



Full length article

Slope failures evaluation and landslides investigation using 2-D resistivity method

M.M. Nordiana*, I.N. Azwin, M.N.M. Nawawi, A.E. Khalil

Geophysics Section, School of Physics, Universiti Sains Malaysia, 11800 USM Penang, Malaysia

ARTICLE INFO

Article history:

Received 1 December 2016

Revised 4 December 2017

Accepted 4 December 2017

Available online 13 December 2017

Keywords:

Slope failure

Landslides

2-D resistivity

Saturated

Boulders

ABSTRACT

Slope failure is a complex phenomenon that may caused to landslides. Buildings and infrastructure such as transportation facilities and pipelines located within the boundaries of a landslide can be damaged or destroyed. Slope failure classification and various factors contributing to the instability using 2-D resistivity survey conducted in Selangor, Malaysia are described. Six 2-D resistivity survey lines with 5 m minimum electrode spacing using Pole-dipole array were performed. The data were processed using Res2Dinv and surfer10 software to evaluate the subsurface characteristics. The 2-D resistivity results show that the subsurface consist of two main zones. The first zone was alluvium or highly weathered with resistivity value of 100–1000 Ω m and depth of >30 m. This zone consists of saturated area with resistivity value of 1–100 Ω m and boulders with resistivity value of 1200–7000 Ω m. The second zone with resistivity value of >7000 Ω m was interpreted as granitic bedrock. The study area was characterized by saturated zones, highly weathered zone, highly contain of sand and boulders that will trigger slope failure in the survey area. This will cause to low strength of soil, debris flow and movement of earth. On the basis of the case examples described, 2-D resistivity method is categorized into desirable and useful method in determination of slope failure and future assessments.

© 2017 Production and hosting by Elsevier B.V. on behalf of National Research Institute of Astronomy and Geophysics. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Landslides and slope failure are always related to hilly areas and restricted essentially to the urban area. Development for tourism and residential is still rampant in these areas. The prevalence of failures is due to a combination of few factors; i.e. topography, climate, geology and land use. Some countries have similar soils but different rainfall patterns, or similar rainfall but different land use. Urban development including used of steep natural slopes for housing and road are potentially caused unstable areas.

The purpose of resistivity survey is to determine the subsurface resistivity distribution by taking measurements on the ground sur-

face. True resistivity of the subsurface can be estimated (Fig. 1). The ground resistivity is related to various geological parameters such as mineral and fluid content, porosity and degree of water saturation in rock. Variations in electrical resistivity may indicate changes in composition, layer or contaminant levels (Telford and Sheriff, 1984).

2. Methodology

Six (6) 2-D resistivity survey lines were conducted in Selangor. Lines RL1-RL3 was conducted towards North-South direction as shown in while RL4-RL6 directed towards West-East (Fig. 2). The length for all the 2-D resistivity survey lines were 200 m except for RL1 and RL4 is 300 m each. RL1 was located outside the collapsed area while RL2-RL6 located in the collapsed area. The protocol used for 2-D resistivity was Pole-dipole with 5 m minimum electrode spacing and the data was processed using Res2Dinv software.

3. Results and discussion

From the 2-D resistivity method, the inversion model resistivity for potential area, RL1 (outside collapsed area) (Fig. 3) shows there are 2 main zones. The first zone is alluvium or highly weathered

* Corresponding author.

E-mail addresses: mmnordiana@usm.my (M.M. Nordiana), nurazwinismail@usm.my (I.N. Azwin), mnawawi@usm.my (M.N.M. Nawawi), amin_khalil@usm.my (A.E. Khalil).

Peer review under responsibility of National Research Institute of Astronomy and Geophysics.



