrical Resistivity Tomography models revealed that in the first profile, M-M1 resistivity generally increases with depth, i.e. over burden clay < loose unconsolidated sediment < fractured or weathered ophiolite formation. In the case of second profile P-P1, the resistivity is decreasing with increasing depth except at isolated and small pockets, which show higher resistivity because of the presence of hard rock and the proximity to a concrete structure that is hard rock > concrete structure > unconsolidated sediment > high clay content. In both profiles, a major part is having clay and loose unconsolidated sediment with sand which is influenced by the heavy leaching condition. During heavy rainfalls, the top soils (loose and unconsolidated sediments) of this area might be highly saturated with water thus the unit weight of the soil might also increase (eg. Vardha cyclone) (Figure.4). As the moisture content simultaneously increases, the weight of the overburdened material would also increase. It increases the shear stress on the weak zone and loose materials, increasing hydrostatic pressure and leading to landslides. In addition to the major Kamaraj Landslide, a few more minor landslides were also triggered by the heavy rainfalls during the cyclone "Vardha" in and around Brookshabad, Port Blair (Figure.7).

5. Conclusion

The integration of 2D Electrical Resistivity Tomography and Total Station survey has utilized on a fresh landslide in Kamaraj Hill, Brookshabad, Port Blair that occurred during cyclone 'Vardha' on 7th December 2016. The key emphasis of this study was on topographical mapping and subsurface characterization along with the identification of possible slip surface by analyzing the data products of total station and electrical resistivity tomography. The total station survey helped collect the topographical information of the Kamaraj landslide on a finer scale where the slope angle was found as 30°. Consequently, the ERT has allowed subsurface characterization and supported the identification of the possible slip surface of the Kamaraj landslide. Multiple ERT profiles were taken but the best one is used to determine the approximate depth of the slip surface, which is expected to be around 6 meters depth. The ERT with a thorough field survey has confirmed the presence of clay in the overburdened materials, which is presumed as the chief contributing factor to the initiation of this landslide. The 2D Electrical Resistivity Tomography integrated with Total Station survey and field observation has proved to be an effective tool for investigating landslides in this area.

Acknowledgments

We are very thankful to Pondicherry University, Port Blair Campus for providing instrumental and institutional support to carry out this study.

Table.1: Slope Information of Kamaraj Landslide acquired by Total Station Survey

Distance in Length (l)	47m
Distance in Height (h)	27m
Slope in Degrees (º)	30˚
Slope in Percentage (%)	55%
Total Distance (t)	57m

