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# Electrical Imaging Resistivity Study at the Coastal Area of Sungai Besar, Selangor, Malaysia

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**Abstract:** A geophysical method was used in studying the effect of environmental impact and shoreline physical changes on coastal-area salinity of both soil and groundwater at the Sungai Besar area in Malaysia. The environmental impact was a previous flooding of the shore by seawater and the consequent severe coastal erosion. 2-D geo-electrical resistivity technique was used in evaluating the extent of salinity to soil and to groundwater. Resistivity was measured through an ABEM SAS 1000 C Terrameter. 2-D electrical-imaging resistivity data of subsurface profile for each survey line were calculated through inverse modelling, aided by borehole data, which showed the lithology; Quaternary alluvium sediments more than 80 m deep, composed of alternating layers of sand, silt and clay. From the two resistivity-image profiles obtained, spots of saline plume were found scattered on top of the impermeable-layer marine clay, with less than 0.2 ohm m, resistivity. Resistivity-image profile $L_1$ showed saline plume spots to have penetrated the first confined aquifer found at depths of 18.00-34.50 m below ground surface, while resistivity-image profile $L_2$ did not show the presence of any such plume. The resistivity-image profiles also revealed that the second confined aquifer of each profile has not been affected by the saltwater contamination. In terms of salinity distance, the $L_1$ image profile dominated the full 400 m distance, whereas the $L_2$ profile shows the salinity condition to be about 250 m from shoreline. The results therefore suggest that the salinity of the groundwater aquifer is due probably to ancient seawater-flooding that has long percolated through the sediments, rather than to direct seawater-intrusion.

**Key words:** Salinity condition, natural process, 2-D geo-electrical resistivity technique, resistivity image, saline plumes

## INTRODUCTION

Saltwater intrusion has been discussed in literatures (Nowroozi *et al*., 1999; Papadopoulou *et al*., 2005; Narayan *et al*., 2007) as a source of contamination. Saltwater intrusion can pose serious problems to coastal areas with freshwater aquifer having marine-aquifer hydraulic interaction. In natural condition, saltwater intrusion happens when the low density of freshwater groundwater interacts with the high density of saltwater. Other sources of saline contamination includes connate water of marine origin (Hing, 1995), saline water of canal and of river which hydraulically interacts with aquifer (Mohamad *et al*., 2001). In these studies, hydro-geochemistry analysis from monitoring wells and geophysical methods were used. The best geophysical method to assign, particularly in salinity mapping is geo-electrical method (Loke, 2000). Various researchers around the world have applied geo-electrical method in demarcating coastal-area hydrogeology condition, ever since development of the interpretation technique by Loke and Barker (1996a). Benkabbour *et al*. (2004) used geophysical method in characterizing saltwater intrusion in the plio-quaternary consolidated coastal aquifer of the Mamora Plains, Morocco. Batayneh (2006) used 2-D geo-electric method in detecting subsurface freshwater and saline water at the alluvial shoreline of Dead Sea, Jordan. In Lagos, Nigeria, Adepelumi *et al*. (2009) used vertical electrical sounding survey to delineate saltwater intrusion into freshwater aquifer at Lekki Peninsula. Sherif (2006) integrated geo-electrical method with hydro-geochemical method in delineating seawater intrusion at the outlet of Wadi Ham, UAE. In context of Malaysia, earlier studies Samsudin *et al*. (2002), Jumary *et al*. (2002) and

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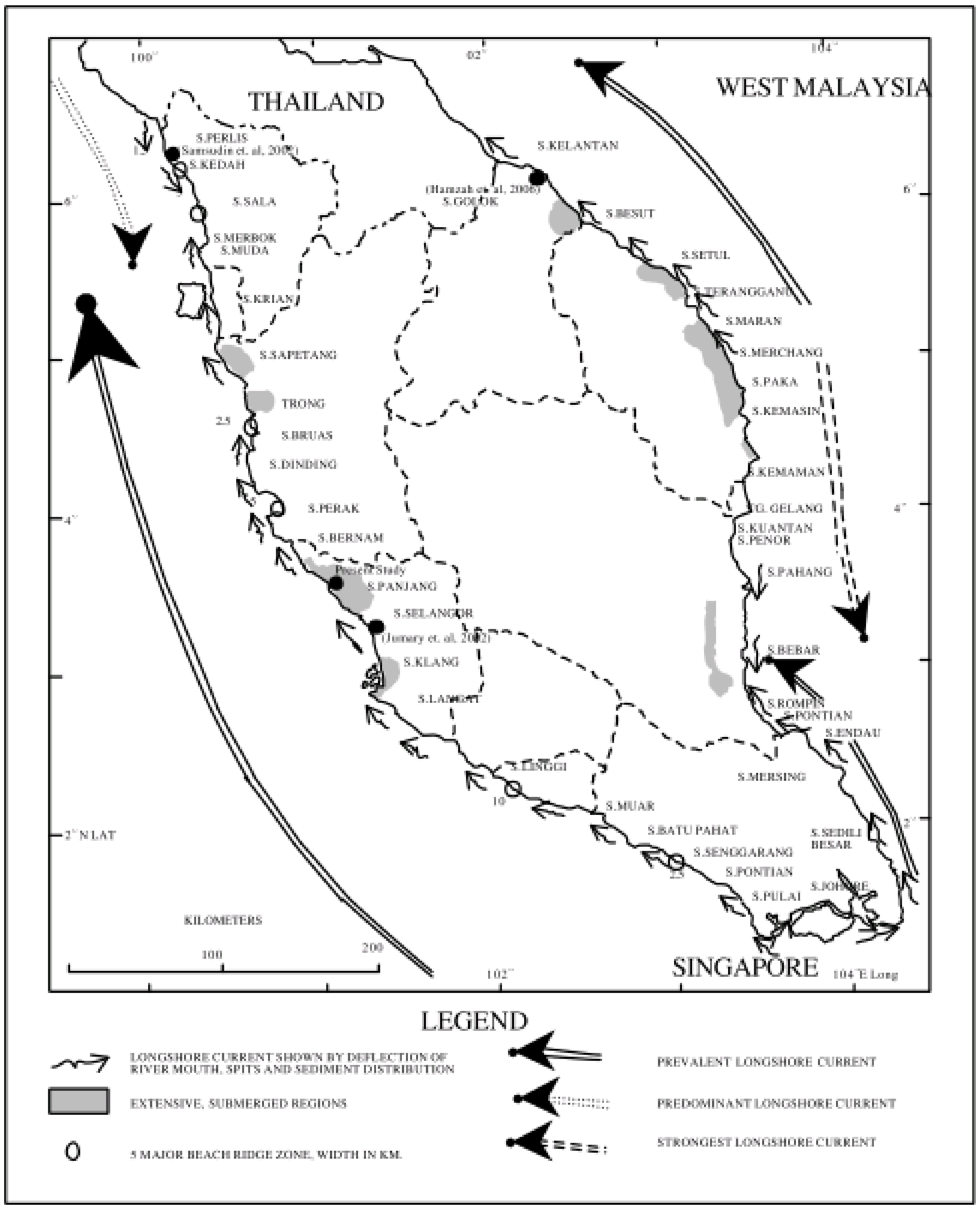


