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Geophysical Mapping and Characterization of Aquifer Zones of the Flooded East Coast Areas of Peninsula Malaysia

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Abstract: During the periods from 15 December 2014-3 January 2015, East coast Peninsula Malaysia was characterized by heavy monsoon rains that left many places with devastating effects ranged from a loss of lives and properties, economic, social, health and educational sectors were not spared by the ugly incidence. The level of loss and destructions led to this study of the primary objectives of bringing together the skills of geoscientists to investigate the nature of the subsurface in the affected areas that are prone to flooding through the application of active methods of geophysical prospecting that employed the electrical resistivity and also that of induced polarization methods of geophysical survey with a view to determining the lithological units and their corresponding depths that are water bearing for groundwater exploitation. Current monitoring programs for surface and ground water though have a very high resolution meteorological, chemical and hydrological observation data sets but the emphasis on the subsurface environment which controls the flow pathways for this surface water lacks in the previous studies in this area. This could be unconnected to the complexity of the subsurface geology and the difficulty often experienced in accurately characterizing the subsurface structures. This study aimed at proposing suitable sites for remediation boreholes sitting that will serve to dampen future occurrences of this catastrophic event that led to the untimely deaths of many and displacement of over 60,000 people that were forced to flee their homes in the worst affected states of Kelantan, Pahang, Perak and Terengganu. Several geophysical field survey were conducted in the selected areas due to the high degree of spatial heterogeneity nature of the subsurface structures underlay the area. We applied a field scale surface active geophysical methods which include direct current electrical resistivity and induced polarization surveys to map the severe floods prone zones. In this study, we can locate nine promising lines where the underlain rocks were deeply weathered and fractured. The minimum depth of >5 m was delineated at Menak Urai Lama, longitude 102°14'9.8" and latitude 5°23'30.1". Whereas the study delineates maximum depth of more than 40 m at Pemberian, longitude 102°14'49.7" and latitude 5°20'06" along the school football field. The study traced the growing affinity for surface and subsurface waters by prospecting for interventions and therefore, suggests guidelines for the borehole sitting.

Key words: Floods, electrical resistivity, chargeability, weathered/fractured bedrocks, groundwater zones, Peninsular Malaysia

INTRODUCTION

Large-scale monsoon rains affected most states along the East Coast areas of Peninsula Malaysia from 15th December 2014-3rd January 2015 which resulted in some casualties and an economic damage worth billions of Malaysian Ringgits. This year's floods is certainly the most destructive and invariably the most devastating natural hazards ever witnessed in recent years where rain events are rather common and by far the worst flooding disaster to strike the country as 10,000 of people lost the core living needs food, shelter and clothes (Fig. 1). Even though significant efforts were made in the past years by the government to tackle the problems of floods across the country but the understanding and preventability of this catastrophic event are somehow limited.

The monsoonal flooding affected most businesses and about 60,000 people displaced. Infrastructural and social facilities were badly damaged in the affected states

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(MSTI., 2015). Intensive rainfall has reportedly caused most catastrophic floods dealings, sometimes combined with a tropical cyclone, typhoon or monsoon. Nevertheless, some foods have been linked to failures of manmade infrastructure such as artificial lake (dam) burst for the period of intensive rains (Kundzewicz and Takeuchi, 1999).

Malaysia is located in the Southeast Asia and separated into 2 distinct parts by the Southern China Sea (Fig. 2). The Peninsular Malaysia to the West and East Malaysia in the East.

Peninsular Malaysia is located South of Thailand, North of Singapore and East of the Indonesian Island of Sumatra. East Malaysia is located on the Island of Borneo and shares borders with Brunei and Indonesia. Peninsular Malaysia is separated from Sumatra Island by the Strait of Malacca. The country is situated in the equatorial doldrums area that lies between latitudes 2°30'N and 6°45'N and longitudes 99°45'E and 118°20'E. The country cover a total land area of about 329, 847 km^2 (MSTI., 2015). There are 3 primary types of seasonal variation rainfall in Peninsular Malaysia the months of November-January recorded maximum rainfall along the East coast states of the Peninsular. On the other hand, this area experiences the driest period in the months of June and July every years. However, the pattern differs from the Southwest coastal zone which experiences double periods of maximum rainfalls within a year between the months of March-May and also in the months of October and November, respectively. Meanwhile, the periods of June-August and February recorded minimum rainfall. On the final note, the rest of the Peninsula aside the Southwest coastal area have maximum rainfall periods in April, May, October and November. Besides the monsoon period in Malaysia, rain always falls in larger part of the country being within a tropical rain forest belt in contrast to other rainfall forest zones of the World (MSTI., 2015). Although, both major and minor floods have occurred during all these seasons the present situation which was as a result of the global warming phenomenon, call for the interest of all due to its devastating effects on both human and the environments, together with the direct economic impact of the floods in many ample areas. It is on this note that East Coast Peninsular Malaysia can be described by the monsoon rains of permanently, periodically and non-periodically flooded zones as illustrated in Fig. 3.

Fig. 1: Areas devastated by the floods: a) One of the bridges completely washed away by the floods and b) Parts of the towns completely submerged

Places affected by this catastrophic floods are; Johor, Kedah, Kelantan, Negeri Sembilan, Pahang, Perak, Perlis, Sabah, Sarawak, Selangor and Terengganu. Therefore, the establishment of an efficient flood monitoring for the Peninsular Malaysia as part of a management scheme to enables her people to develop strategies for a sustainable use of its natural resources is imperative.

In the past decades, geoscientists have made remarkable impacts in the applications of geophysical methods to delineates zones severely prone to floods (Kundzewicz and Takeuchi, 1999; Horritt *et al*., 2001; Hannaford and Marsh, 2008; Hahmann *et al*., 2009,

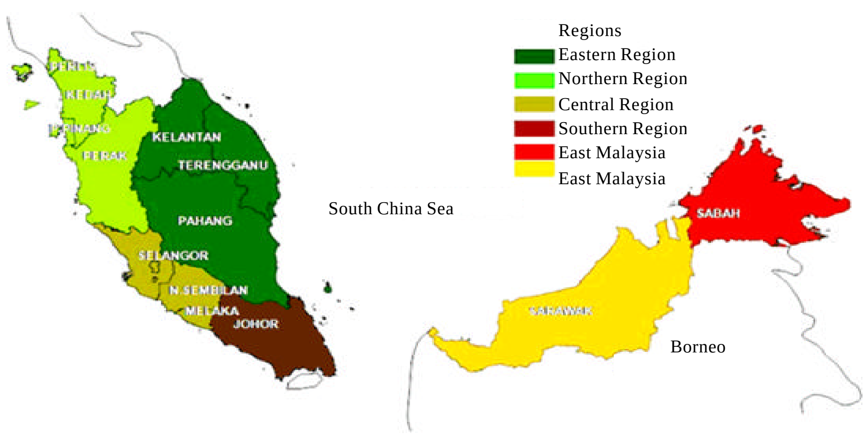

Fig. 2: Map of Malaysia showing the regions, modified after Malaysian Meteorological Department (MSTI., 2015)

