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Salinity study of coastal groundwater aquifers in north Kelantan, Malaysia

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Abstract: The salinity of the ground water along the coastal aquifers of north Kelantan was investigated using both geophysical and hydrogeochemical methods. In the geophysical method, a geoelectrical sounding technique was employed using ABEM SAS 300C terrameter. A total of 53 sounding stations had been established and resistivity values of the ground water in different aquifers were determined. Salinity of the ground water was interpreted using a classification made by Flathe (1974). Based on this classification, ground water with resistivity values of less than 45 Ohm-m is considered as saline or brackish water and those of greater than 45 Ohm-m is fresh water. The results show that the ground water of the first top aquifer is fresh with resistivities ranging from 47 Ohm-m to 164 Ohm-m except in an area along the coast where the water is brackish. The ground water of the second aquifer generally has resistivity lower than 45 Ohm-m and has been classified as brackish water. Resistivity map of the second aquifer indicates that the brackish water covers an area of up to about 6 kilometres from the coastal line. Only few resistivity data were obtained for the third aquifer and values are generally low (ranging from 56 to 72 Ohm-m) indicating that the ground water is relatively fresh.

Salinity of the groundwater in all of the aquifers was also studied by analysing their chloride content. Ground water with chloride concentration of less than 250 mg/l is classified as fresh water and those having higher concentration of chloride is considered brackish or saline. Results of the water analysis show that the chloride concentration of the first aquifer is low and averages to only 15.8 mg/l. The fresh water/ saline water interface in this aquifer is generally located directly in the coastal area, or very close to it. The concentration of chloride in the second aquifer is high with values ranging from 500 to 3,600 mg/l and covers an area of up to about 6 kilometres from the coast. Beyond this area, the concentration of chloride appears to be low, with values ranging from 2 to 110 mg/l. Continuous monitoring of its chloride content (Haryono, 1997) indicates little changes with time inferring that the high salinity is not due to seasonal sea water intrusion. The analysis also reveals low concentrations of sulphate which suggest that the groundwater of the second aquifer may represent fossilised sea water. The chloride content in the third aquifer is generally low with values ranging from 2 to 210 mg/l and thus the ground water in this aquifer is considered fresh and good for domestic use.

INTRODUCTION

The people of north Kelantan, especially those living in villages, use groundwater for domestic purposes. They normally get their water supply from the shallow aquifer through traditionally hand-dug wells as well as from the surrounding rivers. In the late twenties, a conventional groundwater supply distribution system came into existence with the establishment of Kota Bharu Waterworks Department which takes groundwater from much deeper aquifers.

Although to date, there is no report on salt water intrusion in Kelantan, it is very important to have a proper planning and management of the groundwater exploitation especially in the coastal area of north Kelantan. The effect of an excessive withdrawal, especially during dry season, must be taken into account in order to avoid risk of salt water intrusion into the groundwater aquifers.

Detailed study on salt water intrusion has not been conducted in the study area (Peng, 1987) and very little information is known about the nature and movement of the fresh and salt water interface with respect to the seasonal changes and tidal variations. It is anticipated that the salt water intrusion problems may arise in the near future when further development of the existing producing wells are undertaken to cater for increasing water demand (Sofner, 1992), particularly in the coastal area of north Kelantan.

This paper describes the results of the geophysical and hydrochemical investigations of the groundwater aquifers in the coastal area of north Kelantan. The main objective of the studies are to determine the physical parameters such as depths, thicknesses, resistivities and seismic velocities of the aquifers as well as to study the distribution pattern of the groundwater salinity in the study area.

MATERIAL AND METHOD

(i) Geology of the Study Area

The study area is located on the east coast of Peninsular Malaysia, situated along the coastal plain of north Kelantan (Fig. 1). It covers a coastal area of about 40 km length and 10 km width between Tumpat and Bachok in north Kelantan. The study area represents part of the flat Kelantan alluvial plain. The Kelantan plain is covered with Quaternary sediments (Fig. 2) overlying granite bedrock. It is drained mainly by short rivers and streams which flow into the South China Sea. The central part of the plain is drained by the largest river in the region, the Kelantan River, and in the south east, it is drained by the Pengkalan Datu River. A broad division of the alluvium into marine and fluvial origin has been proposed, but intermixing of depositional processes near the larger rivers has resulted in considerable complications in attempting to delineate these two types of deposits.

The thickness of the Quaternary deposits varies from 25 m inland to about 200 m or more near the coast. The loose Quaternary sediments consist of alternating layers of coarse gravels to silts or mixtures of these two..