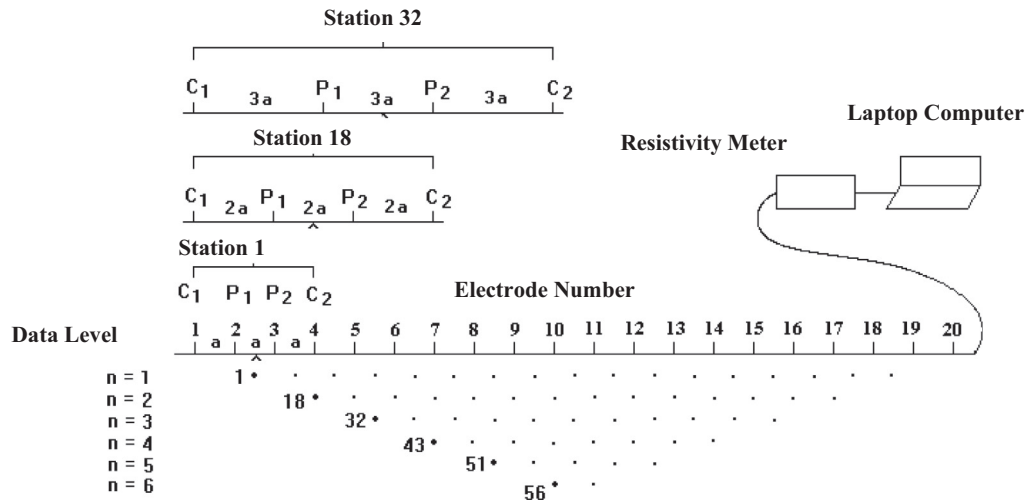


Fig. 1. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo section (Loke, 1999).