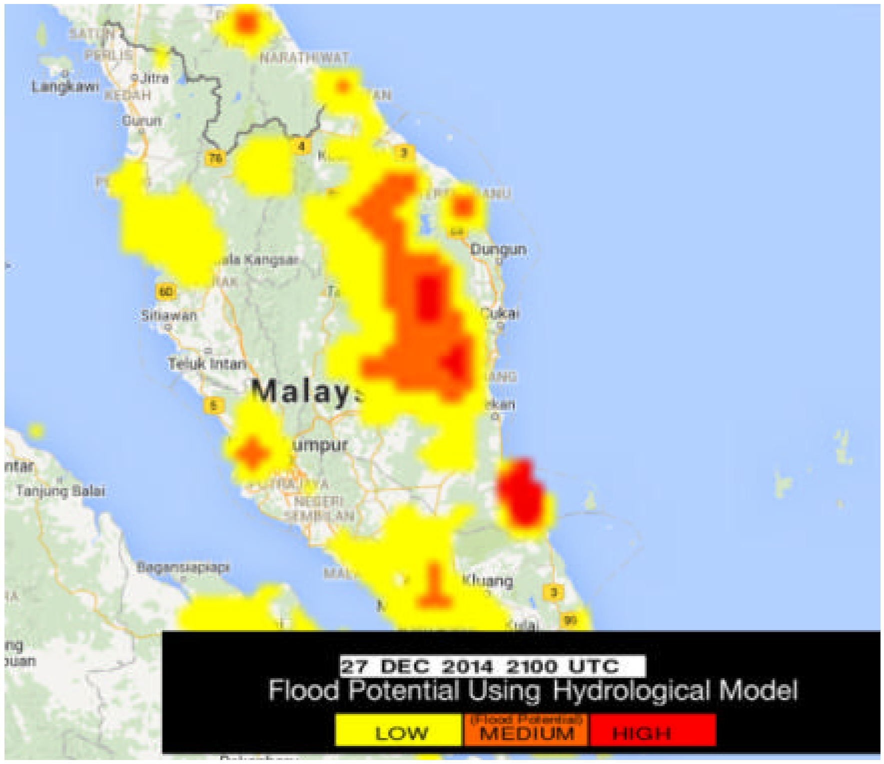

Fig. 3: Potential flood prone zones of Peninsular Malaysia after (MSTI., 2015)

Aizebeokhai *et al*., 2010; Giustarini *et al*., 2013). Traditionally, the delineation of flooded areas was accomplished by varieties of ground observations that were employed to probed the near subsurface hydro-structural characterization with a view to understudying the integrity of the subsurface geological structures and thereby proffer a remediation programme to dampen future occurrences (Corwin and Morrison, 1980; Baksi *et al*., 1987; Costa *et al*., 1995; Tinkler and Ellen, 1998; Bense and Balen, 2004; Delrieu *et al*., 2005; Dahan *et al*., 2008; Dahm *et al*., 2010).

Meanwhile, ground base geophysical measurements were also treasured for monitoring the effects of artificial or manmade changes to the watershed such as roads and rail tracks construction; Floodway construction, artificial lake or Earth dam, field drainage channel alterations, land treatment measures, construction of dikes, levees and flood walls, together with any natural changes that can offset the flooding patterns in a given environment. The reality that water is available throughout the year or at least during certain periods of the seasons greatly affects these manmade structures. Flood monitoring should not only focus on economic aspects but should also be considered concerning ecological impacts it creates on human lives and the environments. However, the driving factor that played a key role in flooding was attributed to climate change together with optimum environmental conditions including moderate to high solar radiation, high precipitation, high temperature and relative humidity, collectively with the regular enhancement in an organic matter brought by this seasonal floods. Variations in the heights of water usually called ‘‘flood pulses’’ are the driving force in floodplain systems. All these processes, primary production, degradation, contamination, depend on the interaction of vegetation and flood characteristics (Junk *et al*., 1989; Bayley, 1995; Tockner *et al*., 2000; Martinez and Toan, 2007). Given this, a remediation program for the East Coast Peninsular Malaysia was proposed with the aims of providing control boreholes that will daunt future sudden occurrences. The acquired data sets were targeted to improving flooding remediation programs by way of understanding various subsurface hydrogeological structures of the study area before sinking control boreholes in the area.

Due to its spatial approach of the direct current electrical resistivity methods of geophysical prospecting which makes it a valuable and reliable active tools capable of mapping Earth’s conductivity. While the phenomenon of induced polarization is used for detecting the chargeability of the Earth’s subsurface and strategies for monitoring the subsurface, chiefly for regions with an extent comparable. In this study, we collected the DC resistivity and IP chargeability data using the same equipment in a non-intrusive method. A combination of these 2 electrical survey methods, i.e., the direct current resistivity and induced polarization methods gives better information on the conductivity and chargeability within a short time as well as cost effectiveness. The information obtained from these surveys enable the use of an existing computerized inversion algorithm to quantitatively and qualitatively mapped the subsurface regions that were devastated by the floods. Previous numerous research showed the application of DC resistivity and IP methods to map severe flood-prone zones (Seigel, 1959; Schiavone and Quarto, 1984; Farquharson *et al*., 1992; Swanson *et al*., 1998; Kundzewicz and Takeuchi, 1999; Wightman *et al*., 2003; Delrieu *et al*., 2005; Maillet *et al*., 2005; Moidaki *et al*., 2006; Aizebeokhai *et al*., 2010; Moreno *et al*., 2013). The electrical conductivity of subsurface fluids, particularly water, together with the medium it occupies within these structures is a physical property that is perceptive to the amount of dissolved solids present in the water (Zudman, 1995).

The motivating factors prompting a new emphasis on flood disaster monitoring include climate change which invariably led to the increased of average precipitation in the study area and the requirement for acquiescence with the Global regulatory agencies to curb this menace. This wittingly placed pressure on local regulatory authorities to provide hydrogeological data and its interpretation for the affected zones and to develop adequate monitoring programmes which will tackle groundwater together as an entity on its own and in terms of its interconnectedness with surface waters (Milly *et al*., 2002; McMichael *et al*., 2006). In response to the floods that hit East Coast Malaysia from 15 December 2014-3 January 2015. The need for full-scale characterization of the subsurface structures in this part of the Peninsular Malaysia makes this research initiative paramount with the emphasis on how to develop a clear strategies and appropriate methodologies for characterising the groundwater systems in the area which while of limited value as public water supplies are often of ecological importance through monitoring groundwater-surface water inflow. In the view of this, alternative approaches applied across a broader spatial scale, among which geophysical methods are particularly appropriate and are required.

The array of geophysical techniques existing, together with unevenness in the physical properties of subsurface structures and pore fluids filling the void spaces in varieties of environments connotes the applicability of a particular geophysical method the way in which it is deployed and subsequently interpreted may perhaps be enormously different (Cassidy *et al*., 2014). A number of notable researchers has demonstrated the significance of multi-geophysical techniques to comprehensively characterised the subsurface geology both at a regional and at a local scale (Malnes *et al*., 2002; Maillet *et al*., 2005; Toyra and Pietroniro, 2005; Martinez and Toan, 2007; Pandey, 2009; Legaz *et al*., 2011; Wagikondi, 2007; Hostache *et al*., 2012; Schlaffer *et al*., 2012; Moreno *et al*., 2013; Niedda *et al*., 2014; Tehrany *et al*., 2014).

These broad concepts of DC/IP are highly developed and well established over several decades. We have therefore considered the application of these methods to the existing knowledge of the areas being study. The application of DC/IP to map areas affected by severe floods was fully described by Burton and Kates (1964), Nakiboglu and Lambeck (1982), Karous (1983), Corwin (1990), Costa *et al*. (1995), Khesin *et al*. (1997), Rogers *et al*. (1997), Tinkler and Ellen (1998), Aristodemou and Thomas-Betts (2000), Holman *et al*. (2003), Delrieu *et al*. (2005), Maillet *et al*. (2005), Adabanija and Oladunjoye (2014). The variability in the subsurface structures and depths to weathered or fractured layers is very necessary for the understanding and managing water resources because these is the main control of the spatial vulnerability of the aquifers the storage capacity and productivity as well as the groundwater flow paths (Cassidy *et al*., 2014).

There is yet as far as we can ascertain to be a systematic and comprehensive geophysical studies in the recently devastating floods in the East Coast Peninsular Malaysia. Hence, this, therefore, offers the motivation for the work presented in this study as we applied a DC and IP geophysical survey methods to investigate and determine the link between the surface and subsurface structures influencing the groundwater-surface water flow in the area.