(ii) Hydrogeology

The groundwater resources in north Kelantan area occur in the coastal alluvial aquifers overlying basement rocks. The study by the German consultants shows that up to four groundwater aquifers exist in the alluvial Quaternary deposits which consist of alternating layers of coarse gravels to silts or a mixture of these two materials. The aquifers are separated from each other by semi-permeable strata of silty clay. The aquifers contain lenses of silt, on the other hand, the semi-permeable strata of silty clay contain intercalations of sands and gravels.

The first (shallow) aquifer consists of sediments varying in size from silt to coarse sand and varies in thickness from a few metres to a maximum of about 15 metres. Although the aquifer is generally unconfined, locally in places confined conditions exist due to the presence of sandy or silty clays. In the first aquifer, the groundwater is recharged by percolation from precipitation. This process takes place either directly when the aquifer crops out at the surface or via semi-permeable silty clayey strata.

In the deep aquifers, the groundwater is confined. The second and fourth aquifers are not distributed throughout the entire region of Kelantan Plain. The third aquifer has its thickness varying from place to place and generally increase towards the coast.

There is no direct hydraulic connection between the groundwater and the river water or the South China Sea.

(iii) Data Acquisition

a) Geoelectrical resistivity survey

The geoelectrical resistivity survey was conducted to determine the thicknesses and resistivities of the aquifers in the study area. The resistivity measurements were carried out using ABEM terrameter. The terrameter which consist of two separate units uses a low frequency alternating current (4 Hz) to measure the earth resistance. For all the soundings that were carried out, the Schlumberger array was used. A total of 52 soundings with current electrode separation of up to 250 metres were conducted.

Quantitative interpretation to determine the specific resistivities and layer thicknesses was carried out using the partial curve matching method (Bhattacharya and Patra, 1968) and a resistivity interpretation software (Resix). Data from the boreholes (where available) were used in the interpretation and modelling.

b) Seismic reflection survey

A limited shallow seismic reflection survey was conducted in Bachok area to determine the depths and thicknesses of the groundwater aquifers. The seismic survey was conducted using a high frequency ABEM 24 channel signal enhancement seismograph with built in data storing facility. An approximately 5 kilogram sledge hammer was used as a source of seismic energy. The 14 Hz Mark products geophones were used to receive the signals. 100 Hz analogue low-cut filters were employed to attenuate low-frequency source generated ground roll and enhance the high frequency content of the signal. A half kilometre profile with common midpoint (CMP) covered was recorded at Bachok. The common midpoint (CMP) geometry (Umar Hamzah and King, 1988) which provides multifold coverage data was used throughout the survey.

The main processes applied to the seismic data included gain recovery, velocity analysis, normal move out correction and common mid point stacking. Stacking velocities were used in normal move out correction of the data. CMP stacking of all profiles enhance the quality of the seismic data by increasing the signal to noise ratio. Static correction was not applied since the survey areas are flat.