2-D RESISTIVITY SURVEY WITH GAPIS RIVER FLOW, SELANGOR, MALAYSIA

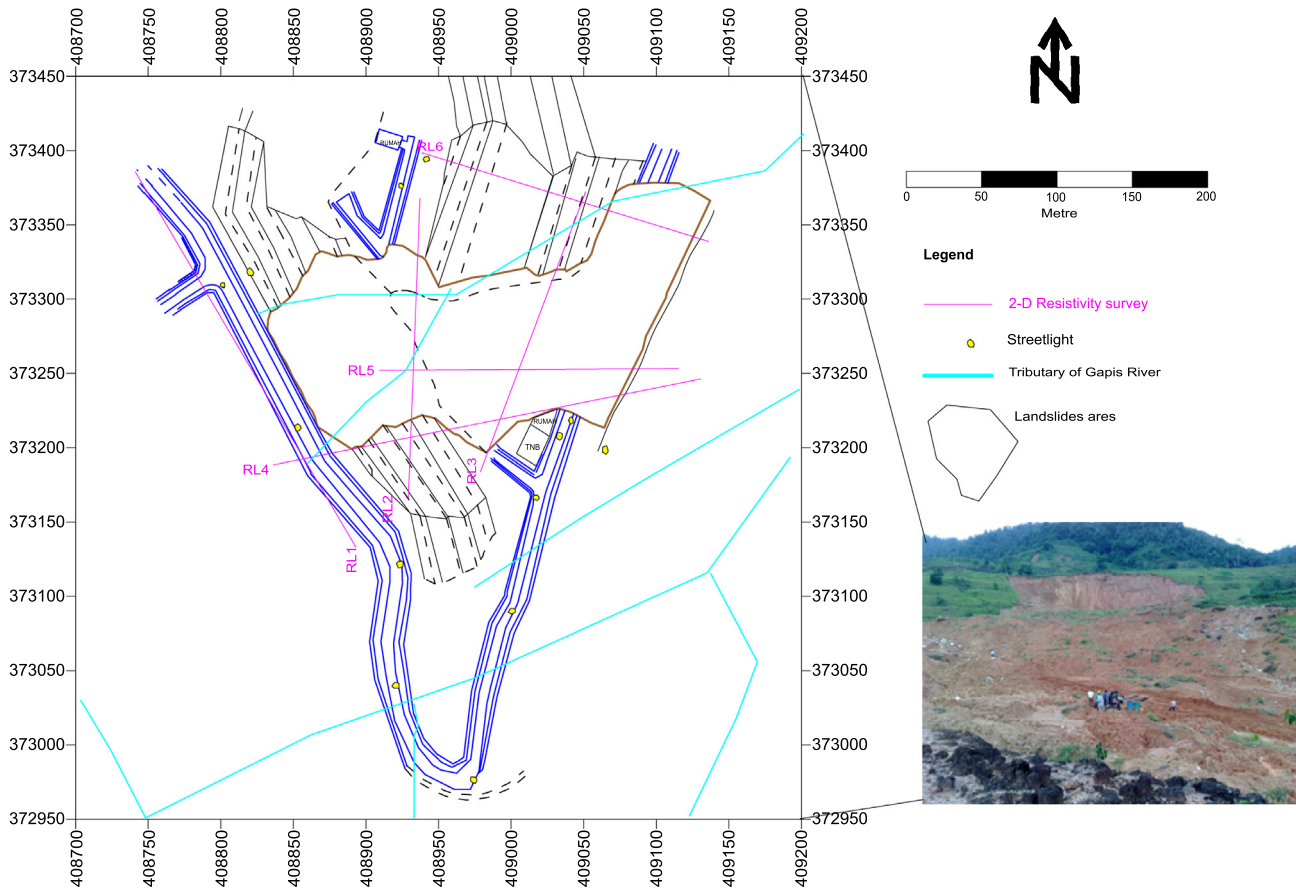


Fig. 2. 2-D resistivity survey in Selangor, Malaysia.

with resistivity values of 100–1000 Ω m and depth of 70 m. This zone consists of saturated zone (1–100 Ω m) and boulders (1200–7000 Ω m). The second zone with resistivity value of >7000 Ω m which interpreted as granitic bedrock. A lot of small fractures can be seen around the study area as shown in [Photo 1](#).

[Fig. 4](#) shows the inversion model resistivity of RL2 and RL3 which has two main zones. The first zone is alluvium or highly

weathered with resistivity value of 100–1000 Ω m and depth of 30–70 m. RL2 shows saturated zone while RL3 consists of alluvium or highly weathered zone. Boulders and fractures were located outside the collapsed area with resistivity value of 1200–7000 Ω m. Alluvium may consist of clay, sand and silt. These types of soils indicate that for hillslopes containing both sandy and silty soils, failure can occur above water table under steady infiltration

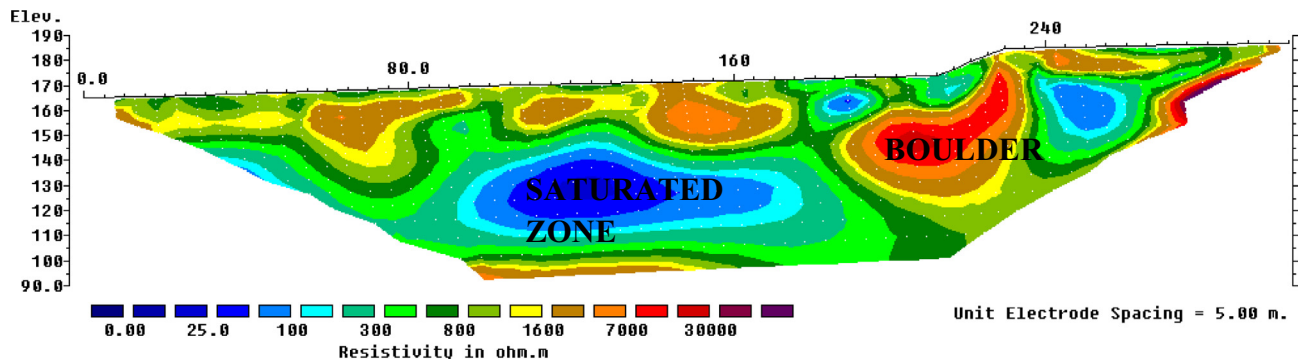


Fig. 3. Inversion model resistivity in Selangor for RL1 (outside collapsed area).



Photo 1. Small fractures located at the collapsed area in Selangor.