Geological settings: The location of Malaysia is on the Sunda shelf within the South-Eastern Asia and it is believed to be tectonically dormant (Alexander, 1968; Hutchison, 1977; Mitchell, 1977; Khoo and Tan, 1983; Jasin *et al*., 1995). The oldest rocks in the country dated as far back as 540 million years ago and are mostly sedimentary. Limestone from the most common structure of rock believed to be produced during the Paleozoic Era. During the Tertiary period, the limestone which laid down in the East Malaysia was thought to have since been eroded and such erosion forms basins of sedimentary rocks that are very rich in oil and natural gas. The mountain ranges in Malaysia were formed through orogenesis beginning in the Mesozoic era. The sequence of rocks was reportedly distributed mostly in the central part of the Peninsular in which geoscientists affirmed to be deposited in a deep sea environment (Raj, 1982; Khoo and Tan, 1983; Tan, 1984; Jasin *et al*., 1995; Spiller and Metcalfe, 1995; Metcalfe, 1996; Ainul *et al*., 2005; Richardson, 2013). Metcalfe *et al*. (1980) classified the Carboniferous sediments of the study area into 1 Sagor, 2 panching and 3 Charu formations with their respective ages and thicknesses as; Late Carboniferous;

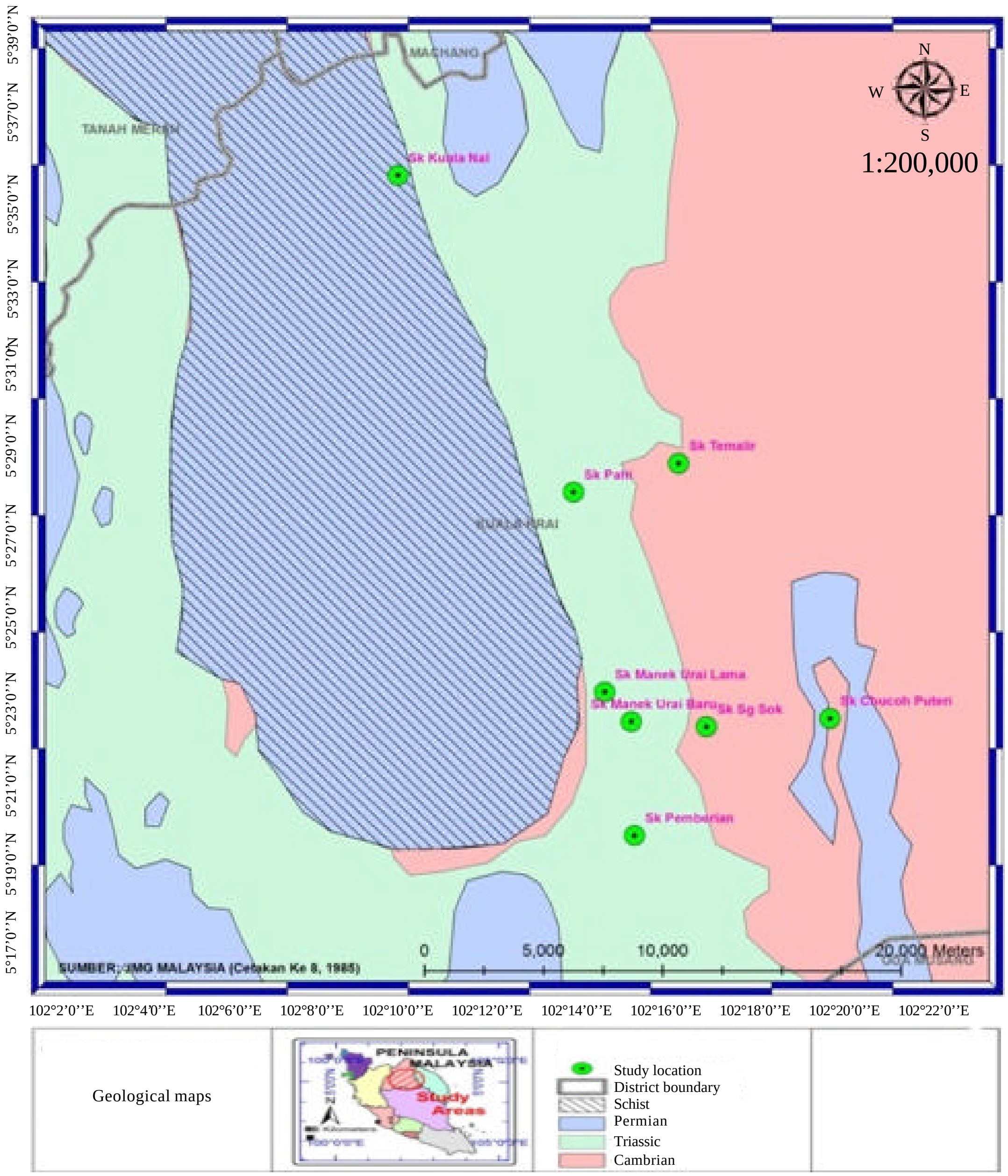

Fig. 4: Geological map of the study area showing data collection points

c150+, Namurian A; c600 and Visean-Namurian A and c1600+. Hence, they named these as Kuantan group (Metcalfe *et al*., 1980). Some rivers drained the country, notable among them are Rajang River with its tributaries located in Sarawak, East Malaysia. This river is situated in the Northwest of Borneo and it was reported to have originated from the Iran Mountains and flows roughly about 565 km Southward to the China Sea which invariably make it the longest river in Malaysia (Chan, 2012). Others include Pahang River and its tributaries; Kuantan River and its tributaries, Perak River and its tributaries and many others located in the Peninsular Malaysia.

Local geological settings: The local geological settings of the area studied presents lithological units as shown in Fig. 4. This area is underlain sequentially by Schist; Permian, Triassic and Cambrian rock units respectfully. The Schist overlay the Permian rock unit which in turns overlay the Triassic unit and together occupied the major parts of the Western area and spread to the central section with some minor intrusion of the Cambrian unit in the Southern part. On the other hand, the Eastern part of the study area is underlain by the Cambrian rock unit with some intrusions of the Permian rock unit along the Southern section of the area. The Permian rock unit was said to have contained some different granitic rocks as reported by Khoo (1980). The 2 main rivers drained the area, River Galas being the longest and biggest river with its tributaries and flows Northward to join River Kelantan, which in turn flows Northward to the South China sea. River Lebir is not as big as the River Galas but forms the major tributary to it.

MATERIALS AND METHODS

The phenomenon of Induced Polarization was first reported by Conrad Schlumberger (Dobrin, 1960). Perhaps he was able to refer to this phenomenon as ''provoked polarization''. In the process of making conventional resistivity measurements he noted that the potential difference, measured between the potential electrodes, time and again did not drop instantaneously to zero when the supply current was turned off. Instead, the potential difference dropped sharply at the initial stage after that gradually decayed to zero for a given period (Fig. 5).

When earth layers are energized with an electric current (either a DC or An AC current) they are capable of becoming electrically polarized thereby exhibit the characteristic of a battery. After cutting off the supply current, Conrad Schlumberger observed that the potential at the output did not return to zero immediately rather it gradually discharges before returning to the stability state. This study of the decaying potential difference (v) as a function of the time (t) is termed, the Induced Polarization (IP) in the time domain (Dobrin, 1960; Seigel, 1959; Johnson, 1984; Telford *et al*., 2004; Seara and Granda, 1987; Luo and Zhang, 1998; Dahlin *et al*., 2002; Davydycheva *et al*., 2006; Loke *et al*., 2006).

The field application of this method is usually in the process of observing subsurface structures in which the potential difference decayed after the input current is cut off. A further technique is to study the consequence of applying alternating currents and the resistivity measured which is termed Induced Polarization (IP) in the ''frequency domain'' (Fig. 6). Application of this method is to locate subsurface structures where the resistivity decreases as the frequency of the input current is increased (Bleil, 1953; Anderson and Keller, 1964; Fox *et al*., 1980; Aristodemou and Thomas-Betts, 2000; Horritt *et al*., 2001; Dahlin *et al*., 2002; Hahmann *et al*., 2009; Cassidy *et al*., 2014).

