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Geophysical mapping of saltwater intrusion in the Kerpan coastal area, Kedah

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Abstract: The salinity of the ground water in the coastal alluvial aquifer between Kerpan-Air Hitam and Sanglang area in Kedah was investigated using both vertical geoelectrical sounding (VES) and 2-D geoelectrical resistivity imaging techniques. The resistivity measurements were made using ABEM SAS 300C and SAS4000 terrameters. A total of 61 VES stations were established over an area of approximately 100 km^2 of Quaternary alluvium. The 2-D imaging was used to study the lateral and vertical changes in resistivity of the alluvial sediments. Salinity of the ground water was interpreted based on the apparent resistivity values. Ground water with resistivity values less than 5 ohm-m is considered as saline and those of greater than 100 ohm-m is fresh water. The resistivity values ranging from 5 to 100ohm-m is for brackish water. The VES and imaging results show that the ground water has resistivities ranging from 0.53 to 670.5 ohm-m. The results of spatial distributions of apparent resistivity indicate that the ground water is mainly brackish with the salt-water affected aquifer confined to the coastal part of the study area. Vertical variations of the resistivity values plotted along profiles perpendicular to the coastal line, indicate that the saltwater has significantly affected the ground water at depth and far away from the coastal area.

INTRODUCTION

The geoelectrical resistivity technique is widely used to measure the geoelectrical resistivity and conductivity of materials in the subsurface. Variations in these two parameters are caused by changes in soil characteristic structures, clay content, degree of water saturation and conductivity of this water. Taking advantage of the relationship between electrical resistivity and chloride ionic concentration, we have attempted to map the saltwater intrusion in the Kerpan alluvial deposits and interpreted ground water aquifer using both vertical electrical sounding (VES) and 2-D resistivity imaging techniques. This study was conducted in collaboration with the Malaysian Institute of Nuclear Technology (MINT) who was requested to investigate the impact of a prawn aquaculture industry and sea-water intrusion to the quality of groundwater in the coastal part of Muda Irrigation area in north Kedah (Bashillah Baharuddin *et al.*, 2001).

The building of canals and a prawn aquaculture industry in the area over the past years has modified the pre-development conditions producing major changes in the ecosystem of the study area. The farmers are extremely concerned about the amount of salt water that has been allowed to flow through the operating prawn farm properties and adjacent areas via flood mitigation channels. Their concerns relate to the problems of salt water intrusion into the groundwater (1.5 – 2 m below surface) as well as into the productive paddy fields in the area.

The mapping of saltwater intrusion in coastal aquifers has traditionally relied upon observation wells and collection of water samples. This approach may miss important hydrologic features related to saltwater intrusion in areas where boreholes or wells are limited and widely spaced, such as the Kerpan area of Kedah. Bashillah Baharuddin *et al.* (2001) has investigated the salinity of the ground water only in the vicinity of the prawn aquaculture area of Kerpan. This study emphasizes not only on the salinity of groundwater in the aquaculture area but it also involved studying the aquifer properties and salinity of the groundwater in much wider area.

To map saltwater intrusion in this area, a different approach has been used. We have relied heavily on vertical electrical sounding (VES) measurements to map lateral variations of electrical resistivity, which are directly related to water quality. Because the bulk resistivity of geologic formations is highly dependent upon pore-water salinity, the resistivity data can give an indirect measure of water quality in the study area.

STUDY AREA AND GEOLOGICAL CONDITION

The area under investigation is located on the north west coast of Peninsular Malaysia, situated along the coastal plain of north Kedah (Fig. 1). It covers an area of about 10 km long and 10 km wide along coastal zone between Air Hitam, Kerpan and Sanglang towns in the district of Jerlun, Kedah. It represents part of the flat Kedah alluvial plain. The Kedah coastal plain is covered with Quaternary sediments and drained mainly by short rivers, streams and canals flowing into the Strait of Malacca. The central part of the plain is drained by the Kerpan river, and in the south it is drained by the Jerlun river.