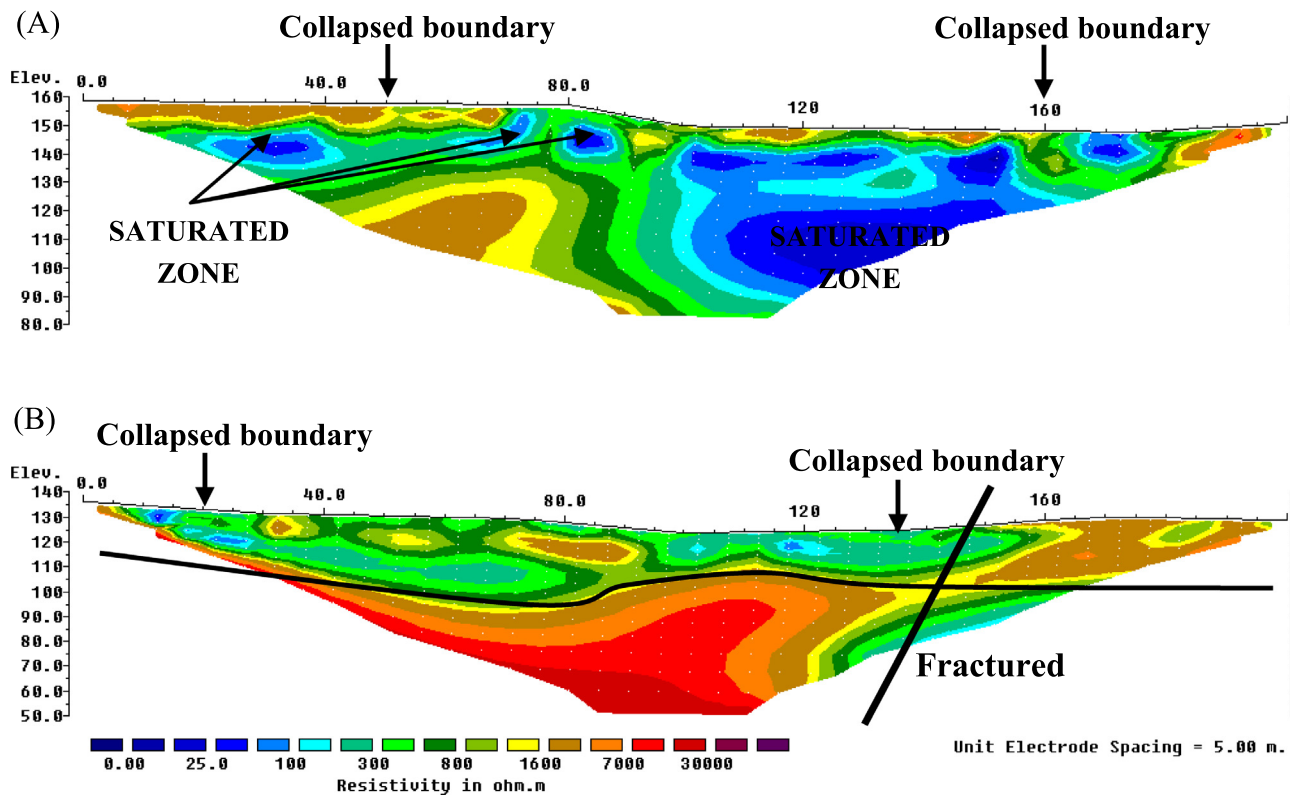


Fig. 4. Inversion model resistivity in Selangor; (A) LR2 and (B) LR3.