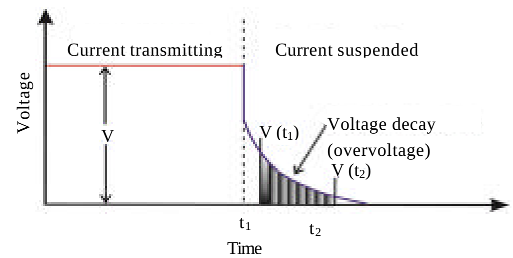

Fig. 5: Illustration of IP time domain effects

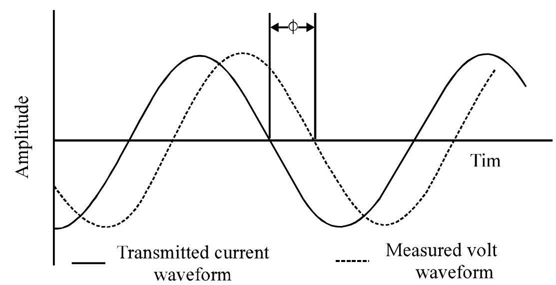

Fig. 6: The IP frequency domain effect

The advantage of Induced Polarization (IP) methods over other geophysical methods of the survey makes it more suitable for prospecting the subsurface in scantily accessible regions with complex structures prompted our selection of the study method that utilized the time domain using the pole-dipole array for this study. It has been showed that the apparent chargeability φ_a over a diverse medium consist of nth similar materials to be more or less related to apparent resistivity ρ given by Eq. 1:

$$\varphi_a = \sum_{i=1}^{n} \varphi_i \frac{\delta \log \rho_a}{\delta \log \rho_i} \tag{1}$$

Where:
φ_i = The chargeability of the ith material
ρ_i = The equivalent resistivity

On the other hand, the validity of this equation is said to be:

$$\sum_{i=1}^{n} \frac{\delta \log \rho_a}{\delta \log \rho_i} = 1 \tag{2}$$

From Eq. 1 and 2, we have:

$$\frac{\varphi_a}{\varphi_1} = 1 + \sum_{i=1}^{n} \frac{\delta \log \rho_a}{\delta \log \rho_i} \left\{ \frac{\varphi_a}{\varphi_1} - 1 \right\} \tag{3}$$

If ρ_a the apparent resistivity is known then φ_a/φ_1 the reduced apparent chargeability can be derived (Seigel, 1959; Seigel *et al*., 2007; Nordsiek and Weller, 2008;

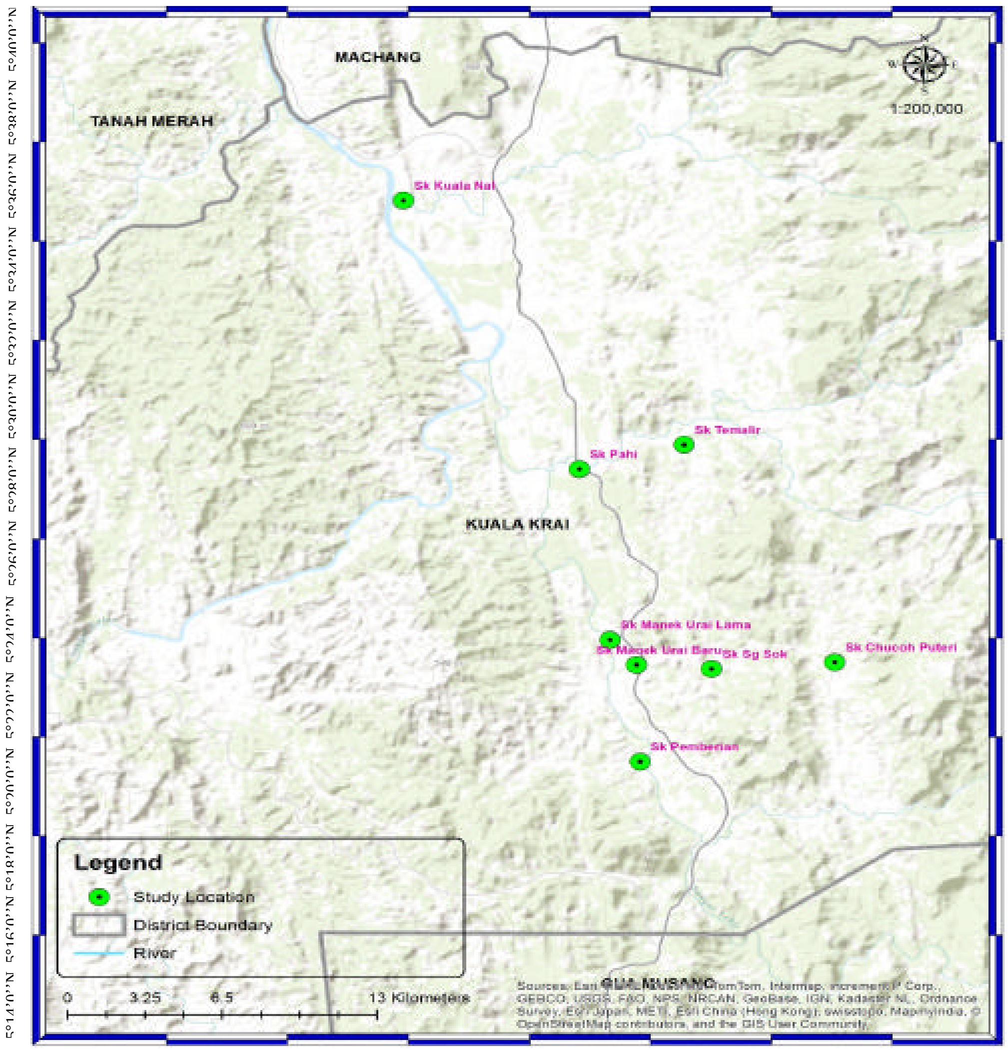

Fig. 7: Topographic map and geophysical layout of the study area

Table 1: Chargeability and resistivity of some common subsurface materials and minerals

Type of the subsurface structure	Chargeability φ (msec)	Resistivity ρ (Rho) (Ω-m)
Groundwater	0	10-100
Alluvium	1-4	10-80
Gravel	3-9	65-1500
Schist's	5-20	20-180
Sandstone	3-12	315-4500
Clay	8-15	1-100
Quartzite	5-12	65-1500
Precambrian (weathered)	8-20	65-100
Precambrian granites	6-30	320-10000
Limestone	10-20	15-650
Shale	50-100	5-20

Zhdanov, 2008). Table 1 gives the standard values of the chargeability and resistivity of some subsurface material and minerals after Telford *et al*. (2004) and the University of British Columbia.

The principal objective of this study is to be able to locate a suitable site for control borehole by identifying features of subsurface geological structures that are appropriate for groundwater accumulations. This required field-scale investigations into the subsurface structures in the area with the application of DC resistivity and IP methods of geophysical survey. To rapidly study the variations in the clay contents, porosity, water saturation and concentrations of dissolved electrolytes in the subsurface structures, electrical resistivity methods give a brisk means of achieving this (Loke *et al*., 2006). Nine profiles were taken across the survey area (Fig. 7).

The method of survey was the same for all the nine profiles. ABEM SAS 4000 Terrameter with LUND ES464 electrode selector, Fig. 8 was used with a maximum survey length of 200 m at an electrode spacing of between 2.5 m and 5 m for both the DC resistivity and the IP survey methods. Due to limited accessibility in the areas surveyed, pole-dipole array configuration, Fig. 9 was adopted to mapped this area to achieve the required depths using strong signals for both the current C and potential electrodes P.

The pole-dipole array is an asymmetrical array with asymmetrical apparent resistivity anomalies in the pseudo-sections over a symmetrical structure which could influence the inversion model. It has relatively good horizontal coverage and higher signal strength compared with the dipole-dipole array. It is much less sensitive to telluric noise than the pole-pole array (Aizebeokhai *et al*., 2010). To eliminate the asymmetrical effect measurements with this type of electrodes configurations they are used in the reverse order. In this case, the combined measurements of the forward and reverse pole-dipole array would remove any bias in the model due to asymmetry. However, this will increase the survey time as the number of data points to be measured would be invariably doubled. The signal strength of the pole-dipole array is lower than that of Wenner and Schlumberger arrays and is very sensitive to vertical structures. The pseudo-section data plots are merely a convenient method for showing all of the data along one given a line in one presentation. The data collected in this study was processed using a RES2DINV Software computer package which permits a significant amount of data to be calculated within a very short time by converting the apparent resistivity measured to a genuine resistivity of the subsurface structures (Loke, 2014).

