GEOPHYSICAL RECONNAISSANCE OF KARST SINKHOLE OCCURRENCES IN JERAM, KINTA VALLEY, WEST MALAYSIA AFTER THE 2004 INDIAN OCEAN EARTHQUAKE

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Abstract
Geophysical and geospatial reconnaissance of karst features associated with sinkholes has been carried out in Jeram, Perak, West Malaysia. A rapid increase of sinkholes occurrences were reported after the disastrous 26th Dec. 2004 earthquake in Sumatera. Over 45 sinkholes of various sizes occurred in a small area of the ex-mine land. Many cavities are present in the subsurface karst that is covered by thin layers of loose sands and clay materials. These cavities are thought to be pre-existing features that had been rapidly filled with sand/clay, due to the tremor triggered from the earthquake.

Keywords: Subsurface karst, Sinkholes, Sumatran earthquake, Geophysics

Introduction
According to the report by Malaysia Department of Minerals and Geoscience, there are about 166 occurence of sinkholes in the state of Perak, West Malaysia from 31 August 1955 to 26 February 2008. A total of 70 or 42% occurs from 26 December 2006 to 26 February 2008. 45 of these sinkholes occurred in an area of about 0.186 km^3 in a time span of about two days from 28 December 2004 to 14 April 2005.

The huge increase of number of occurrence shortly after the earthquake has prompted speculation that the occurrences are related to the tremor induced by the earthquake. This study presents preliminary geophysical reconnaissance of sinkhole area in Jeram. The objective is to study the characteristics of subsurface karst in this area by geophysical method.

Study Area
The study area lies in the western West Malaysia and Jeram is located approximately at latitude 35.200°N, longitude 48.80°E (Figure 1). Kinta Valley lies between two granitic highlands, the Main Range in the east and Kledang Range in the west. Geologically, the Kinta Valley is underlined by limestone dated Devonian to Permian (Suntharalingam, 1968). Kinta Valley karst is made up of steep-sided limestone hills that protrude above vast low-lying floodplain with gentle rolling hills of metasedimentary rocks. The plain is covered by alluvium of varying thickness and underlain by rugged and uneven subsurface limestone platform. Only 30% of limestone in Kinta Valley occurs as limestone hills while the rest are subsurface karst.

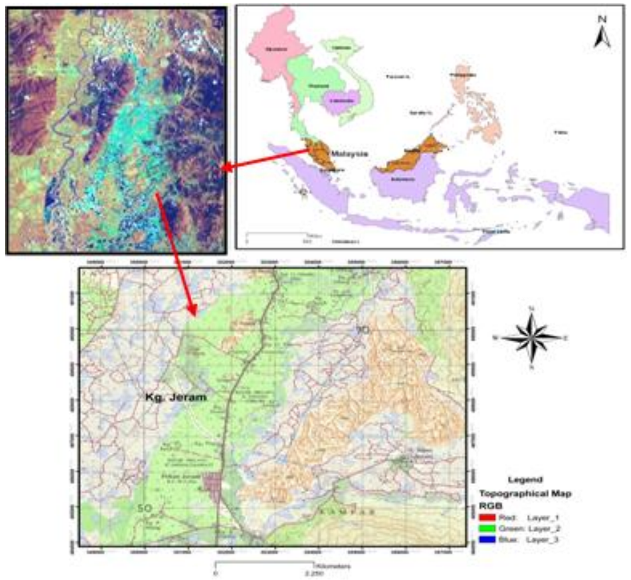

Figure 1: Location of the study area

Methodology

Spot 5 imagery is used to see the changes or the occurrences of the sinkholes before and after the earthquake (Figure 2). Field reconnaissance had been carried out to map the distribution of the sinkholes. The dimension of the sinkholes had been measured by measuring tapes, laser range finder and compass. Electrical resistivity tomography (ERT) was used to image the subsurface immediately above the sinkholes. Six electrical resistivity profiles with a line interval of 30 m over the study area were done. Three out of these six profiles were oriented in (W25^{0}S), perpendicular to the trend of sinkholes in the area. The remaining three were oriented in (N20^{0}W).