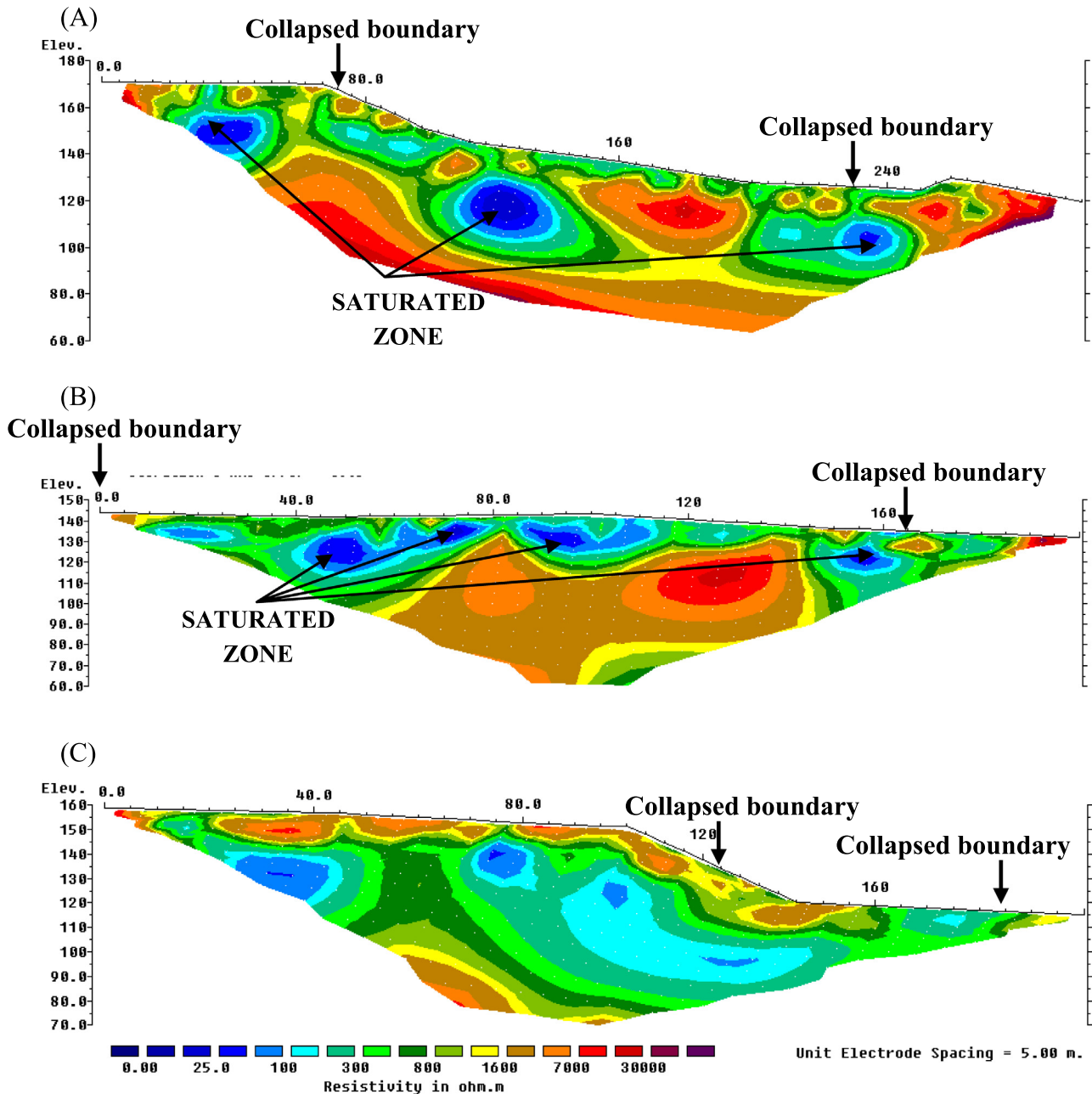


Fig. 5. Inversion model resistivity in Selangor; (A) RL4, (B) RL5 and (C) RL6.

conditions (Lu and Godt, 2008). Rainfall is also one of the factors that may cause to the instability of the slope. Lu and Godt, 2008 present that shallow landslides may occur on the slope under very heavy precipitation conditions. Because soils under these conditions are very nearly saturated, shallow landslides that are generated by this mechanism may mobilize into debris flows (Iverson et al., 1997). Seasonal high rate of rainfall, allowing part of the soil possibly to become fully saturated several times during wet seasons of any year. The study area is either decomposed volcanic rock (silt) or decomposed granite (silty sand) and both soils have high strength when unsaturated during dry season but a low strength when fully saturated. The saturated zone, boulders and highly weathered rock will trigger the slope failure.

Inversion model resistivity of RL4–RL6 shows two main zones (Fig. 5). The first zone with resistivity values of 100–1000 Ω m was

interpreted as alluvium or highly weathered rock with depth of 20–70 m. The zone consists of saturated zone and boulders with resistivity value of 1–100 Ω m and 1200–7000 Ω m respectively. A mass movement can occur any time and the slope may become unstable if the process is continuous. It should be noted that the boulders are very close to instability due to change or removing the rock that holds the slope in place (Nelson, 2013; Filip et al., 2017). The movement of mass from its original place may trigger to instability of slope. Second zone is granitic bedrock with resistivity value of >7000 Ω m. In a wet tropical region like Malaysia, deep weathering profile can have a thickness of up to 100 m. Even though the characteristics of weathering profiles differ from place to place, two most common types of profiles are with and without corestones (Komoo, 1985, 1989, 1998). Highly to moderately weathered (grades IV and III) materials contain core stones of various sizes