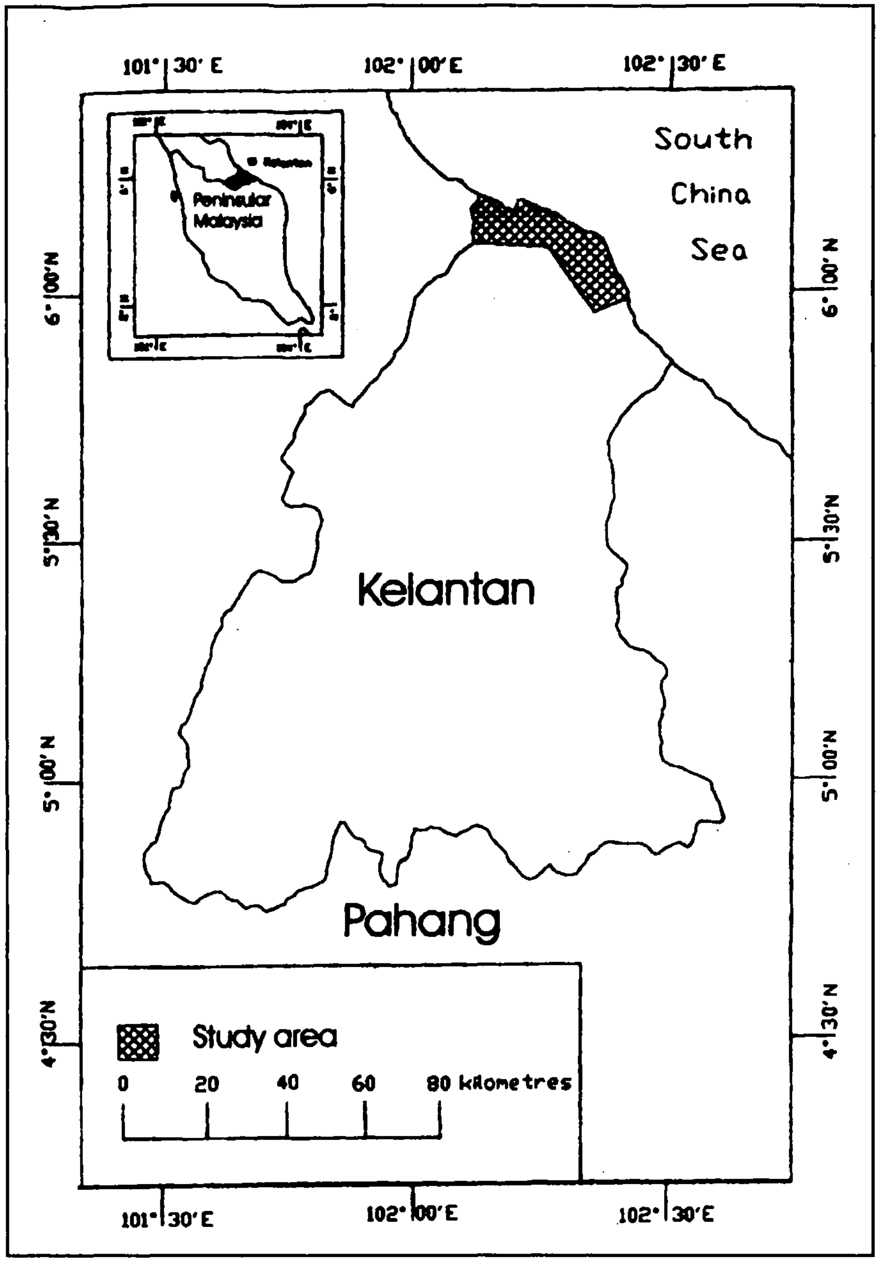

Figure 1. Location of the study area.