Figure 2: Satellites images showing the occurrences of sinkholes in the study area.

The use of two-dimensional resistivity profiling in karst terrain is well recognized. The tool commonly employed is the SAS1000 Resistivity Meter and ABEM Lund Automatic Electrode Selector system. The two Dimensional Resistivity Profiles were acquired by using a 41-channel array in winner configuration. The length of each profile is 200 m., with an electrode spacing of 5m. The locations of these profile lines are shown in Figure 3.

Results

On average, 190 data points were collected for each (41-electrode) in one resistivity profile, and approximately 1140 data were collected for the total six profiles in this site.

Additionally, the data were processed to generate two dimensional resistivity models of the subsurface using RES2DINV, inversion software developed by Loke and Barker, 1996. Assuming the subsurface is uniformly layered, lateral smoothing (mixing) will occur in non-layered strata.

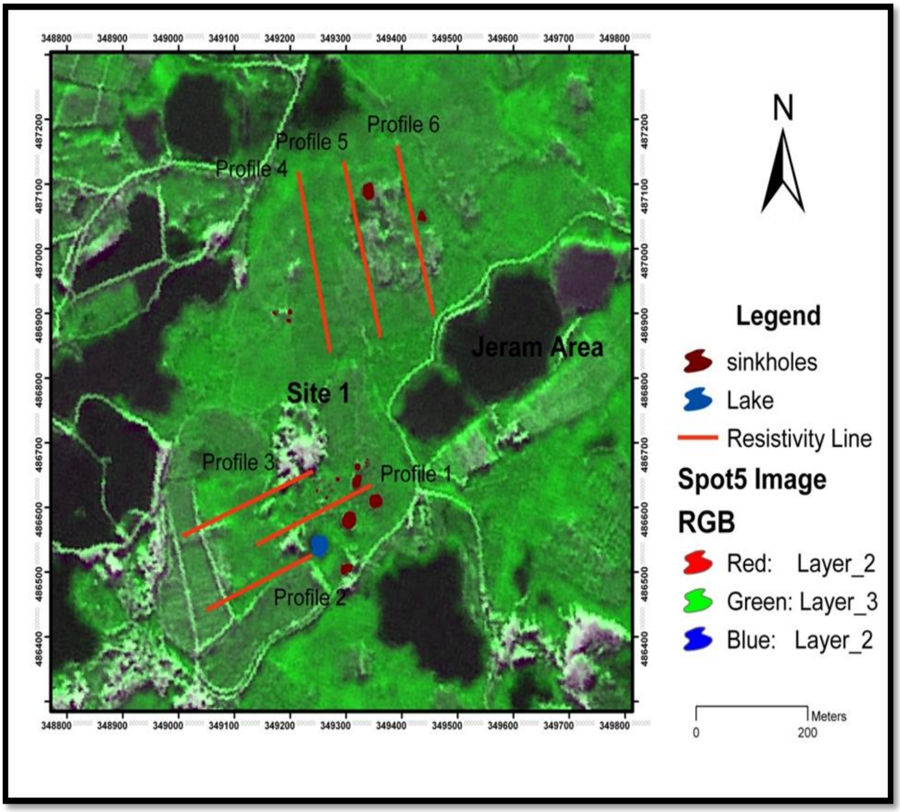

Figure 3: The location of resistivity profile lines

Based on reports of the geophysical surveys results in many karst terrains round the world (Abdel Alqadir, *et al*,. 1995), deductions on the variations in electrical resistivity values enabled geological classification of the study area into claystone, limestone and sand. The electrical resistivity values for each rock/sediment unit are tabulated in Table 1. Inverse model of electrical resistivity section for all profiles are shown in Figur 4 and Figure 5.