Fig. 1: Map of Peninsular Malaysia showing the location of earlier studies and of present study on salinity. The map also shows the area that received severe erosion due to long shore current (Gobbett and Hutchison, 1973)

Samsudin *et al*. (2008) indicated that saltwater intrusions occurred at several coastal areas in Peninsular Malaysia (Fig. 1). These studies also revealed that geo-electric method, combined with borehole data, is effective in depicting saline-water boundaries as well as subsurface lithology profiles within the area. The same technique was implemented by the authors, at Sungai Haji Dorani, which is located on the West coast of Peninsular Malaysia, to identify saline water (through subsurface profiles) and coastal-area aquifer system, but aided by information related to the environmental history of the area studied. The environmental history that will be discussed here is the physical changes to the coastal area, which can influence determination of the coastal-area's contamination source; saltwater intrusion always been said to be the one.

## MATERIALS AND METHODS

The study area is at Sungai Haji Dorani Village near Sungai Besar (in the district of Sabak Bernam) some 90 km to the North of Kuala Lumpur. The exact location of the area is at longitudes E 101°00' 16.3" to E 101°00' 48.8" and latitudes N 03° 38' 38.6" to N 03° 38' 59.6" (Fig. 2). A topographic map of the area shows that it is a flat terrain from East to West and stretches from North to South to form the long coastal area facing the Straits of Malacca. Two main rivers, the Besar river and the Haji Dorani river, flow from East to West near the area studied, into the Straits of Malacca, indicating that the flow of fresh groundwater is from East to West. The study was conducted for 3 months starting from 1st Nov 2008 until 30th January 2009.