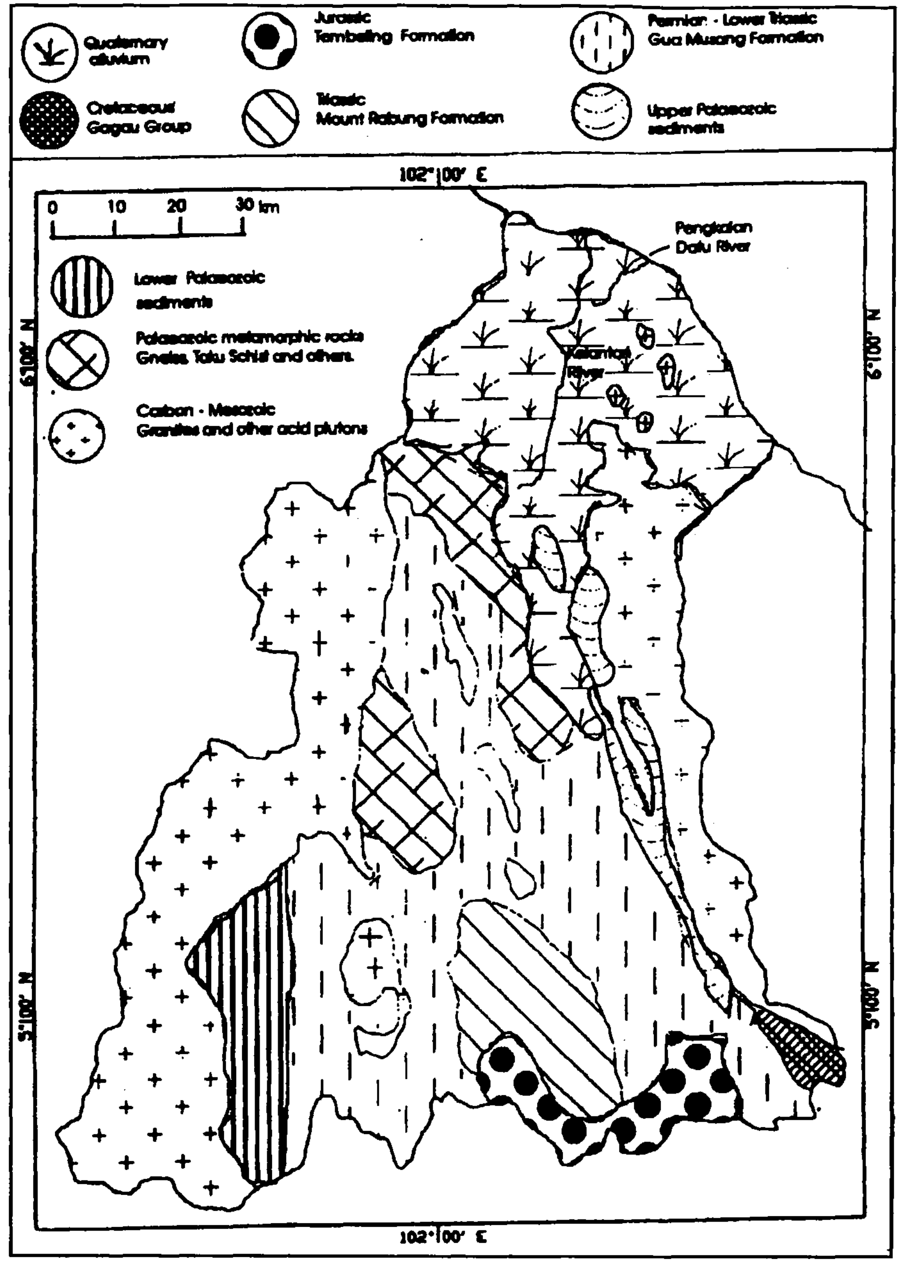

Figure 2. Simplified geological map of Kelantan, Malaysia.

c) Hydrochemistry data

Both primary and secondary chemical data were used in the study. The secondary data were mainly taken from results of chemical analyses conducted by the German consultants. The quantitative data for major ions, conductivity and total dissolved solids (TDS) were used in classification and interpretation of chemical characteristics of the groundwater.

Trilinear Piper's diagram (Piper, 1944) and geochemical maps were used to determine the chemical types and constituents of the groundwater respectively.

RESULT AND DISCUSSION

(i) Subsurface Geological Condition

Information on soil stratification and aquifers position below ground surface were gathered from a combination of an existing borehole data (Pfeiffer and Tiedemann, 1986) and surface geophysical data (seismic and resistivity). A stratigraphic sequence of the Quaternary deposit (Fig. 3) in Tg. Mas (2.5 km north east of Kota Bharu) is derived from an existing data of one of the previous exploratory borehole. The 160 m deep exploratory borehole passes through all four groundwater aquifers. The first aquifer lies between 5 to 15 metres depth below ground surface. The second aquifer occurs between 20 to 35 metres depth and it is separated from the first and third aquifers by the semi-permeable silty clay layers.

The third aquifer which lies between 45 to 130 m depth contains the good quality water and thus has been developed at Tg. Mas. The fourth aquifer occurs between 140 to 155 metres depth.

For this study, data from an exploratory borehole at Bachok Waterworks (about 20 km east of Kota Bharu) was used in conjunction with the seismic reflection and resistivity studies. The borehole log shows the presence of fine sand light brownish in colour with grey clay and shells from 0 to 6 metres depth. This layer represents the first aquifer. The semi-permeable layer between 6 to 30 metres consists of soft clay light grey to grey in colour. This layer is underlain by the second aquifer layer which occurs at depth from 30 to 39 metres and consists of medium to coarse sand mixed with stiff light grey clay. Underneath this layer is the light grey clay layer (aquiclude) with thickness of about 15 m. Underlying this aquiclude is a 40 metres thickness of coarse sand with some fine gravel third aquifer (Umar Hamzah *et al.*, 1996).

An interpreted seismic section (Fig. 4) shows lateral variation in thicknesses of the second and third aquifers. The first aquifer is too shallow to be detected by the reflection technique. The second aquifer occurs between 30 to 41 metres depth whereas the third aquifer lies between 51 to 90 metres depth. The presence of the fourth aquifer is not clearly shown in the seismic depth section. The thicknesses of the aquifers obtained by the seismic reflection survey appears to correlate well with the subsurface geological thicknesses derived from the borehole.

The geoelectrical soundings indicate resistivity ratio to depths of about 40 metres The results show that the resistivity of the first aquifer ranges from 50 to 100 ohm metres, whereas for the second aquifer the values are generally very low, mostly below 1.0 ohm metre. The low resistivity observed could possibly be related to a high salt concentration of the groundwater in the second aquifer. Abdul Rahim Samsudin *et al.* (1995) indicated that the low resistivity is related to the high chloride content of the groundwater in the aquifer. The geoelectrical thickness of the first aquifer varies from 1 to 5 metres and the second aquifer appears to be much thicker in places with a maximum thickness of about 15 metres. These results are consistent with the thicknesses obtained from the borehole data. The third and fourth aquifers are much deeper and could not be detected by the resistivity meter used.