Table 1: The description of the range of resistivity values with the expected geological unit deposit.

No.	Range of Resistivity Values	Expected geological units deposit	Color in Inverse model of electrical resistivity section
1-	5 ohm-m. - 10 ohm-m.	Soft clay with ponded water.	Red
2-	10 ohm-m. - 20 ohm-m.	Clay with highly mineralization.	Orange
3-	20 ohm-m. - 50 ohm-m.	Clay with low mineralization.	Yellow
4-	50 ohm-m. - 70 ohm-m.	Soil, silty clay or sandy clay.	Brown
5-	70 ohm-m. - 200 ohm-m.	Clayey or silty sand.	Light green

No.	Range of Resistivity Values	Expected geological units deposit	Color in Inverse model of electrical resistivity section
6-	>100 ohm-m. - 160 ohm-m.	Sand.	Dark green
	160 ohm-m. - 200 ohm-m.	Transitional zone consist of rock fragment of limestone and sand.	Light blue
7-	>200 ohm-m. - < 400 ohm-m.	Weathered limestone, probably consisting of wet fractured and/or clay in-fill.	blue
8-	>400 ohm-m. - <3000 ohm-m.	Compact or intact limestone.	Dark blue
9-	>3000 - 4000 ohm-m.	Voids or Cavity air infill.	black

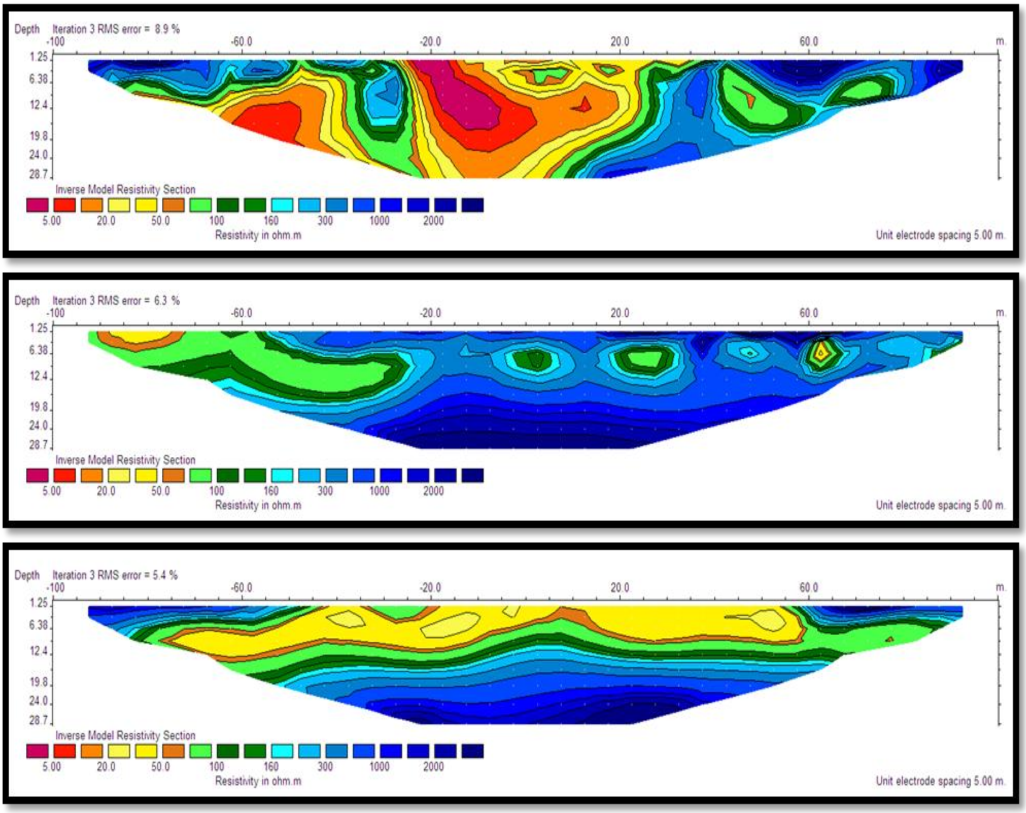

Figure 4: Inverse model of electrical resistivity section for profiles #3, #1 and #2 showing interpreted location of shallow limestone cavities and sinkhole.