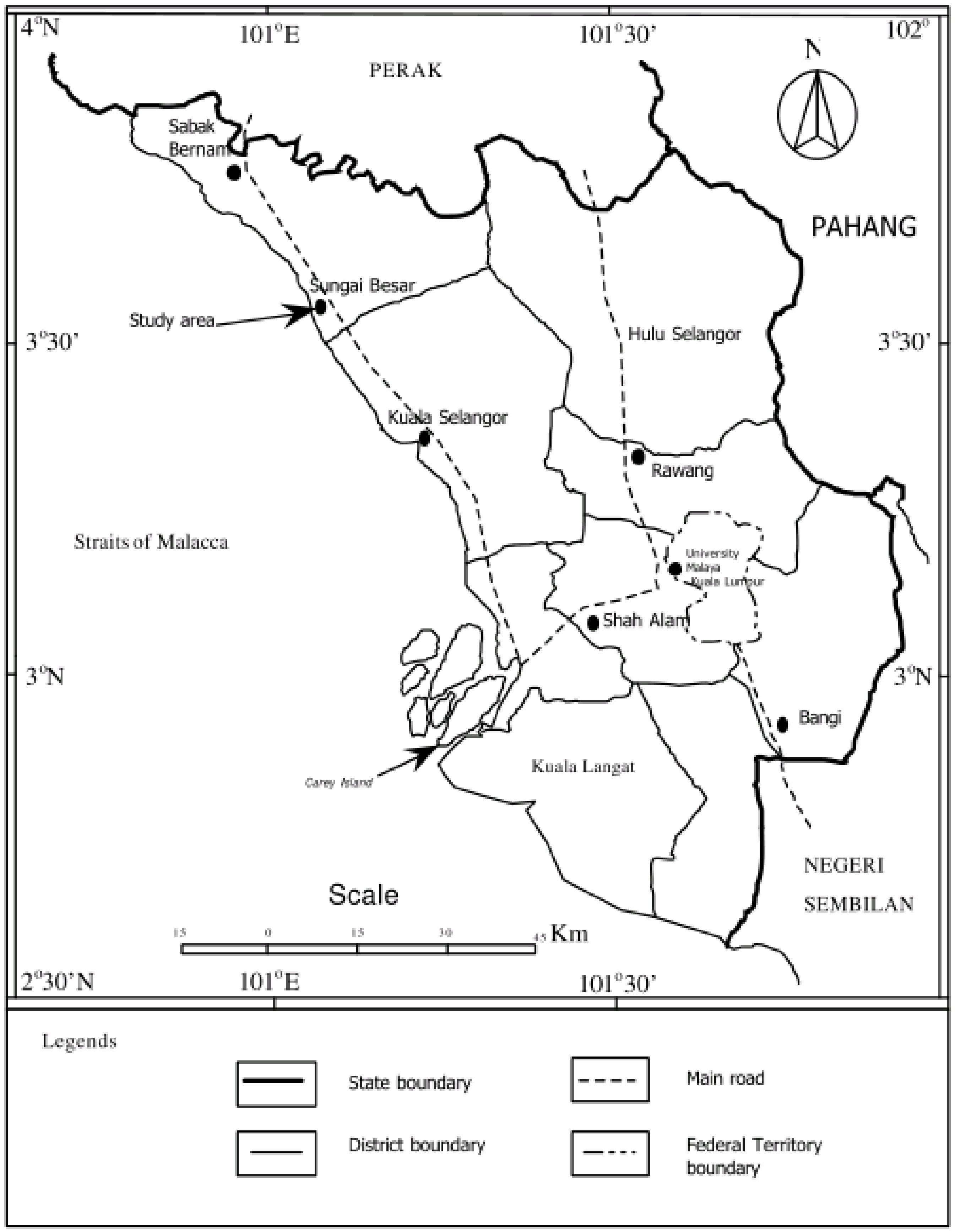


Fig. 2: Location of the area studied

In the area studied, the land is generally used for agriculture, for specific types of plants. In the coastal area, plants with fibrous root, such as coconut tree and palm oil tree, are the main crop, but 1km to the east, the agricultural scenery changes to paddy fields and orchards bearing fruits such as mango. Geomorphology physical changes show the study area to have experienced critical erosion from prevalent long shore current (Gobbett and Hutchison, 1973) (Fig. 1). According to the National Chief Audit Report (2007), the Sungai Haji Dorani beach has faced severe erosion that has resulted in its classification under Category 1, which is the critical level, where economic activities and properties are threatened and socioeconomic impacts has gotten to unacceptable level. It was also mentioned in the report that Category-1 erosion caused loss of the mangrove forest, the bund to be subjected to wave attacks, the gabbion armor to fall and some overtopping. The bund, constructed to prevent overflow of seawater, was built in the 1970s. It is 3.66 m wide and 3.00 m high from the mean sea level (msl) and stretches 1.5 km long. The bund, being near to the sea, has experienced serious erosion caused by overtopping seawater flowing over it during high tide, which reduced its width and height (3.00 to 2.70 m); in its consequent deteriorated state, the bund failed to block seawater overflow when big waves occurred. In 1991, to protect the bund against further erosion, the Department of Irrigation and Drainage (DID) Malaysia built a revetment on the bund's seaward slope.

A topographic survey conducted in January 2009 confirmed that the height of the bund has remained at the level reported before. A station monitors elevation

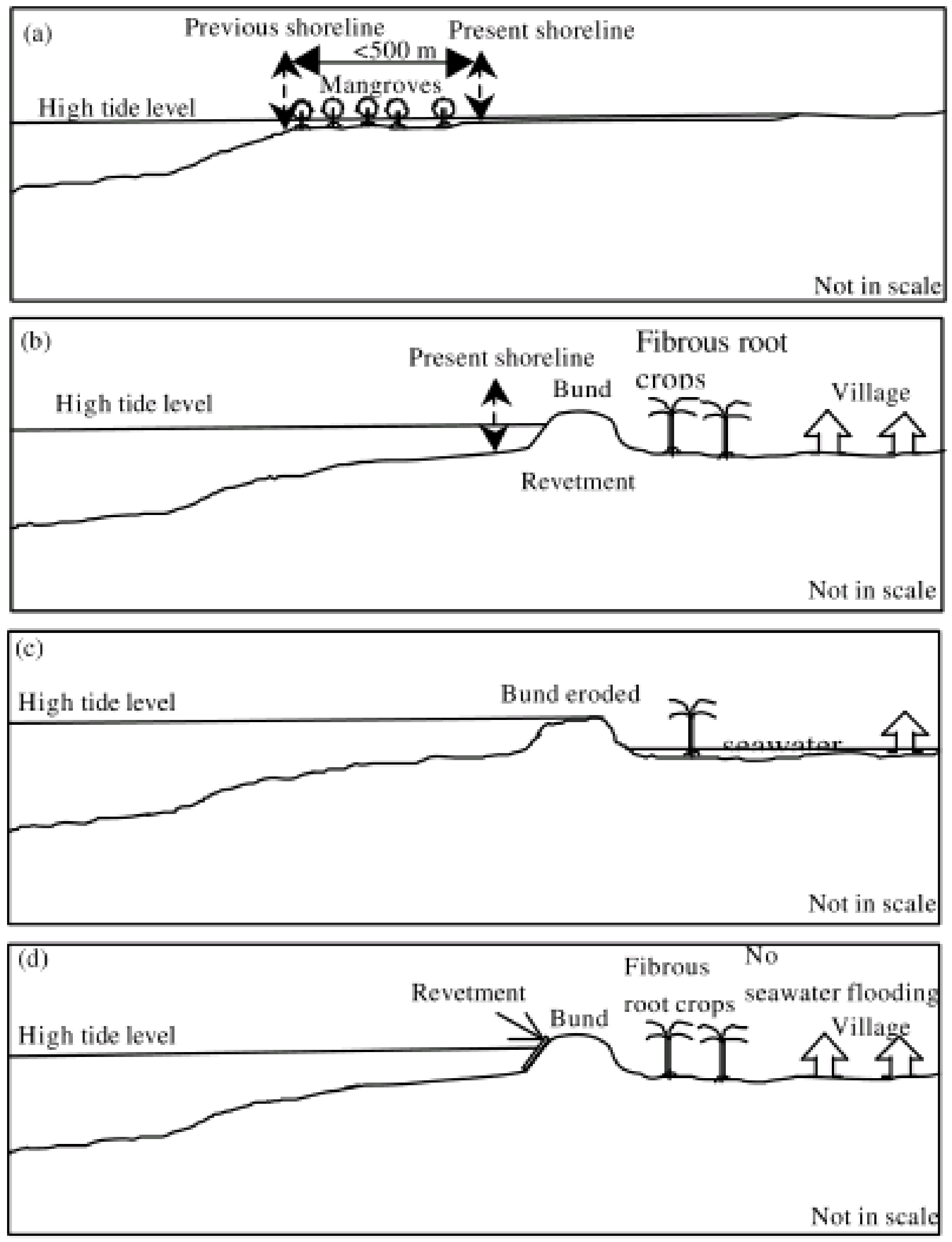


Fig. 3: History of environmental impact to the area studied, (a) 1950, (b) 1977, (c) 1997-1991 and (b) After 1991 present