INVERSION MODEL RESISTIVITY WITH GAPIS RIVER FLOW, SELANGOR, MALAYSIA

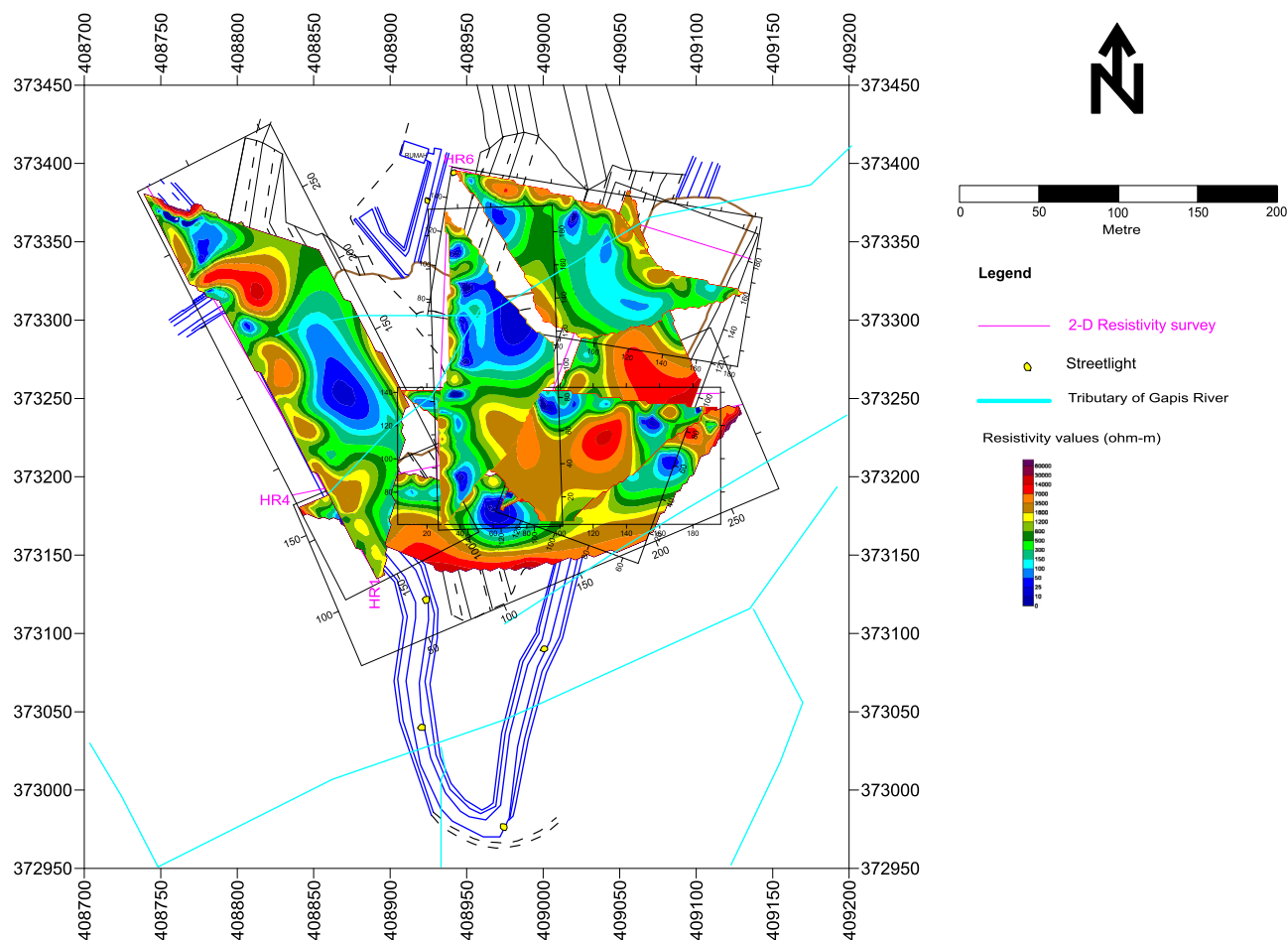


Fig. 6. The arrangement of inversion model of resistivity with underground water from Gapis River.

Table 1
Summarize of slope failure evaluation using 2-D resistivity in Selangor.