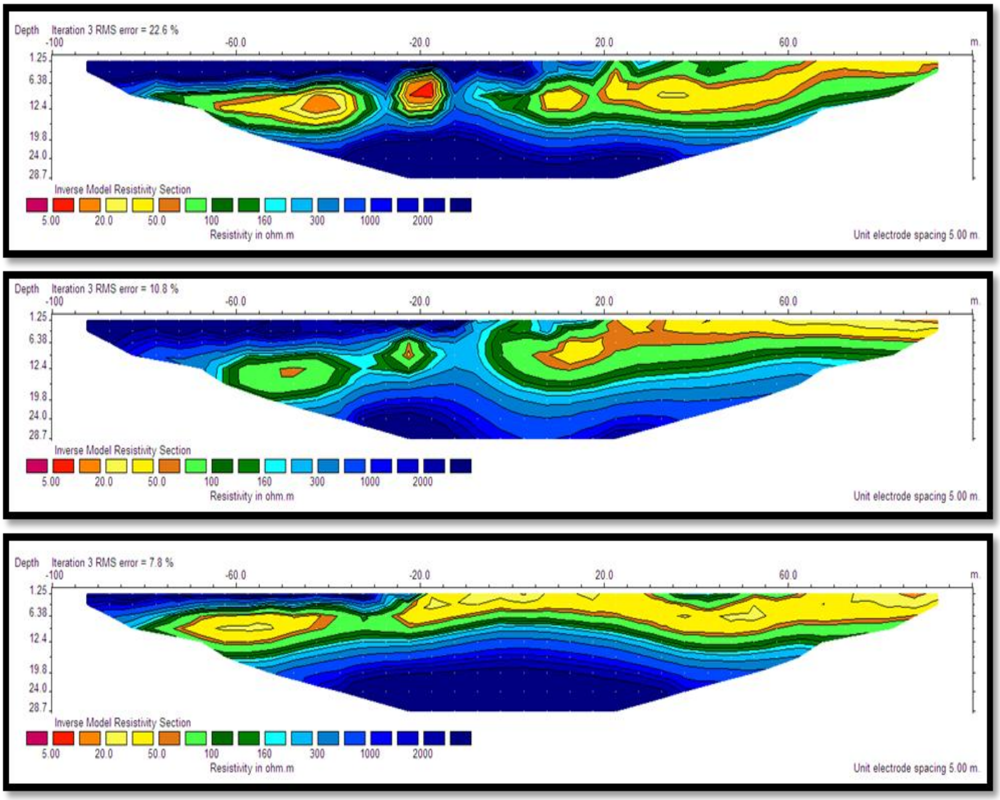

Figure 5: Inverse model of electrical resistivity section for profiles #4, #5 and #6 showing interpreted location of shallow limestone cavities and sinkhole.

Resistivity profile#3. Profile #3 shows a sinkhole with the shallowest subsurface depths less than 1.5m. and continues after the depth of 28.7m. Bedrock unit beneath and adjacent to the sinkhole at depths below 20 m., is interpreted as transitional zones of weathered limestone probably consisting of wet fractured and/or clay in-fill mineral.

Two cavities were located at the subsurface immediately to the east flank of the sinkhole. The first cavity in the left is less than 20 m wide and the height is 19 m with 1.25 to 19.8m. The middle of this cavity consists of anomaly with resistivity values of between 50 to 60 ohm-m and is interpreted as silty or sandy clay. These are surrounded by resistivity values 70 to180ohm-m and interpreted as silty sand, sand and/or deeply weathered rock fragments. The second cavity on the right is less than 15 m wide with and 6.0m high and from 6.38m to12.4m deep. It is anomalous with resistivity values of 70 -200 ohm-m, interpreted as containing clayey or silty sand, sand and deeply weathered rock fragments. These feature or cavities are interpreted as a solution widened joint or zone of deeply fractured rock.