changes. As for the land surface's height, a survey was conducted based on 6 monitoring wells already existing in the area; the range is between 1.697 and 2.047 m.msl. This shows that during high tide, if the bund had not been present and the revetment had not been constructed, the area would have been flooded by an overflow of seawater, more than 1m from the land surface. In 1991, after the revetment's construction, seawater stopped overflowing into the study area. At the moment, the rate of erosion is unknown, but from discussions with locals, in the 1950s, the shoreline width was 500 m wider than it is now (2009). Figure 3 shows the history of changes to the coastline and of the area's seawater overflow.

The subsurface data was obtained between November and December, 2008. Six monitoring wells, 10-80 m, were constructed. Rotary-wash-boring method was used in drilling the boreholes; they were drilled by locally trained drillers, with their technical supervision and instruction given according to BS 5930 (1999). Soil samples were collected for visual examination and for laboratory test experiments to determine their physical parameters (BS 1377, 1990).

Resistivity traverses were performed in one day in November 2008. The geo-electric surveying was conducted by the proposed device, ABEM Terrameter SAS 1000 C, combined with ES 10-64 electrode selector. Two resistivity image profiles ($L_1$-$L_2$, Fig. 4) were measured across the area. For each profile, 81 electrodes were strung and anchored into the ground surface at the site. The survey traverses were oriented W-E. The Wenner array was chosen for the resistivity traverses because it gives a dense near-surface cover of resistivity data. Also, the array provides a good vertical resolution and can give a clear image of groundwater and sand-clay boundaries as horizontal structures (Hamzah *et al*., 2006). The Wenner array provides the basic configuration, with electrodes of 1a constant spacing. By using the Wenner array, current was injected into and received from, the ground, through two outer electrodes, $C_1$ and $C_2$. The potential difference was measured between two inner electrodes, $P_1$ and $P_2$. The configuration was kept constant and moved along the profile until all possible measurements had been made with 1a electrode spacing. Measurements were then made by using electrode