Category	Description
Zone	Two main zones with the first zone with 100–1000 Ω m was interpreted as alluvium or highly weathered rock. The zone consists of saturated zone (1–100 Ω m) and boulders (1200–7000 Ω m). Second zone is granitic bedrock with resistivity value of >7000 Ω m
Fractured Underground water	Small fractured/fault may caused to the earth movement The flow of Gapis River contributes to low resistivity value which indicated as saturated zone
Soil structure	Has high resistivity values due to the highly contained of sand and boulders

(from few cm to few m in diameter). Both types of profiles are prone to rainstorm-induced landslides (Chigira et al., 2011).

Generally the results show that the study area consists of high resistivity value, it might due to sand. It was observed that the topsoil was characterized by isolated low resistivity materials that were identified as saturated zones, highly weathered zone and boulders. The saturated zone might be due to the present of Gapis River as shown in Fig. 6. Such water can seep into fracture (geological discontinuity) present at the study area and replacing the air in the pore space thus increasing the weight of the soil. It leads to increase in effective stress resulting into failure of the slope. The higher the porosity will give higher permeability. Porosity can be a factor in permeability. Water flows quickly through material with

high permeability. The Gapis River can be easily flow in the study area due to the sand contained. These low materials overlie the bedrock produce unstable slope which trigger slope failure and may cause to landslides in the study area.

4. Conclusion

The 2-D resistivity method has been carried out in Selangor, Malaysia. Six 2-D resistivity survey lines were carried out in order to identify the subsurface characteristic of slope failure. Results of inversion model resistivity indicates that the topsoil was characterized by isolated of low resistivity materials that were identified as saturated zones. The saturated zones, highly weathered zone, highly contain of sand and boulders will trigger slope failure in the survey area that finally may cause to landslides. Table 1 shows summarize of slope failure evaluation using 2-D resistivity method. The 2-D inversion model resistivity has been correlated well with the geological map of Gapis River. Thus, the 2-D resistivity survey has provided valuable information on the subsurface characteristic and the results obtained may be useful for future slope instability investigation.

Acknowledgments

The authors thank to the technical staffs of the geophysics laboratory, School of Physics, Universiti Sains Malaysia (USM) for

their assistance during data acquisition. The authors also would like to express their appreciation of Research University (RUI) Grantt, Universiti Sains Malaysia with the title Geophysical Application and Approaches in Engineering and Environmental Problems (1001/PFIZIK/811323) for their supports.

References

- Chigira, M., Zainab, M., Lim, C.S., Komoo, I., 2011. Landslides in weathered granitic rocks in Japan and Malaysia. *Bull. Geol. Soc. Malaysia* 57, 1–6.
- Filip, D., Kacper, J., Marek, K., Piotr, M., 2017. The role of landslides in downslope transport of caprock-derived boulders in sedimentary tablelands Stołowe Mts, SW Poland. *Geomorphology* 295, 84–101.
- Iverson, R.M., Reid, M.E., LaHusen, R.G., 1997. Debris-flow mobilization from landslides. *Annu. Rev. Earth Planet. Sci.* 25, 85–138.
- Komoo, I., 1998. Deep weathering: Major course of slope failure in wet tropical terrain. In: Moore, Hungr (Eds.), *Proc. 8th International Congress International Association for Engineering Geology and the Environment*. Balkema, Rotterdam, pp. 1773–1778.
- Komoo, I., Engineering properties of the igneous rocks in Peninsular Malaysia. In: *Proc. 6th Regional Conference on Geology, Mineral and Hydrocarbon Resources of Southeast Asia*, Jakarta, Indonesia, pp. 445–458, 1989.
- Komoo, I., Engineering properties of weathered rock profiles in Peninsular Malaysia. In: *Proc. 8th Southeast Asian Geotechnical Conference*, Kuala Lumpur, Malaysia, pp. 3.81–3.86, 1985.
- Lu, N., Godt, J., 2008. Infinite slope stability under steady unsaturated seepage conditions. *Water Resour. Res. AGU J.* 44, 1.
- Nelson, A., 2013. S. Slope Stability, triggering events, mass movement hazards. *Nat. Disasters*.
- Telford, W.M., Sheriff, R.F., 1984. *Applied Geophysics*. Cambridge University Press.