Profile #1. The bedrock extends from electrode 2 to electrode 16 representing a semi tubular shaped anomaly representing a sinkhole. It is noted that the limestone borders around the sinkhole. Zones around the sinkhole with resistivity greater than 200 ohm-m and u to 400 ohm-m are interpreted as zone of weathered limestone, probably consisting of wet fractured and/or clay in-fill.

The base of the sinkhole was visible and the walls were both steep and weathered. Four oval-shaped cavities and one void were located along this profile, believed to be the extension of cavities from profile #3. Their size are about 5 to 17 m wide, from 4.6 to 10 m high and located at the depth from 1.25 to 13.3 m. Except for the second cavity that is filled with air and dry, the rest of the cavities are filled with clay, sandy clay, silty clay, silty sand and sand. All of the 3 sinkholes are believed to be an outlet for the transmitting of water and materials from the sinkhole collapse.

Profile #2. A tubular shaped anomaly which is representing a sinkhole can be observed here. Localized of high resistivity values of more than 200 ohm-m to 400 ohm-m is observed in the shallowest subsurface from depths of less than 1.25 m. These resistivity values and patterns are consistent with visual observations around the sinkhole and cavities, jointed limestone to a depth of at least 16 m.

At depths below 19.0 m., bedrock beneath was characterized by higher resistivity in excess of 400 ohm-m, but less than 2000 ohm-m, interpreted as intact or compact limestone bed rock.

Small voids are visible between electrodes 28-29, approximately 7.0m wide and 5.0m high and from 1.25 to 6.38m deep. This void is filled with sands and other remnant of rocks. The center is characterized mostly by resistivity of more than 3000 ohm-m representing air infill voids.

A karst depression feature extends from electrode 11 to electrode 33. This anomaly is consistent of different patterns of resistivity values in the shallow subsurface overall, from depth of 1.25m to 13m.

Intact or sold boulders of limestone with higher resistivity 400 of 1000 ohm-m are found bordering this location on both flanks of resistivity profile from electrode 5-11 and from electrode 33-40. In the shallowest subsurface from depths of 2.0m to 8.0m,

200 ohm-m to less than 400 ohm-m is interpreted as transitional zones of weathered limestone probably consisting of wet, fractured and/or clay in-fill.

Beneath the subsurface, localized intact or sold limestone bedrock, extends over the entire profile from the depth to19.8m to depth 29.0m, with higher resistivity of more than 400 ohm-m to less than 3000 ohm-m.

Profile #4. The first cavity to left flank from electrode 7 to electrode 15 was oval-shaped, approximately 40m wide and 8.62m high and from 6.38m to 15.6m deep. The base of this cavity is visible and filled with soft clay and surrounded by sandy clay, silty sand and sand. The walls of this cavity are of highly weathered limestone. The second cavity, in the middle of this profile, from electrode 16 to electrode 18, is approximately 10m wide, 11.70m high and from 2.8m to14.5m deep. It appears to have near-rounded walls, is filled with wet clay and surrounded by sandy clay, silty sand and sand. Horizontal trend anomaly in tubular shape, about 95m wide, 18m high and from 1.25 to 19.8m high is also observed.
Observation in the field shows that the surface is underlain by clay or sandy clay, in the area across the profiles. This survey shows the sinkhole and cavities in the shallowest subsurface karst extend from to depth of 7 to 19 m.