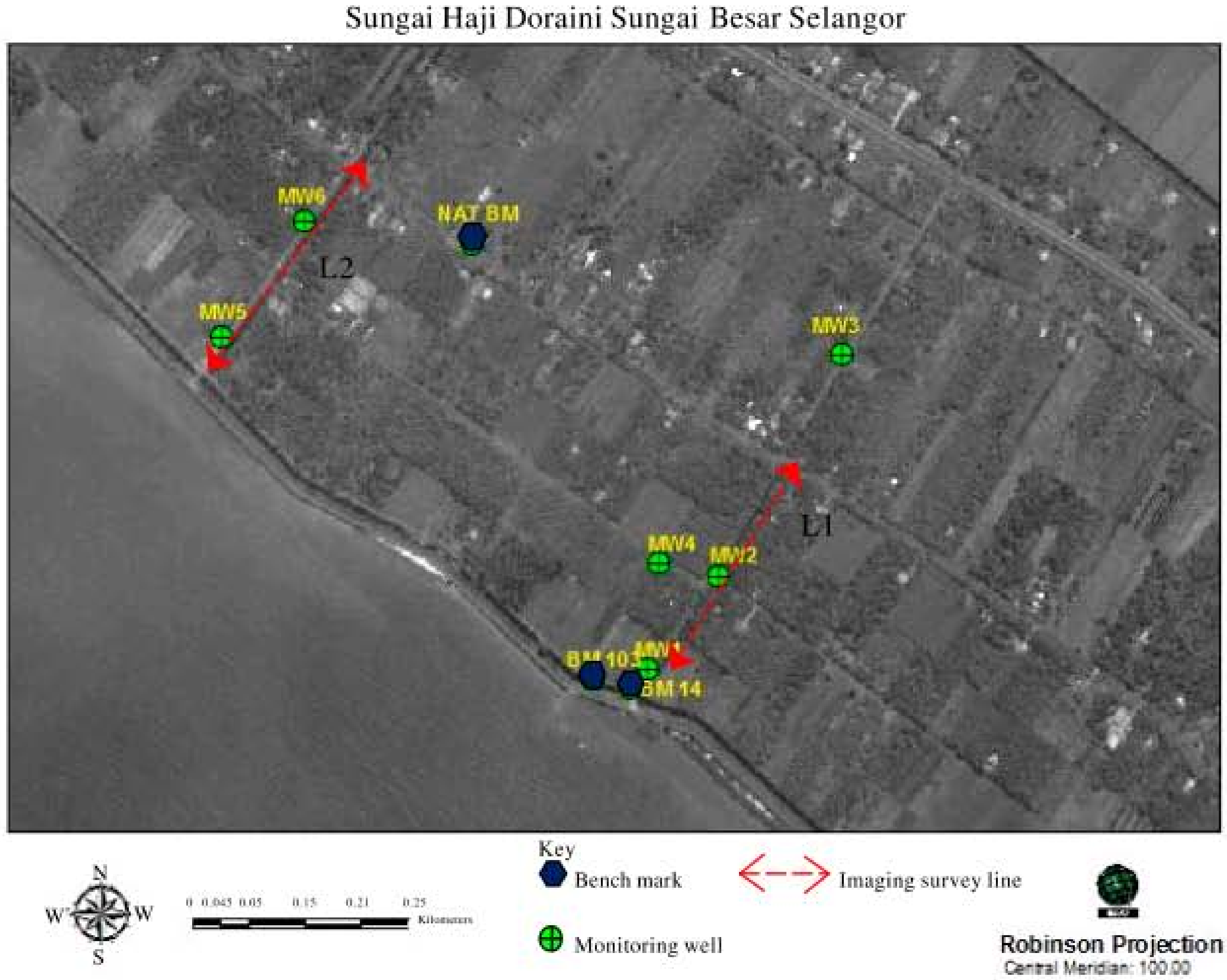


Fig. 4: Location of monitoring wells, survey lines and bench mark (Satellite image captured on May 2008)

combinations that gave basic separations of 2a, 3a, 4a, etc (Fig. 5) so that information about deeper structures beneath the profiles could be obtained (Loke, 2000). The data gathered in this survey were interpreted through the RES2DINV software of Loke *et al*. (2003) to provide an inverse model that approximates the actual subsurface structure. Holes in the apparent resistivity data were filled-up by using Surfer 8. The holes were caused by the negative resistivity obtained during data acquisition. Nearest-neighbour method was used as it is the most effective method in filling holes in the data or creating a grid file with blanking values assigned to those locations where no data were present. Another advantage of this method is that it does not extrapolate Z grid values beyond the data's range. To obtain a resistivity section, the inversion algorithm, RES2DINV was used to process the data, as proposed by Loke and Barker (1996b). The inversion routine used by the program RES2DINV is based on the robust method. Nassir *et al*. (2000) had used the robust method effectively in their saltwater-intrusion study. This program divides the two-dimensional model used in the subsurface into a number of rectangular blocks (Loke and Barker, 1996b). To minimize the difference between the measured and the calculated apparent resistivity values, the resistivity of the blocks was adjusted iteratively. The latter was calculated by the finite-difference method of Dey and Morrison (1979). Resistivity field data collected through the Wenner array from individual survey lines were inverted individually to generate a two-dimensional Wenner resistivity model. The inversions were performed on an AMD Athlon(tm) 64 X2 Dual-Core Processor TK-57 1.90 GHz with 3.00 GB of RAM. An initial model was produced, from which a response was calculated and compared to the measured data. The starting model was then modified in such a way as to reduce the differences between the model response and the measured data. The differences were quantified as Root-Mean-Squared (RMS) errors. This process continues iteratively until the RMS error falls within acceptable limits, usually below 5%, or until the change between RMS values calculated consecutive iterations becomes insignificant (Batayneh, 2006). The model with the lowest possible RMS errors, however, is not always the most appropriate one as it can show unrealistic variations in the resistivity model (Loke, 2000). The data were edited to remove extreme and bad points. Random

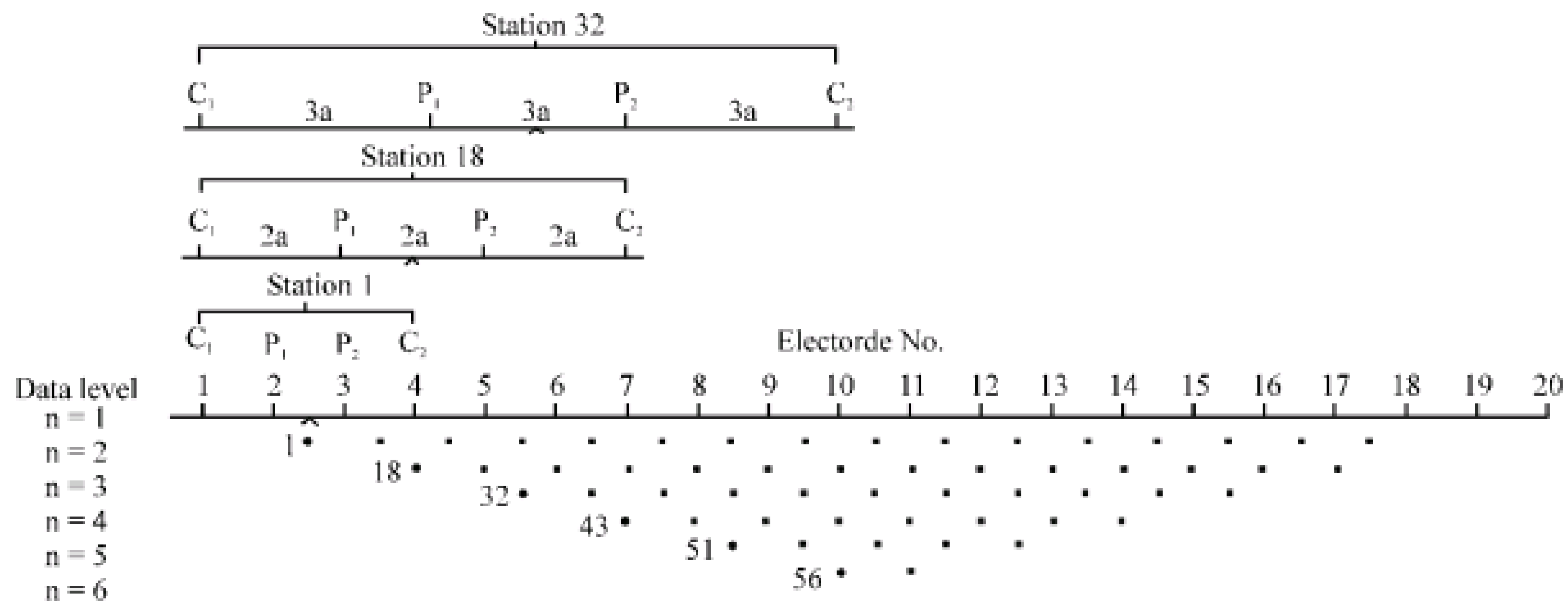


Fig. 5: The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo-section (Loke, 2000)