The subsurface structures are naturally heterogeneous, consequently, the resistivity value obtained is perceptible that is the resistivity of a homogeneous subsurface medium that would give the same resistivity value for the same electrode configuration. Apparent resistivity can thus be seen as a weighted average of several measurements of the quantity of subsurface resistivity under the 4 electrodes, i.e., (2 currents and 2 potentials) configurations. The apparent resistivity, therefore, depends on these settings of the electrodes and is determined by the injected current and voltage Then as a result of this the apparent resistivityis therefore, given by Eq. 4:

$$\rho_a = G\frac{\Delta V}{I} \quad (4)$$

Fig. 8: ABEM SAS 4000 Terrameter with its accessories

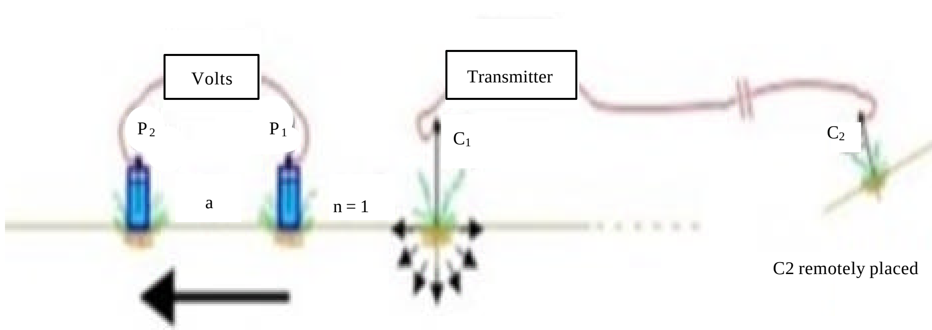

Fig. 9: Electrode configurations used in this survey, pole-dipole array

where G is the geometrical factor and it is a function of electrode configuration. In the case under consideration, G is as expressed in Eq. 5 for pole-dipole array, (Kearey *et al*., 2002):

$$G = 2\pi n(n+1)a \quad (5)$$

Where:
a = The electrode spacing
n = The multiplier

This study employed in the field using 2 conductor cables which allow several values of the spacing multiplier n to be measured from one current dipole location.

RESULTS AND DISCUSSION

Geophysical interpreted results and discussion: The primary targets for groundwater accumulations in subsurface aquifers is the weathered or fractured depths in the hard rock which primarily control the inflow of water, storage and transport (Cassidy *et al*., 2014). The absolute perceptive of basement aquifers origin and their distinction in aquifer properties have a practical magnitude on exploration and development of groundwater resources in these aquifers. Clay materials, metallic oxides and sulfide minerals are the only regular soil materials that can transmit a considerable amount of electrical current in the course of the material itself. As such, the resistivity of most near-surface geologic structures is principally controlled by the quantity and the chemistry of the pore fluids contained by these structures. The results obtained from the analysis of observed electrical resistivity tomography field data, Table 2 showed noteworthy variations in the depths to the aquifer zones in this area. The minimum depth of >5 m was recorded at Menak Urai Lama, longitude 102°14'9.8'' and latitude 5°23'30.1''. Whereas the study delineates maximum depth of more than 40m at Pemberian, longitude 102°14'49.7'' and latitude 5°20'06'' along the school football field.

In the first site, situated on longitude 102°9'26.7'' and latitude 5°35'42.4'' at Kuala Nal Primary School happens to be the most Northerly region in the study area moreover, 2 survey lines were carried out here. The results from the resistivity profiles show a potential point for groundwater exploration between 40-100 m along line 1 (Fig. 10) while line 2 demonstrated an excellent point

Table 2: Interpreted geophysical parameters of the study area

Location	Longitude (E)	Latitude (N)	Resistivity (Ω-m)	Chargeability φ (msec)	Depth to aquifer (m)	Survey length (m)
Kuala Nal	102°9'26.7''	5°35'42.4''	18.8≥859	-75.3≥116	>25	120
Pahi	102°13'9.15''	5°28'12.14''	18.9≥3997	-380≥695	>12	160
Menak Urai Baru	102°14'40.71''	5°22'48.57''	5.15≥425	-227≥213	>10	100
Menak Urai Lama	102°14'9.8''	5°23'30.1''	21.4≥446	-150≥249	>5	100
Sg Sok	102°16'22.93''	5°22'42.66''	12.5≥9947	-118≥256	>10	100
Chuchoh Puteri	102°19'16.8''	5°22'53.2''	2.6≥1519	-912≥812	>20	200
Temanir	102°15'50.12''	5°28'54.78''	6.7≥24880	-782≥505	>30	200
Pemberian	102°14'49.7''	5°20'06''	31.0≥1816	-71.9≥301	>40	120

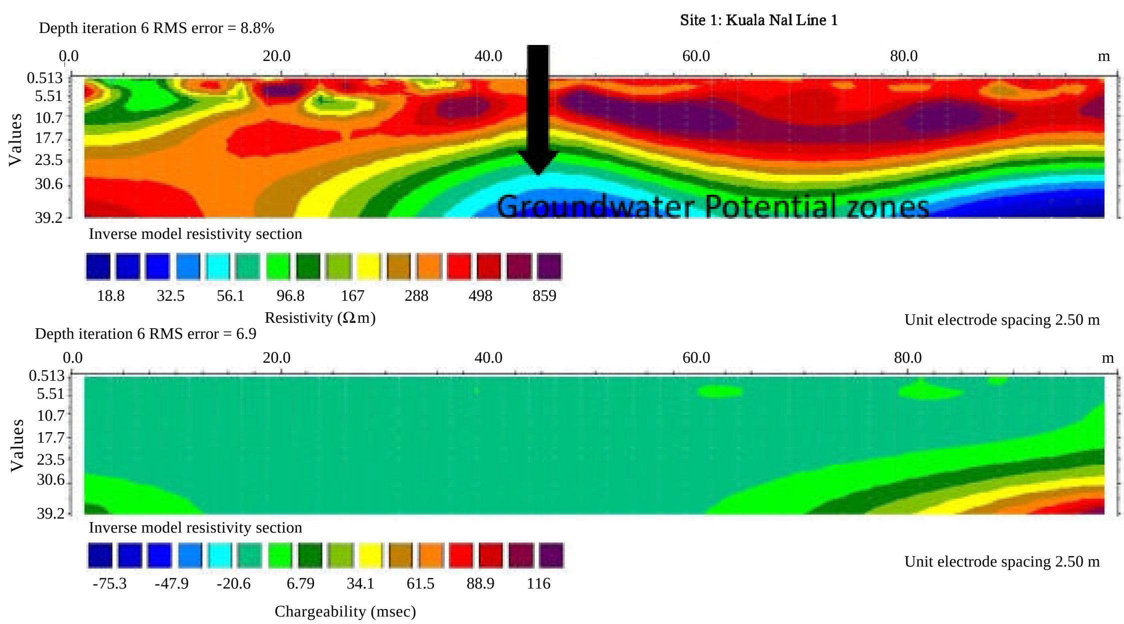

Fig. 10: Inverted 2D sections for ER and IP obtained at Kuala Nal primary school site 1