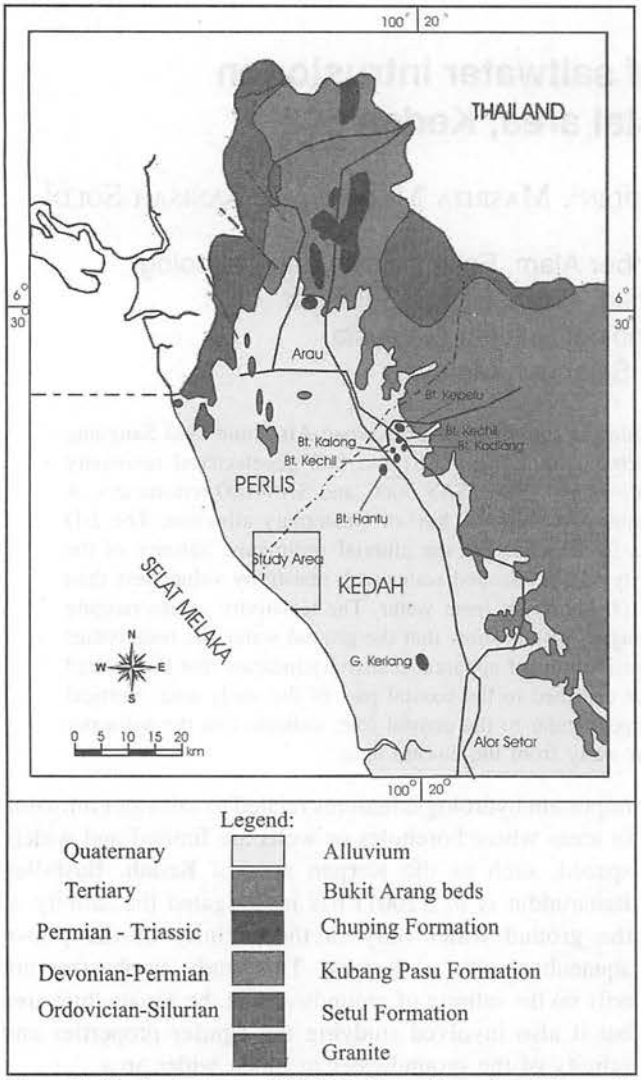

Figure 1. Geological map of NW Kedah and location of the study area.

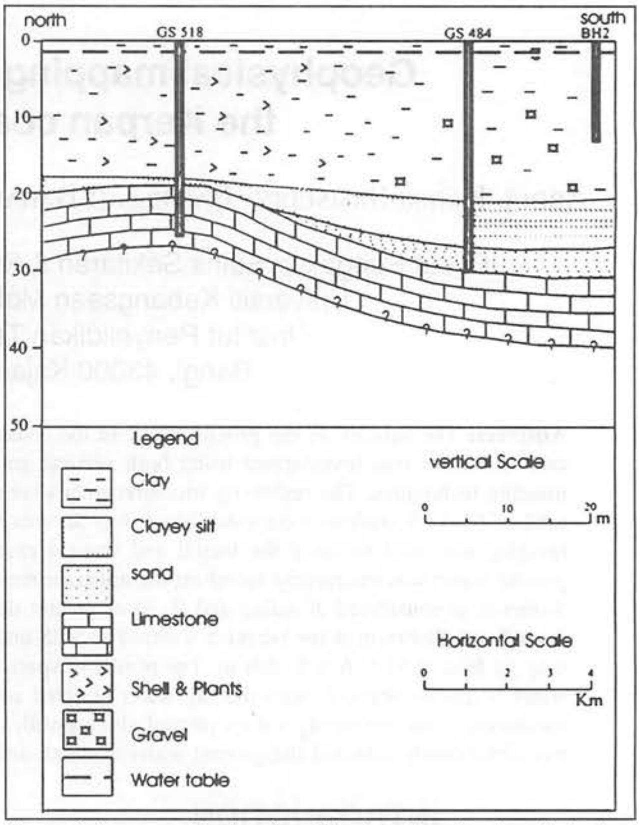

Figure 2. Interpreted subsurface lithology based on borehole data.

The overall thickness of the Quaternary deposits in the study area is not known but based on the existing data of bore holes located about six to seven km from the coast, it varies from 20 to 30 m. However the deposits in the coastal area is expected to be thicker. The Quaternary sediments consist of thick upper layer of silty clay and fine to coarse sand layer at the bottom. These layers are underlain by limestone bedrock of Chuping Formation (Jones, 1978)

GEOHYDROLOGICAL CONDITIONS

The groundwater resources in north Kedah area occur in an interpreted coastal alluvial aquifer overlying basement rocks. Schematically, based on data of boreholes (GS484 and GS518) drilled by the Department of Mineral and Geoscience, two detrital Quaternary units can be differentiated. The lower unit is interpreted as a semi-confined aquifer composed mainly of fine to coarse sand, and the upper unit constitutes an aquiclude consisting of thick marine clay (Fig. 2).

The aquiclude layer occupies the entire study area with thickness varies from a few metres to a maximum of about 27 m. The underlying semi-confined aquifer layer, which is underlain by the limestone bedrock appear to increase in thickness towards south. Information from the existing boreholes suggests that the semi-confined aquifer is thin and discontinuous in nature. However this fact needs to be verified by drilling more bore holes in the future works.