low or high apparent resistivity values would distort the derived resistivity model. Finite difference method was used as the data did not include topography. Given the relatively flat surface of the field area, it was concluded that the topography would not significantly affect the resistivity models. To make the calculated apparent resistivity values more accurate, the mesh grid used had 4 nodes between adjacent electrodes, with intermediate-mesh-size refinement. The distribution of percentage difference between the logarithms of the observed and the calculated apparent resistivity values was used to eliminate misfits of individual data points. Both data from $L_1$ and $L_2$ show maximum apparent resistivity of more than 300 times the minimum value and showed large resistivity variations near the surface. To obtain a significantly better result, half-unit electrode spacing was used.

Two-dimensional inversion techniques are common and often acceptable in assessing resolution and in the determination of data-set limitations, as shown by Dahlin and Loke (1998). The resistivity of fresh groundwater varies from 10 to 100 Ωm depending on the concentration of dissolved salt. Note the low resistivity (less than 0.2 Ωm) of sea water, caused by the relatively high salt content (Loke, 2000). This makes the resistivity method an ideal technique for mapping saline and fresh water interface in coastal areas. Alluvium resistivity was noted to range from 10 to 800 Ωm depending on soil type.

## RESULTS AND DISCUSSION

Based on borelog analysis, the lithology is composed of Quaternary alluvium sediments more than 80 m deep. The Quaternary alluvium sediments were composed of alternating layers of sand, silt and clay. No gravel was found during drilling and sampling. The groundwater potential within this area was indicated to be of poor-to-intermediate potential. Also, sand size (more than 70% of which ranging from 0.1 to 0.3 mm), can be categorized as fine according to AASHTO soil classification, if based on grain size (Liu and Evett, 2005). As field-pumping test had not yet been carried out in evaluating hydraulic conductivity, the Hazen formula was used (Fitts, 2002),

$$K = C(d_{10})^2 \tag{1}$$

where, K is hydraulic conductivity in cm $sec^{-1}$, C is a constant with units of (cm sec)$^{-1}$ and $d_{10}$ is the grain diameter in centimeters such that grains this size or smaller represent 10% of the sample mass.

The hydraulic conductivities for fine sand in the area studied were between 0.004 and 0.01 cm $sec^{-1}$ with d10 = 0.01 cm. Sieve analysis of 20 sand samples showed the C value of 40-100 (cm sec)$^{-1}$ for fine sand. Soil classification was based on hydraulic conductivity (Terzaghi *et al*., 1996) and the values obtained show that the soil is of moderate permeability ($4\times10^{-5}$ to $1\times10^{-4}$ m $sec^{-1}$).

Figure 6a and b show a typical cross-section of the area studied. Two aquifers were found to be present in the Quaternary sediments. All aquifers are separated by a semi-impermeable clay layer. The presence of fragmented shells at depths ranging from 1.00 to 9.00 m proved that the uppermost impermeable-layer deposit was carried by marine current. The thickness of the uppermost semi-impermeable layer varied from 18.00 to 34.50 m below ground surface, composed of light grey, marine silty clay. The first confined aquifer is composed of fine, light grey sand, with silty marine clay and shells. The depth and thickness of the aquifer below the marine-clay layer ranged between 25.00 and 33.00 m. The second aquifer was encountered at depths of 54.0 to 58.5 m, consisting of light grey, fine sand and unmixed with other soil materials.