Profile #5. A continuous limestone cover is interpreted on the left flank with the depths ranging from 1.25m to 12.38m. Beneath it is a horizontal trend anomaly in tubular shape with approximate measurement of 100m wide, 18m high, from depths of 1.25m to depth 19.8m.
A prominent zone of relatively different pattern of resistivity anomaly is also observed at the depth of 6.38m beneath the cover. These oval-shaped features are interpreted as two previously identified cavities in Profile 4. They are filled with clay, sandy or silty clay and sand. The first cavity to left flank from electrode 9 to electrode 14 is oval-shaped, approximately 25m wide and 12.0m high and from 7.25m to 19.0 m deep. The second cavity, in the middle of this profile, from electrode 15 to electrode 18, approximately 15m wide and 10m high and from 2.5 to 12.4m deep in cross-section appeared to have near-rounded walls The base of these cavities are visible and filled with remnant of surficial soil or silty sand and surrounded by sand. The walls are highly weathered limestone.

Limestone bedrock of strongly widened fracture with clay infill, extend across the profiles, is observed beneath and adjacent to the sinkhole and cavities in the shallowest subsurface from depths of 6 to 24 m. Overall, it is characterized with high resistivity of more than 200 ohm-m but less than 400 ohm-m.

Continuous bedrock of solid or non weathered limestone was localized in the depth of about 24 m with overall higher resistivity of more than 1000 to 3000 ohm-m.

Profile #6. Survey under electrode 16 to electrode 40 represents a horizontal trend anomaly in tubular shape with the width of about 115m, thickness 18m and depths from 1.25 to 15.5m. It continues to left flank to electrode 2 to electrode 16, which is partly covered by the bedrock that is characterized mostly by resistivity of between 1000 to less than 3000 ohm-m. The thickness of this cover is from about 1.25 to 6.38 m. The centers of this cavity are filled with soft clay and surrounded by residual superficial soil or sandy clay.
The rest of the profile shows that areas a large sinkhole filled with clay. The shallowest subsurface karst is located from depths of19 to 24 m. Overall, it is characterized with high resistivity of more than 200 ohm-m but less than 400 ohm-m.
Continuous bedrock of solid or non weathered limestone was localized at the depth of 24 m with overall higher resistivity of more than 1000 to 3000 ohm-m.

Discussion and Conclusions

The karst corrosion plain is commonly veneered with alluvium and when uplifted, glaciated or strip mined for placer deposits, removal of the clastic veneer reveals an impressively planar rock floor that in the tropics, in particular, can sometimes be rugged in detail because of etching down joints (Ford and Williams, 1989). This can be commonly seen in Kinta Valley karst where the subsurface is exposed (Muhammad, 2003). Prolong process of dissolution under clay or sand cover may have produced the topography as what we can observe in Jeram. In the study area, very thin limestone of up to 12m thick presents as cover on the surface. The rest is in the subsurface, overlain by clay and loose sands material. Some of the thin covers may already been washed down in the large sinkholes during the collapse.

Most of the cavities found in this site appear as channels for transmission of water and material from the surface. However some of these channels are thought to be non active due to the absence of soft clay. The overlying sandstone were found in many places on the surface in the area of study, characterized mostly by high resistivity, interpreted as dry and friable sands and with limestone or rocks fragment, probably previously stripped by excavators from the pits of mine, due to ex -mining excavating operation.

The basal limestone bedrock is covered by soil or sandy clay and friable sand in some place and dissected by cavities that are believed to be produced from solution-widened joints by further dissolution.

Sinkholes and cavities found here are of tubular and cylindrical shape. These observations may indicate that these sinkholes and cavities are newly developed due to a collapse feature. This support the thought that the origin of all these cavities were of pre-existing feature as joints, and likely widened due to subsidence/collapse movement in the area that had rapidly filled with clay.

Further studies will involve the studies on the geochemistry of the water, the behaviour of water flow, comparison with other sinkhole and non-prone sinkhole areas and closer monitoring of occurrences in relation to the Sumatran earthquake in the future.

Acknowledgement
This study is sponsored by University of Malaya Research Grant.

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