GEOELECTRICAL RESISTIVITY SURVEY

The VES survey was conducted to determine the thicknesses and resistivities of the subsurface alluvial layers in the study area. This technique was chosen for its low cost and usefulness in defining the expected targets. Saltwater is electrically very conductive and is easily detectable with geoelectrical techniques. Electrical resistivity was used to determine if the water within the alluvial and aquifer layers was brackish or fresh and to establish its spatial and vertical distributions.

The VES and imaging measurements were carried out using ABEM SAS300C and SAS4000 terrameter respectively. For all the vertical electrical soundings that were carried out, the Schlumberger array was used. A total of 61 VES stations with current electrode separation of up to 600 m were established (Fig. 3). The maximum electrode separation was sufficient to reach the desired investigation depth. Quantitative interpretation to determine the specific resistivities and subsurface layered thicknesses was carried out using the partial curve matching method (Bhattacharya & Patra, 1968) and a resistivity interpretation software (Resix). Five geoelectrical imaging lines were also established to determine the vertical distribution of the subsurface resistivity in the coastal and inland areas.

The interpretation of the resistivity soundings took into account the borehole data and the hydrogeological concept of a simple groundwater system in coastal aquifer described by Urish & Frohlich (1990) and Flathe (1976). The main components of a simple groundwater system in a coastal zone are unsaturated zone, a fresh-water layer, a transition zone, and underlying salt-water which may be bounded by bedrock at depth. Information from the boreholes were used in the interpretation of the resistivity data.

RESULT AND DISCUSSION

Subsurface geological condition

In this work, information on soil stratification and aquifer position below ground surface were interpreted from the existing borehole data. Figure 2 shows sedimentary sequence of the Quaternary deposit in the study area obtained from a vertical section of boreholes GS484 and GS518. The boreholes appear to pass through the semi-confined groundwater aquifers and hit the limestone bedrock at depth of about 30m and 18m below ground surface respectively.

The aquiclude, which consists of predominantly silty clay lies between 0 to 27 m depth below ground surface. Underneath it, there is a semi-confined aquifer layer which occurs at depth from 27 to 30 m.

There is no information regarding the lateral extension of the aquifer but information from the two boreholes suggested that their thickest section is located in the southern part of the study area. The aquifer is bounded by the limestone bedrock which is interpreted to have an irregular topography and probably cavernous in nature.

Resistivity sounding data

The interpreted VES data give four to six geoelectrical layers with resistivities range from 0.53 Wm to a maximum of 670.5 Wm. The first resistivity layer with thickness between 0.27 m and 4.2 m represents the top alluvial layer, which consists of unsaturated and part of saturated zone with resistivity values ranging from 0.32 Wm to 203 Wm. This layer consists of dark coloured clays with shells as indicated by the borehole data. The wide range in resistivity of the layer is interpreted to be due to the sea water intrusion or the effect of fertilizers used by the farmers.

The second and third resistivity layers give resistivity values ranging from 0.53 ohm-m to 56.3 ohm-m. The layers are variable in thicknesses with depth of up to 29 m. They represent the aquiclude layer which is mainly made up of silty clay. The low resistivity values suggest that the aquiclude materials contain mainly brackish with salt-water confined to the upper portion of the layer. The salt-water appears to have extended laterally as far as 7.0 km from the coastal line (Fig. 4). Abdul Rahim Samsudin *et al.* (1997) has detected the salt water intrusion in north Kelantan (east coast of Peninsular Malaysia), as far as seven kilometers from the coast.

The fourth and fifth layers have the resistivity values between 0.16 ohm-m and 252 ohm-m. These layers are interpreted to represent the semi-permeable and semi-confined aquifer layers, which are made up of fine and coarse sand respectively. The layers extend up to a maximum depth of 90.0 m below surface. The extremely low resistivity anomalies (<1.0 ohm-m) which occur in several isolated zones suggest the presence of salt water,

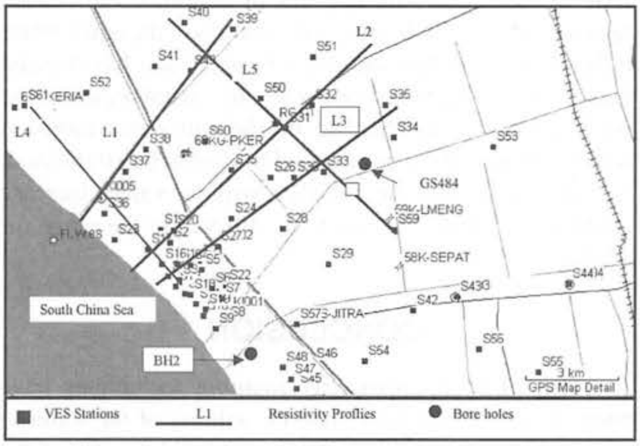

Figure 3. Location of VES stations and boreholes.