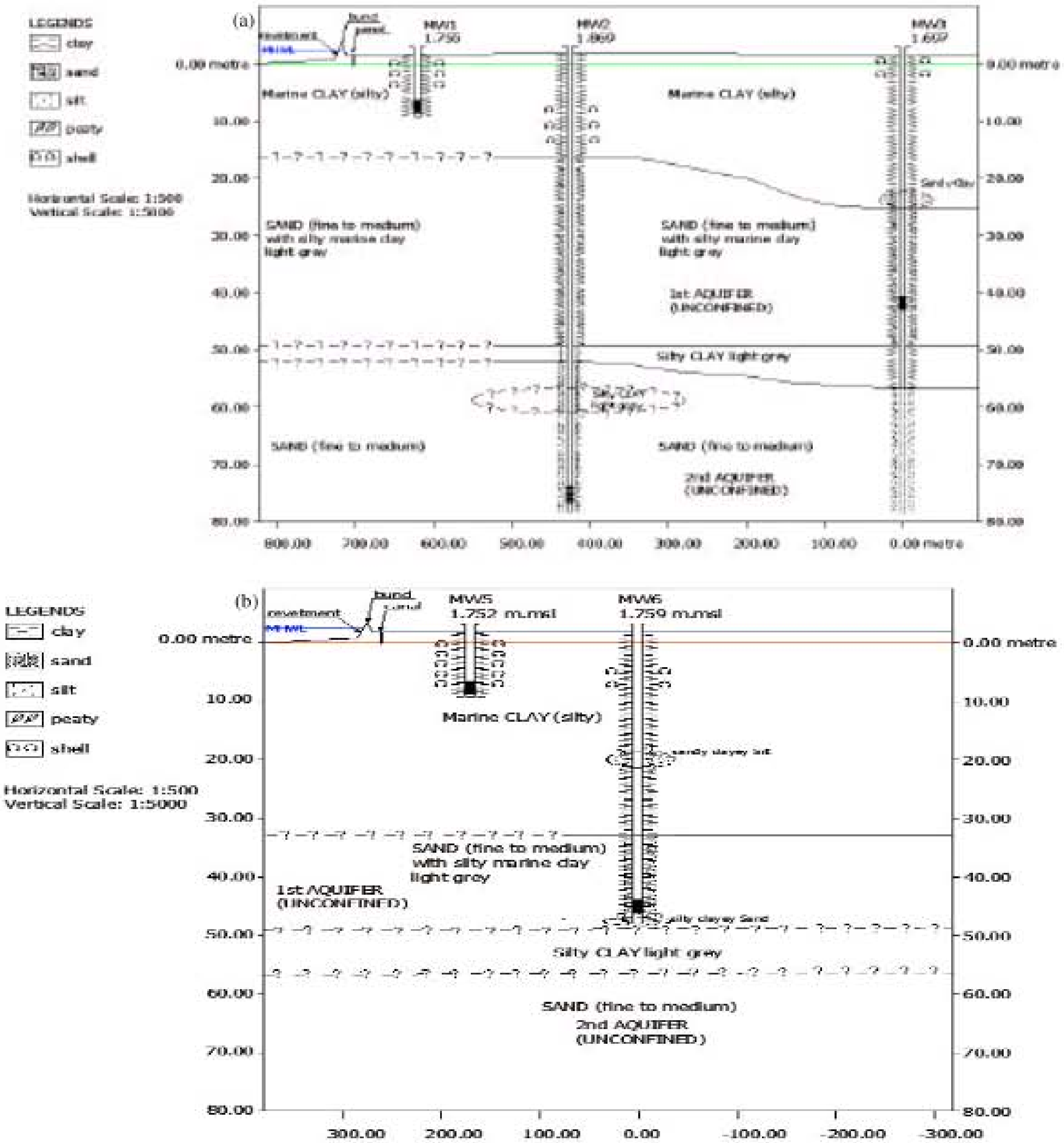


Fig. 6: Subsurface geology from (a) MW3 to MW1 and (b) MW6 to MW5

The thickness of these aquifers was unknown owing to borehole-depth limitation. Bedrock was not encountered at the area. Based on the Gobbet and Hutchison (1973) report, boring conducted at the lower Bernam river, 15 km away from the area studied, penetrated weathered Quartzite bedrock at 135 m deep. There was no groundwater extraction for domestic or for economic use in this area. Detailed investigation of the soil studied provided better pictorial information of the area's geological strata and hydro-geological condition.

The salinity of groundwater and soil water under ground level was determined by using two resistivity lines ($L_1$ and $L_2$). As a reminder, the salinity of water is qualitative, not quantitative. The resistivity line L1 runs and crosses from monitoring wells MW1 to MW2, East-West, for a total length of about 400 m. Figure 7a and b show the inverse resistivity image of this line. The RMS error values calculated for $L_1$ is 5.2% and $L_2$ is 8.3%.

On the top layer, the resistivity image was dominated by saline and brackish water of low resistivity, in the 0.02 to 5 Ωm range. Domination of this type of water crosses over marine clay and sand layer as the first unconfined aquifer with depths ranging from 0 to 35 m from ground level. The influence of salinity still dominated the full 400 m image distance. Meanwhile, at the second unconfined aquifer, the range of resistivity was from 15 to 80 Ωm. The second aquifer was indicated to be dominated by fresh groundwater. The image showed spots of saline water, starting from the top of the marine clay, to the sandy aquifer layer. In the marine-clay layer, saline water spots movement was inclined and after a depth of 18 m (fine sandy aquifer) lateral dispersion