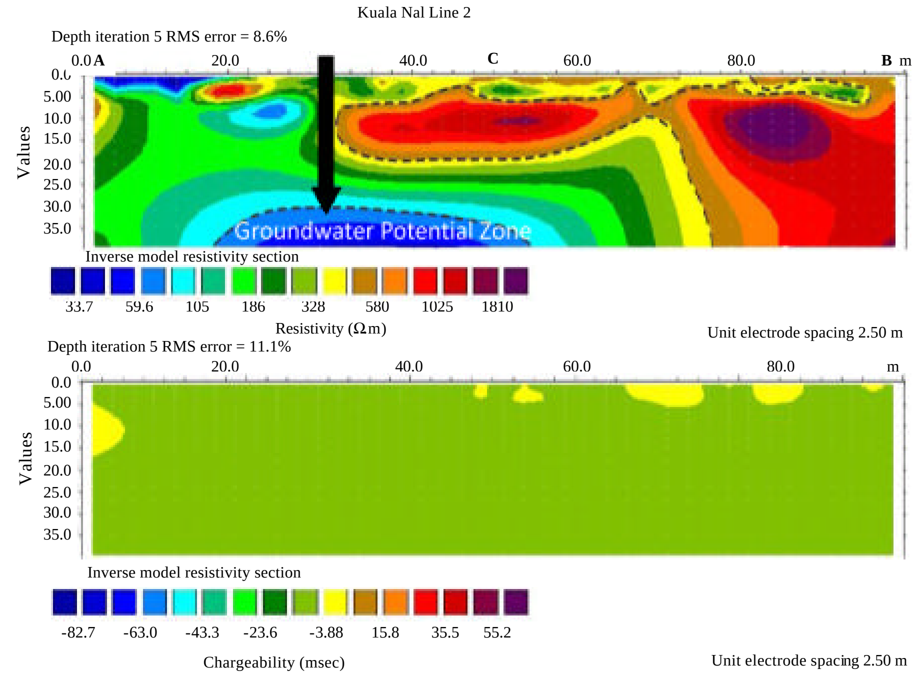

Fig. 11: Inverted 2D sections for ER and IP obtained at Kuala Nal primary school site 2

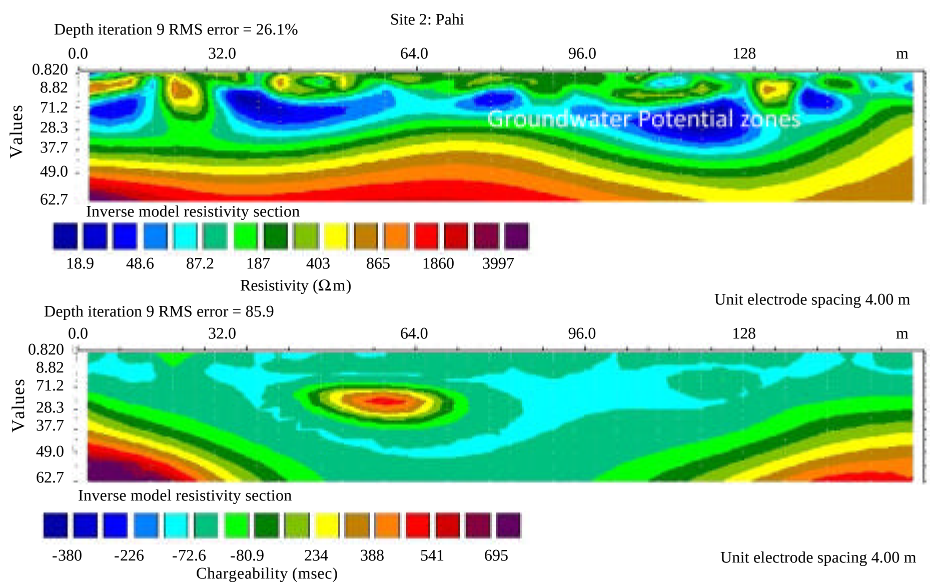

Fig. 12: Inverted 2D sections for ER and IP obtained at Pahi primary school

between 10-60 m (Fig. 11). The section consists of a highly resistive top layer in line 1 with a range of resistivity >400 Ω-m and chargeability $\leq$6.79 msec, respectively. This condition placed the aquifer in this site as a "protective" type of aquifer. Maximum depth of more than 40 m was delineated by the 2 methods of survey in line 1 with resistivity range of between $18.8\geq\rho\leq 859$ m and chargeability range of between $-75.3\geq\varphi\leq 116$ msec respectively. On the same note, line 2 showed a maximum depth to the aquifer at the same level as in line 1, i.e., >40 m with resistivity range of between $33.7\geq\rho\leq 1810$ Ω-m as well as chargeability range of between $-82.7\geq\varphi\leq 55.2$ msec, respectively. Nevertheless, the regolith in this line has moderately low resistivity of between 300-$\leq$500 Ω-m with the corresponding chargeability of $\leq$15 msec.

Profile 2 is located at Pahi primary school field situated on longitude 102°13'9.15" and latitude 5°28'12.14" South-Easterly flank to the first site and nearly Southwest-Northeast orientation (Fig. 12). Only 1 line was carried out here, utilizing electrode spacing of

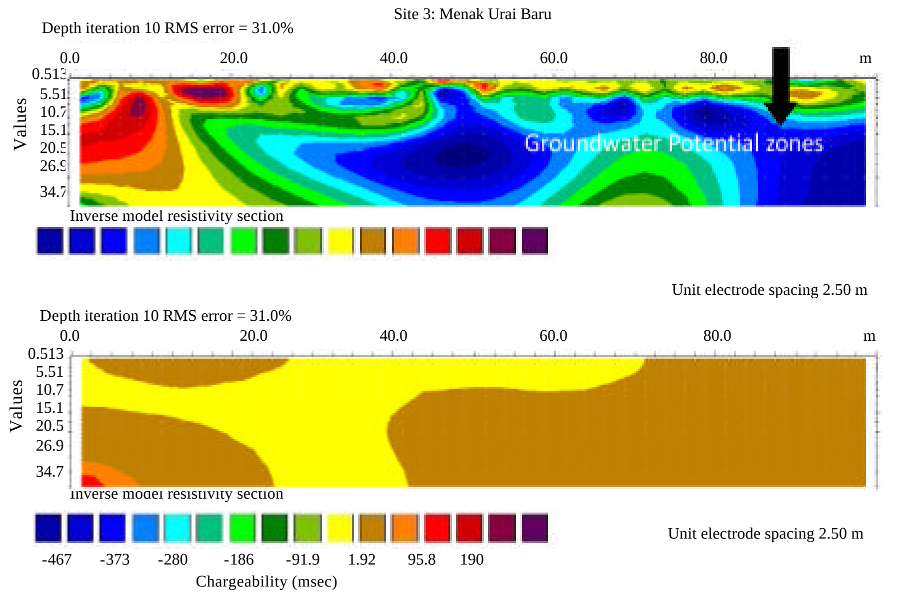

Fig. 13: Inverted 2D sections for ER and IP obtained at Manek Urai Baru close to primary school gate

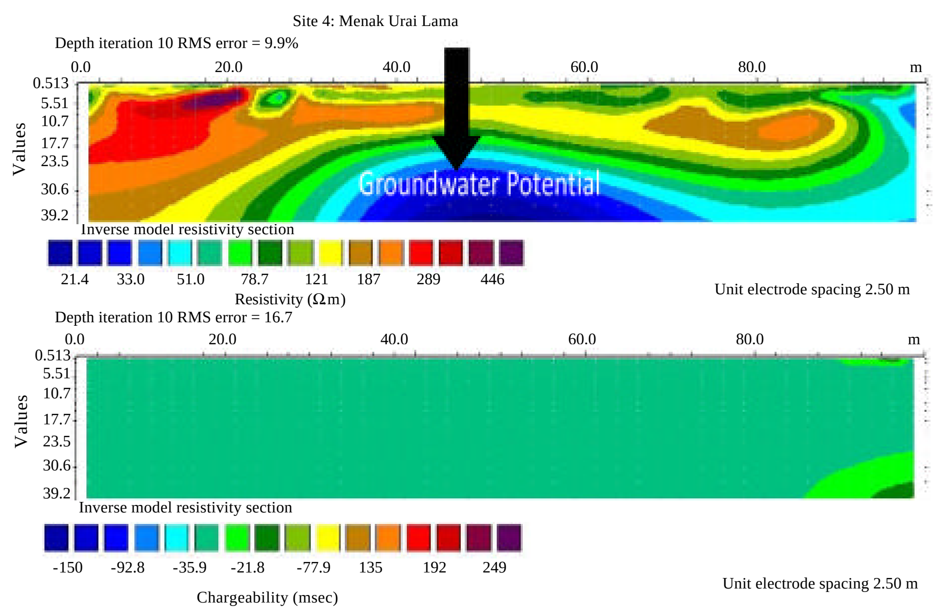

Fig. 14: Inverted 2D sections for ER and IP obtained at Manek Urai Lama primary school

4 m amid resistivity range of between 18.9≥ρ≤3997 Ω-m and chargeability range of between -380≥φ≤695 msec, respectively. Depth to the aquifer at this site is shallow as the thickness of the regolith is about 40 m. Most parts of site 2 are very promising with aquifer depth of 12 m and above.