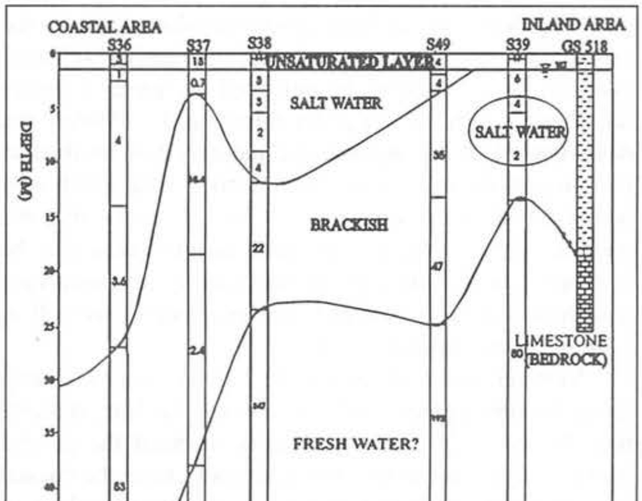

Figure 4. Interpreted subsurface salinity profile based on five VES stations.

probably trapped in marine clay lenses in a mainly brackish water dominated layer. The ground water in this aquifer has probably been contaminated by the salt-water from the top aquiclude layer.

The sixth layer with resistivity of up to 347.7ohm-m is interpreted to be the limestone bedrock with fresh water. The limestone bedrock was detected only at a few sounding stations and this suggests the bedrock occurs at different depths and its probably has irregular subsurface topography. This is substantiated by the two borehole data which recorded limestone at depths of 18.0 and 30.0 m respectively.

The spatial distribution of the resistivity was studied by contouring the resistivity values for each of the interpreted resistivity layers. The contouring was accomplished by using the commercially available SURFER software. The surfer plots indicated that the zone of low resistivity appears to dominate the coastal region especially in the prawn pond areas of the aquaculture industry (Fig. 5). This indicates the salt water has affected the salinity of the ground water in the coastal region of the study area. The mechanism of the salt-water intrusion which is believed to has occurred has yet to be established. It is also noted that the overall resistivity values increase slightly away from the coast but still within the range for brackish water.

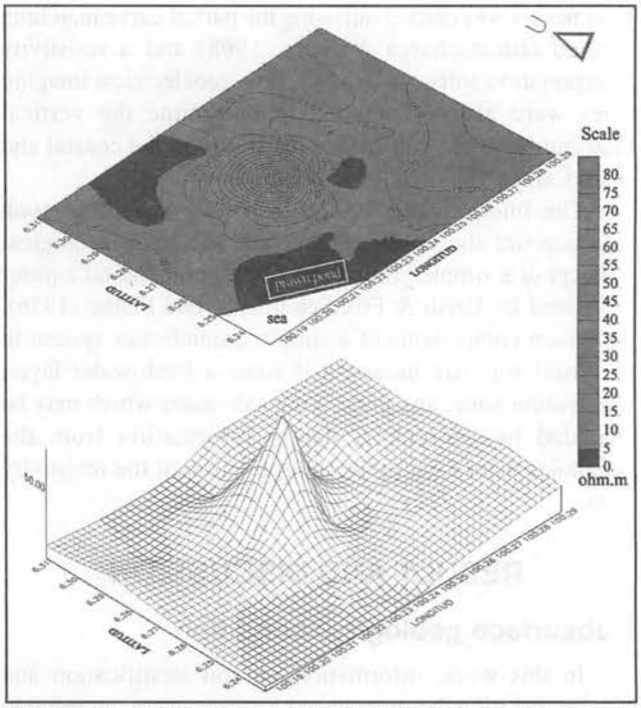

Figure5. Spatial distribution of resistivity plot showing zone of low resistivity in the coastal region.

CONCLUSION

The VES and resistivity imaging techniques have been successfully used to map the salinity of the water in the aquiclude materials and semi-confined aquifer of the study area. The water saturated clay of the aquiclude is generally brackish but it appears to be saline nearer to the coast. The decreasing resistivity (increasing salinity) towards the coastline is believed to have a direct relationship with the sea water intrusion. In addition, the development of the aquaculture industry has resulted in pumping of the sea water into the study area which may increased the intrusion effect. It is also noted that the geoelectrical resistivities vary with depths which may be attributed to differences in the nature of subsurface aquiclude and semi-confined aquifer materials as well as salinity of the ground water.

Vertical variation of the resistivity values plotted along profiles perpendicular to the coastal line, indicate that the saltwater has significantly affected the ground water at depth and as far as 9.0 km away from the coastal area. It is suggested for future works that the chemistry of the ground water in the aquifer has to be thoroughly studied and systematically monitored to ensure the sustainability of the ground water resources.

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