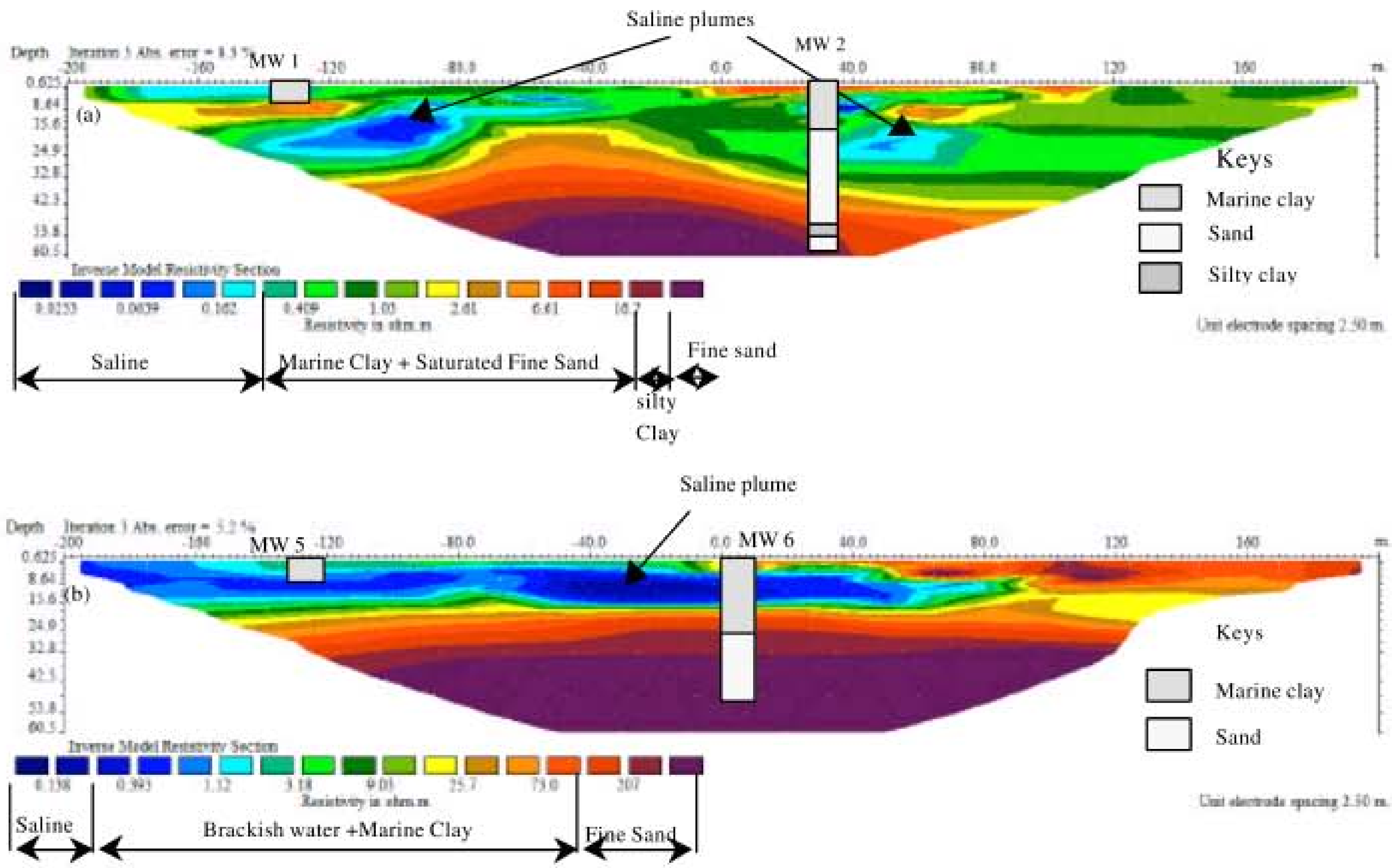


Fig. 7: Inverse model section for (a) line $L_1$ and (b) line $L_2$

started. This shows that the dispersion of saline-water spots in the marine clay moved gravimetrically and through the high porosity of the marine clay as saline water is denser than freshwater. After entering the sandy aquifer regime, freshwater flow pushed the saline-water spots into the Straits of Malacca. The other resistivity line, $L_2$ running and crossing from MW5 to MW6, revealed that the uppermost resistivity image is still dominated by salinity, with resistivity ranging from 0.01 to 5 Ωm, but it is dominated by marine-clay layer, from the ground level to 18.0 m deep. A preliminary conclusion is that the first aquifer on the $L_2$ profile is not contaminated by salinity compared with the $L_1$-profile's resistivity image. The distance of salinity is shorter in $L_2$ (about 250 m from the shoreline) than in $L_1$. The resistivity at depths below 18.0 m ranges from 10 to 800 Ωm, indicating that the second aquifer is not contaminated. From the hydrodynamic aspect, the diffusion of the saline spots did not spread to the first aquifer.

Earlier studies done by Jumary *et al*. (2002) and Samsudin *et al*. (2002) had mapped the distribution and profile of the salinity along the coastal area of West Peninsular Malaysia; these aligned with the current study. Relatively, in geological lithology, their study located at Quaternary alluvium sediments which had the same geological condition with the current study. Their studies consists of marine clay on the top layer with the depth of 15 to 30 m and aquifer can be found after that layer with the thickness of 30 m. The results from the electrical imaging resistivity aided with borehole data showed that the saltwater appears to have extended laterally as far as 7 km from shoreline with the resistivity value of less than 1 Ωm. The depth of the saltwater can reach down to 30 m especially near the coastal area (Samsudin *et al*., 2002). Study conducted by Jumary *et al*. (2002) showed that the saltwater penetration (resistivity value less than 5 Ωm) near the coastal area in the range from 4 to 8 km with the depth of 30 m. Both studies described the decreasing in the resistivity value (increasing in the salinity value) towards the shoreline was believed to have a direct relationship with the saltwater intrusion. Compared to the current study, the saline contamination did not happen as a whole, only at short distance as showed in profile $L_2$ which contradict with the previous study. The electrical image resistivity showed that the decline movement of salinity from top surface caused by previous seawater flooding. The lateral movement of the salinity towards the sea by fresh groundwater flow showed the best evidence that the salinity condition is not from seawater intrusion. In addition, the report by Gobbet and Hutchison (1973) mentioned that this area was in the extensive submerged region which strongly proved this area has experienced seawater flooding before (Fig. 1). Concurrently, the condition became worst with the severe erosion of the shoreline which allows the seawater flooding to spread more extensively further to inland. Installation of revetment on the bund's seaward slope in 1991 stopped these impacts. Furthermore, the previous studies were not located at submerged region that can be used to support the saline contamination came from the percolation process of previous seawater flooding. This study suggested that the mapped of submerged region produced by Gobbet and Hutchison (1973) and report of the environmental impact of the study area can be used to give preliminary information to study the salinity condition along coastal area in Peninsular Malaysia.

Further study need to be done to confirm the qualitative results obtained. Among the required quantitative data are sampling and geochemistry analysis on the constructed monitoring wells, aquifer-leaking test through piper diagram to confirm leakage source, additional borehole-information and pumping test to obtain hydrogeology parameters and the aquifer's capability in producing ground water. A modeling of this area's groundwater flow could help in understanding its groundwater movement and predict salinity of the water.

## CONCLUSIONS

The application of geo-electric method aided by borehole data has demonstrated that electrical-resistivity imaging is an effective tool in defining environmental impact. The aquifers can be concluded to be dominated by fresh groundwater flow regime and the presence of saline water spots concluded to be owed to previous floods that happened continually and not from saltwater intrusion. Saltwater intrusion is believed to have happened beyond 500 m of the existing shoreline before entering the first aquifer. Severe erosions were spotted at other areas including the one studied, as Fig. 1 shows.

Another conclusion is that tidal flooding caused the salinity problem. This study can also assist local authorities and villagers when planning the area's socioeconomics, through understanding of the preliminary results of salinity into soil and groundwater at the coastal area.

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