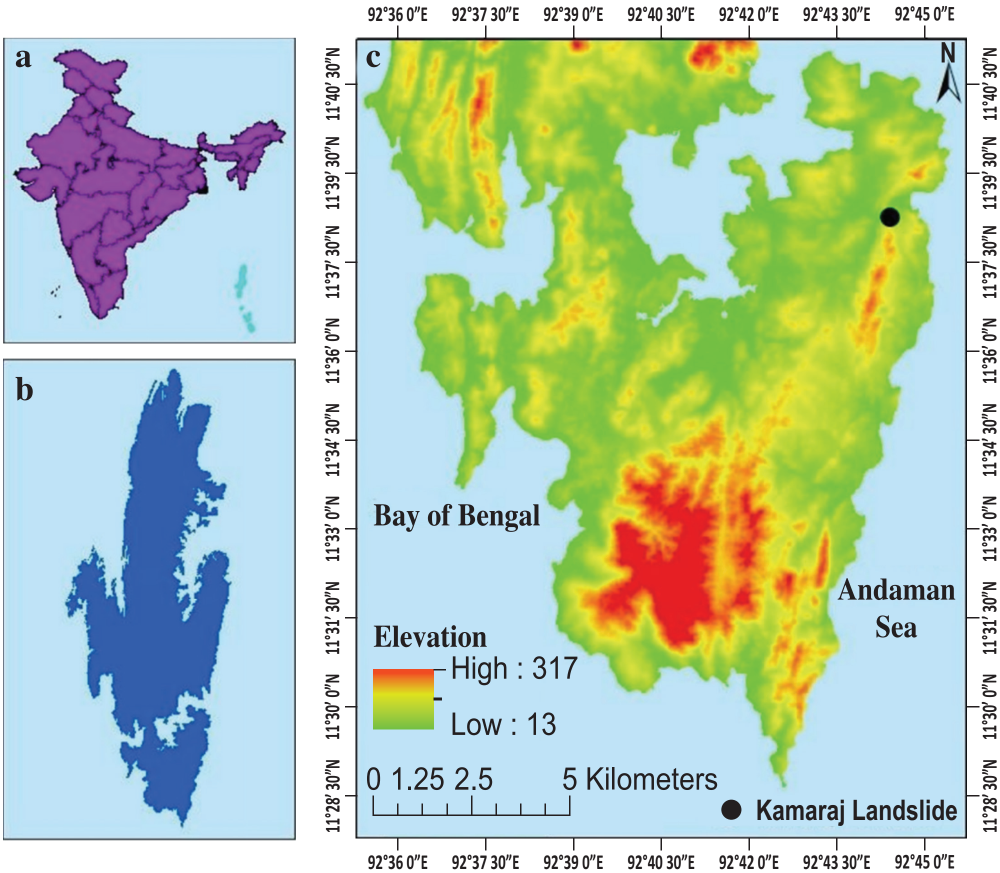

Figure 1 : (a) India (b) Andaman Islands (c) South Andaman Island and the location of Kamaraj Landslide

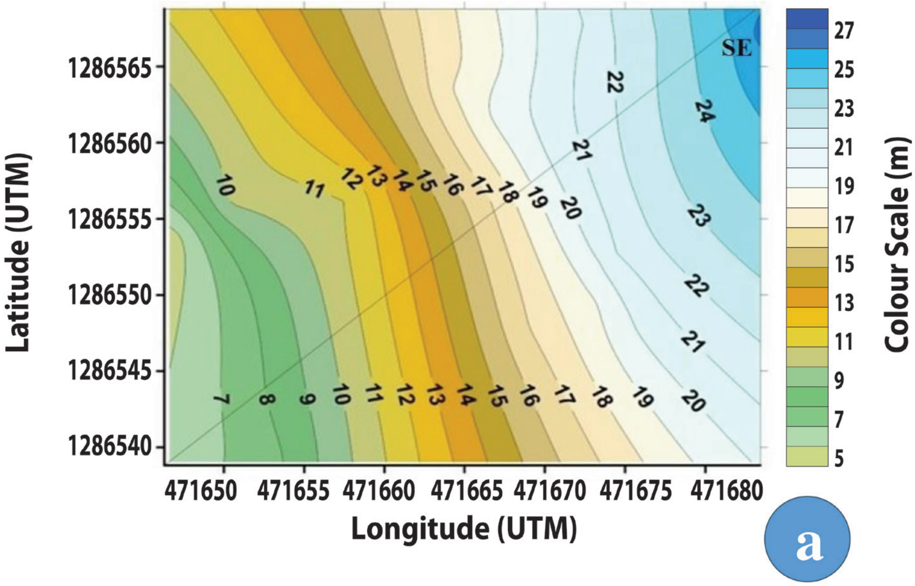

Figure 2 : Large-Scale 3D Topographic Model of the Kamaraj Landslide Surface.

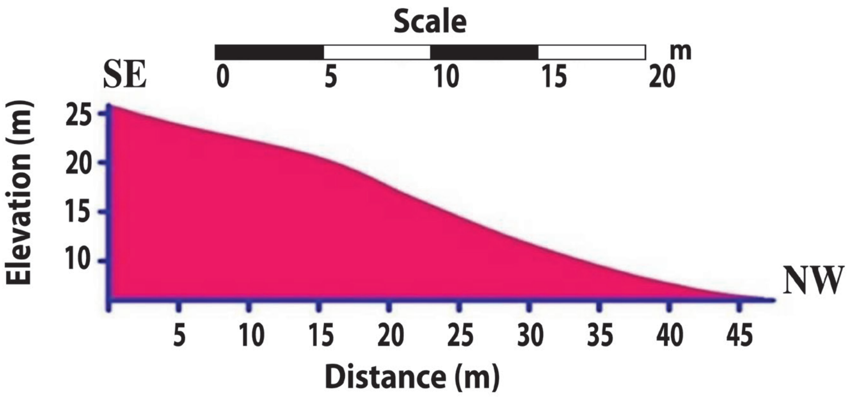

Figure 3 : (a) Large-Scale Topographic Map Prepared using Total Station Measurements with the help of Surfer Software Showing Topography on Large Scale. Identified Elevation of the Kamaraj Landslide Body Varies from 5 to 27 Meters.