Manek Urai Baru is where we have the third profile, located along longitude 102°14'40.71" and latitude 5°22'48.57" South of the second profile as well as very close to the primary school gate. Electrode spacing of 2.5 m was selected due to space constraint (Fig. 13). Resistivity range of between 5.15≥φ≤425 Ω-m and chargeability range of between -227≥ρ≤213 msec were delineated, respectively. Depth to the aquifer zone was obtained between 10-30 m at a horizontal distance of between 0-85 m.

Manek Urai Lama is situated along longitude 102°14'9.8" and latitude 5°23'30.1" Northwest of Menak Urai Baru as well as where we have the fourth profile in front of the Primary School with East-West orientation (Fig. 14).

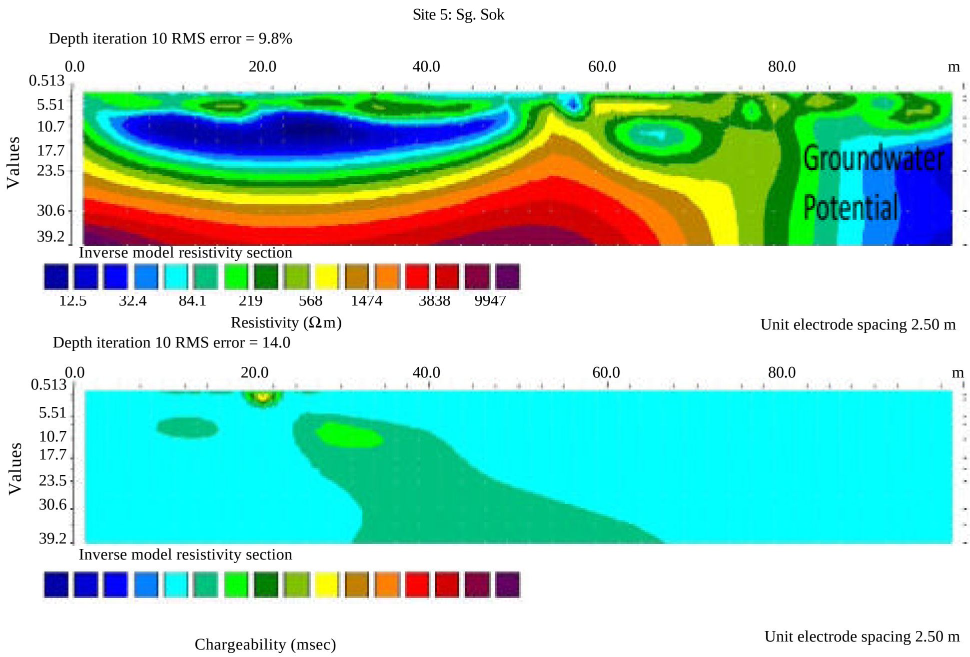

Fig. 15: Inverted 2D sections for ER and IP obtained at Sg. Sok school premises

Groundwater potential zone was located between 30-100 m along the horizontal distance of the survey line with a minimum depth of more than 5 m to the aquifer was delineated along this profile. The resistivity range of between $21.4 \geq \rho \leq 446$ Ω-m and chargeability range of between $-150 \geq \varphi \leq 249$ msec were delineated, respectively along the profile. High resistive regolith was delineated between 0-30 m along the survey line with a maximum depth of 30 m.

Site 5 of the study area was located at Sg. Sok school premises due East of Menak Urai Baru and situated along longitude 102°16'22.93" and latitude 5° 22' 42.66" (Fig. 15). The survey line was conducted near the academic building of the school with an electrode spacing of 2.5 m. The aquifer zone was delineated at a minimum depth of 10 m as well as the resistivity range of between $12.5 \geq \rho \leq 9947$ Ω-m and chargeability range of between $-118 \geq \varphi \leq 256$ msec. The aquifer zone delineated between a surface distance of 85-100 m along the survey line at a maximum depth of 30 m.

At the school field in Chuchoh Puteri is site 6 location along longitude 102°19'16.8" and latitude 5°22'53.2" (Fig. 16). The site is situated due East of Sg. Sok School and Menak Urai Baru with a the survey line conducted along a maximum length of 160 m and electrode spacing of 4 m. Depth to the aquifer was delineated at more than 20 m as well as the resistivity range of between $2.6 \geq \rho \leq 1519$ Ω-m and chargeability range of between $-912 \geq \varphi \leq 812$ msec, respectively. A maximum depth of about 64 m was delineated along this profile with moderately high resistive regolith from a surface distance of about 140 m along the profile line towards the end point. The aquifer zone spread from 0-12 m.

Site 7 was located at Temalir along longitude 102°15'50.12" and latitude 5°28'54.78" Northeast of Pahi where site 2 was located (Fig. 17). The survey was conducted along the road leading to the school compound with the distance between the electrodes selected to be 5 m and maximum length of 200 m was covered. Depth to the aquifer was delineated at more than 30 m in surface positions between about 70-170 m along the survey line as well as the resistivity and chargeability ranges of between $6.70 \geq \rho \leq 24880$ Ω-m and $-782 \geq \varphi \leq 505$ msec, respectively.

Pemberian is the last site which is situated along longitude 102°14'49.7" and latitude 5°20'06" Southern flank of Menak Urai Baru with the survey line located on the school field. The distance between the electrodes was selected at 3 m for a maximum survey length of 120 m (Fig. 18). The depth of the aquifer unit was delineated at about 40 m at points 0-12 m along the survey line. The resistivity range of between $31.0 \geq \rho \leq 1816$ Ω-m and changeability range of between $-71.9 \geq \varphi \leq 301$ msec were delineated, respectively along the profile.

However, the change in the lithology of the area along the stratigraphic sequence also has strong implications for the groundwater flow and storage. The area is more deeply weathered which make the extent of

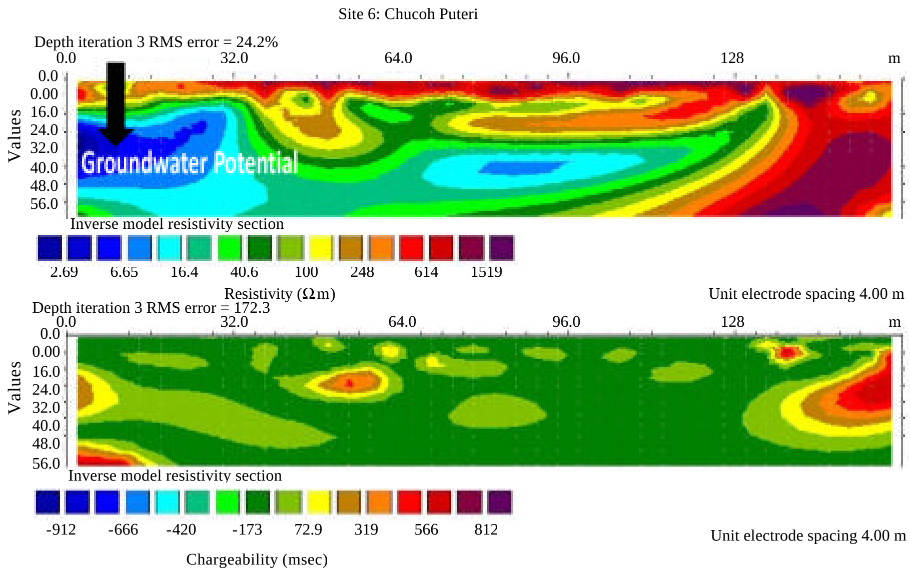

Fig. 16: Inverted 2D sections for ER and IP obtained at Chuchoh Puteri school premises