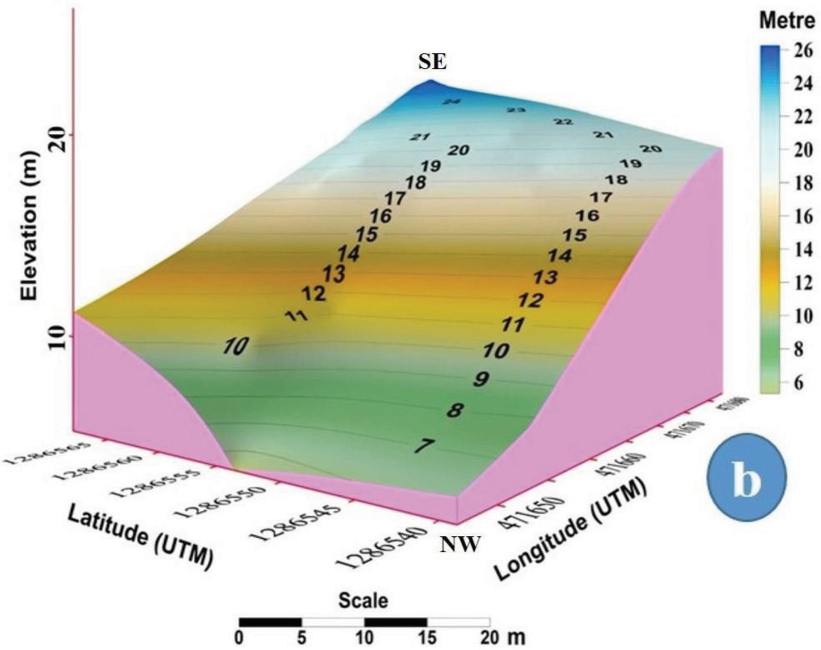

Figure 3 : (b) Large-Scale 3D Topographic Model of the Kamaraj Landslide Surface.