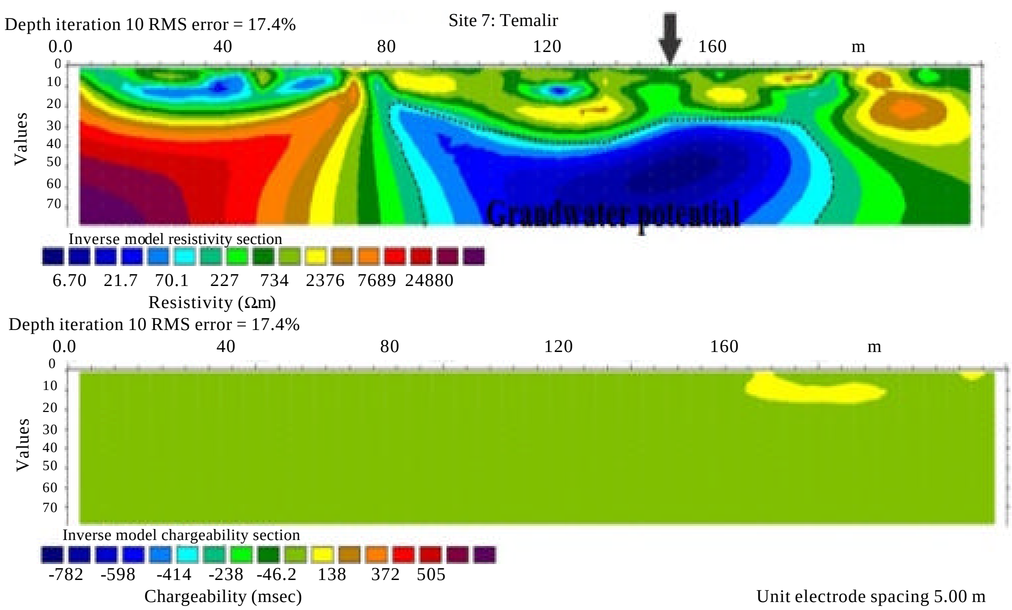

Fig. 17: Inverted 2D sections for ER and IP obtained at Temalir along school road

the overburden depth to be highly variable and significance from vulnerability to floods from the point of view. The compilation from the pole-dipole array measurements as shown by the 2D inversion indicate that fresh bedrocks that have been significantly weathered and fractured were delineated between 90 and 100 m along the survey line 2 of Kuala Nal which gives a maximum fresh bedrock resistivity of >1800 Ω-m at a depth of more than 35 m. The site was located in the schist belt zone of the area. The highest bedrock resistivity of >9947 Ω-m was recorded at Sg. Sok site along the survey line between points 0-60 m at a depth >30 m. Pahi and Temanir in the Southern flank to Kuala Nal gave moderately high resistivity values of more than 3997 and 2488 Ω-m at depths of >60 and >30 m, respectively. From the geological point of view these sites were underlain by the Cambrian and Permian formations of Peninsular Malaysia. On the other hand, the moderate high resistivity of more than >1500 Ω-m at a depth of >60 m was recorded at Chuchoh Pueri between about 130-160 m along the survey line which was located on the Permian. It is not a coincidence for other sites like the Pemberian, the Menak

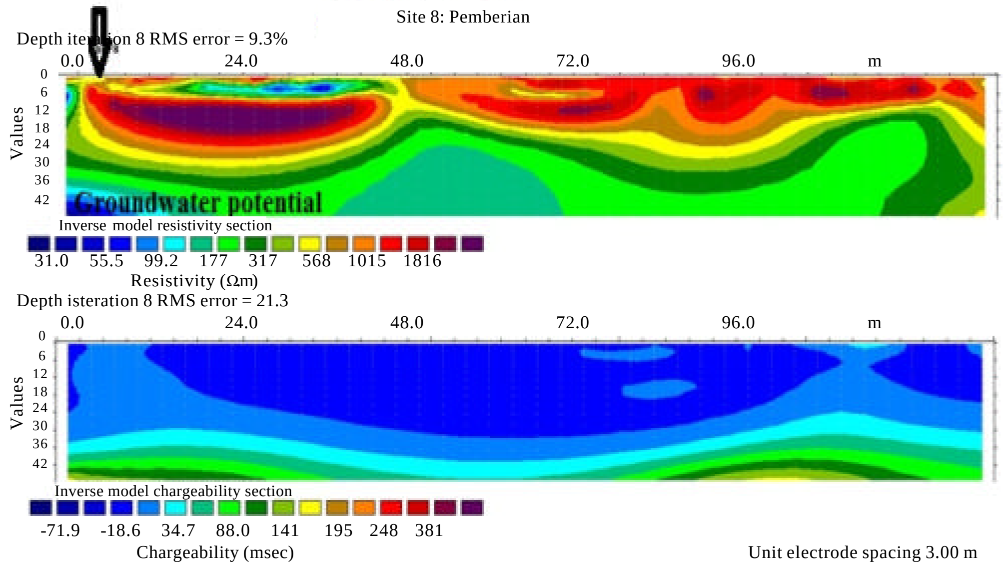

Fig. 18: Inverted 2D sections for ER and IP obtained at Pemberian school field

Urai Baru and Menak Urai Lama to give very low resistivity values >100 Ω-m with depth variation of between 35≥56 m as they are all situated on the Triassic formations that are more deeply weathered than the Cambrian and Permian formations (Fig. 10-18 and Table 2).

CONCLUSION

We collected, analyzed and interpreted active geophysical data utilizing electrical resistivity tomography and induced polarization methods to explored the complete understanding of the basement aquifers genesis and their relationship to flooding in the study area. This study demonstrates that the geomorphologic processes of basement rocks are weathering or fracturing and stripping which are controlled by tectonic quiescence are responsible for the occurrence of shallow aquifers in the basement rocks underlay the area. This study was able to show that occurrence of floods in the East Coast Peninsular Malaysia is spatially controlled as identified groundwater zones are particularly in shallow regolith regions. The area under study has been deeply weathered/fractured following climate variations, since, Late Miocene and has resulted in the vertical heterogeneities leading to the development of shallow aquifers. The 2D inverted sections for both the electrical resistivity and the induced polarization delineated strong overburden at sites 1 line 1, 6 and 8 representing Kuala Nal, Chuchoh Puteri and Pemberian, respectively. The other sites studied, i.e., lines 2-5 and 7% a feeble and thin regolith that could easily permit transmissivity between surface and ground water in an intense precipitation. These events may not be unconnected to the feebly by a high non-linearity in the hydrological response related to brink effects and structured heterogeneity at all scales in forecasting the initiation and run out of rainfall-induced floods in this area. The limited extent (if not total absence) of the transition zone which should have provides significant storage and transmissivity if present in the hard rock of this area would have restricted surface-ground water flow across the sites and hence prevent or reduce the effect of floods minimally.

Furthermore, this study highlights with the purpose of identification of the linkage between the surface and underground water which the geophysical methods applied was able to produce by way of delineation of the groundwater promising zones as deeply weathered/fractured areas and also the weak regoliths overlay the bedrocks. The nine lines considered followed general trends with very little variations in the depths to the aquifers. The morphology of these shallow aquifers mostly followed general trends in the nearly bowl-shaped like as delineated by the electrical resistivity method which could be most likely submission controlled. The ERT and IP surveys exposed the variability in the extent of the low resistivity near-surface zone across the study area.

The low resistivity zones are interpreted as weathered/fractured bedrock which could be confirmed by the time the borehole is sunk and geophysical analyzes are done and correlate with the lithologic units obtained from this study. The geophysical parameters reflects the underlying geology that these near-surface zones are open fractures with little in situ weathered clay minerals or infill materials which would have to disallow fluid movement between the surface and subsurface during rainfall events. Delineating the depth and layering within the study area provides an indication of aquifer recharge and subsequent vulnerability to contamination from surface water during flooding which should have been prevented by sufficient clay layers.

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