Figure 4 : Kamaraj Landslide at Brookshabad, Port Blair

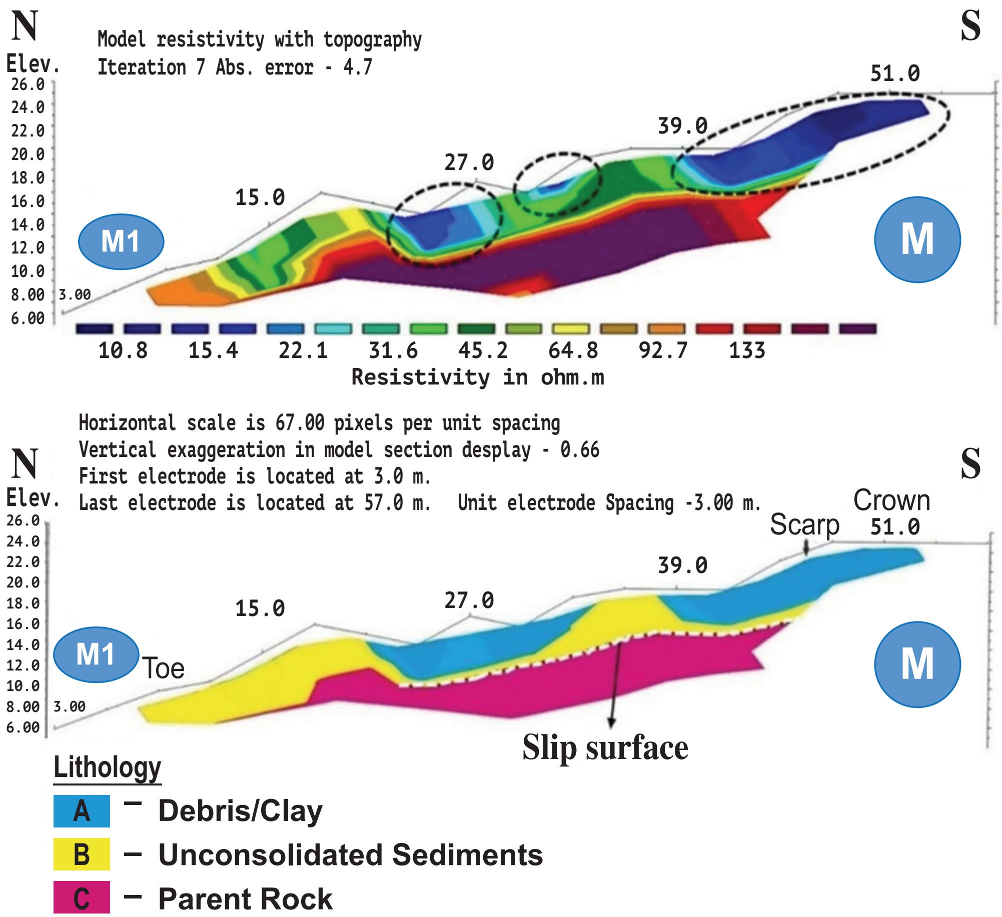

Figure 5 : Depth Section Presenting True Resistivity Values of Subsurface Parallel to the Longitudinal Axis of the Landslide (M-M1 section), Derived through Wenner Array Configuration and produced in Res2D.INV Software. The names have been given to the different layers of Lithology using Corel draw. The Clay/ High Water Saturation was marked by Black Dotted Circles and the Possible Slip Surface was marked by a Dotted White Line.

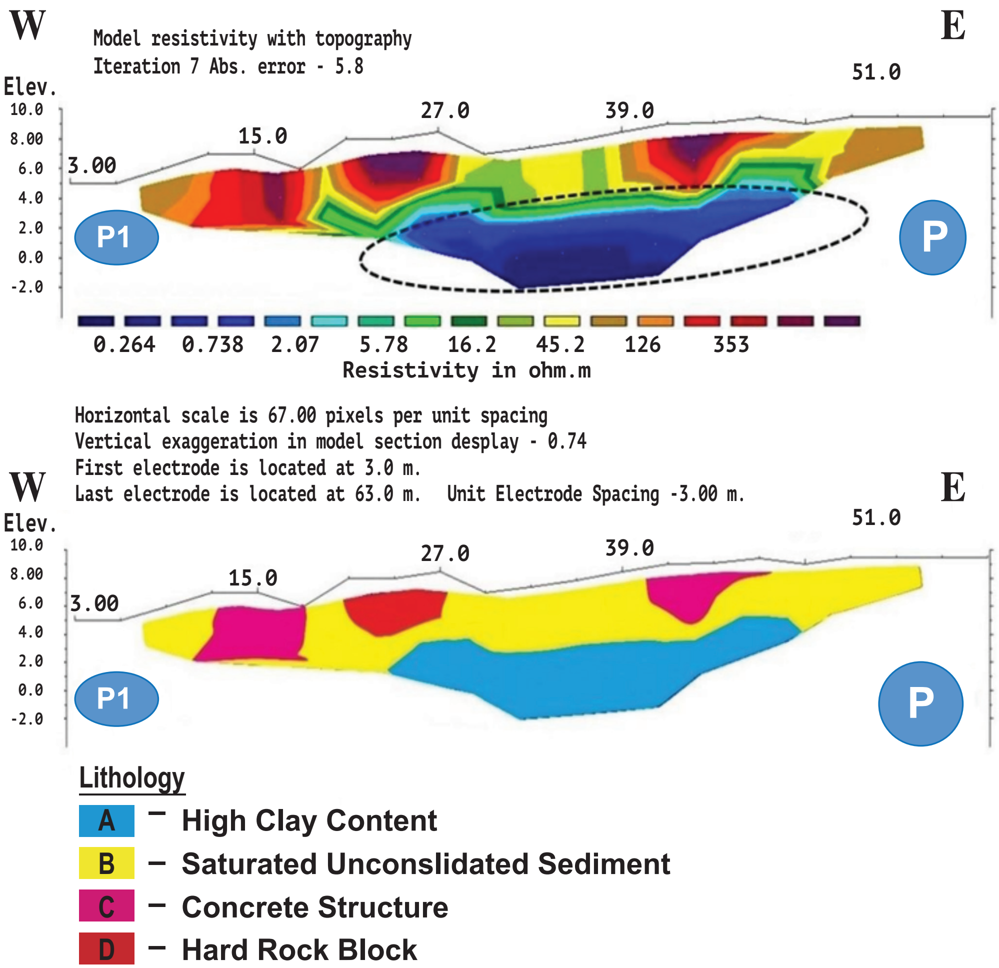

Figure 6 : Depth Section Presenting True Resistivity Values of Subsurface Perpendicular to the Longitudinal Axis of the Landslide (P-P1 Section), Derived through Wenner Array Configuration and Produced in Res2D.INV Software. Corel draw is used for naming the different Lithological Layers. The High Clay content is marked by a Black Dotted Circle.

Figure 7 : Field photo after heavy rain during cyclone 'Vardha' (Photo- Gunda Goutham Krishna Teja)

Figure 8 : Landslide Damage in some other Sites of Brookshabad, Port Blair after Cyclone 'Vardha'

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