(ii) Salinity and Chemical Condition

The chloride concentration of the groundwater in the first aquifer is low and average only 15.8 mg/l. The salt water/fresh water interface in this aquifer is generally located directly in the area of the coast or very close to it. The low salinity of the shallow aquifer is mainly attributed to the climatic conditions of the area (Ismail bin Mohd.Noor, 1979). Heavy rainfall that directly recharge the aquifer had flushed out most of the salts from the aquifer. Based on the dominant anions and cations, the groundwater of the first aquifer can be classified into three groups: sodium chloride, calcium bicarbonate and sodium bicarbonate groups. The sodium chloride water group occupies a large part of the study area and it is mostly confined along the coastal area. The change in chemical character of the groundwater could probably be attributed to the process of cation exchange.

The concentration of chloride content in the second aquifer is shown in Figure 5. The chloride content is considered high, with values ranging from 500 to 3,600 mg/l, in an area of up to about 6 kilometres from the coast. Haryono *et al.* (1995) indicated that the groundwater in the second aquifer is brackish up to about 5 km from the coastal line based on both chloride concentration and resistivity data. Beyond this area, the concentration of the

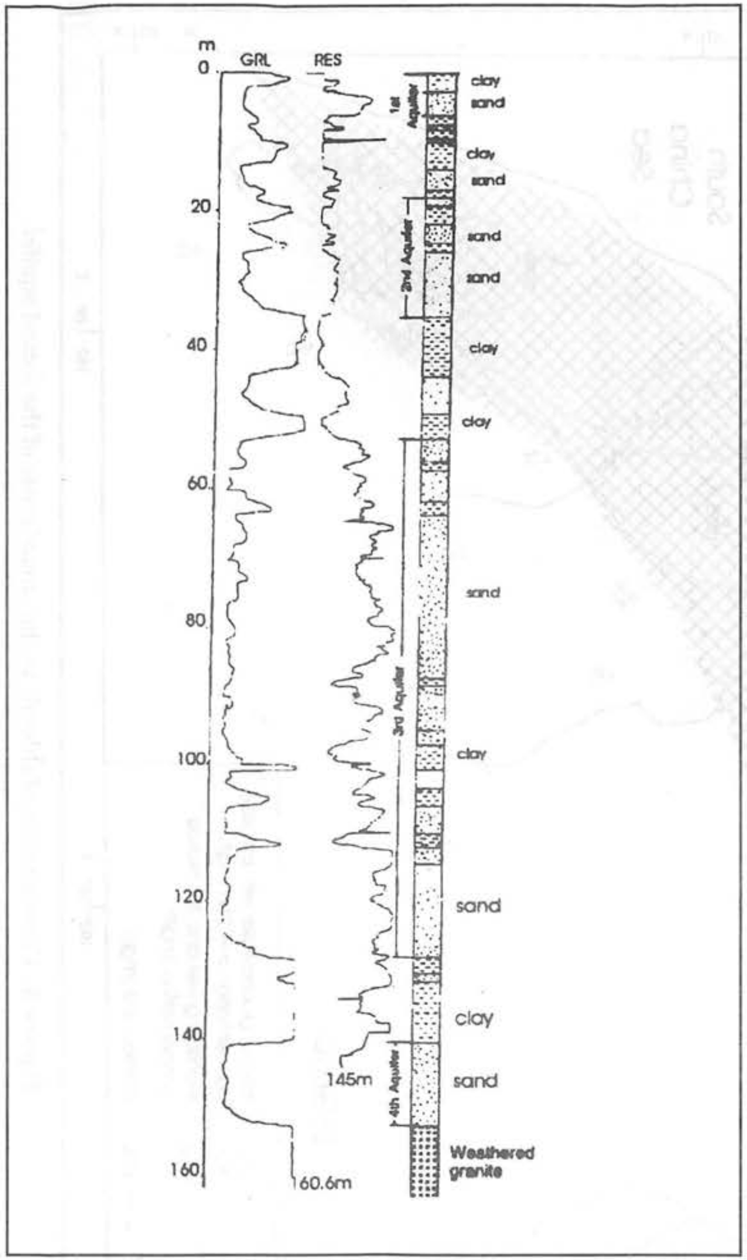

Figure 3. Geophysical well logs and stratigraphic sequence of the Quaternary at Tg. Mas (after Pfeiffer and Tiedemann, 1986).

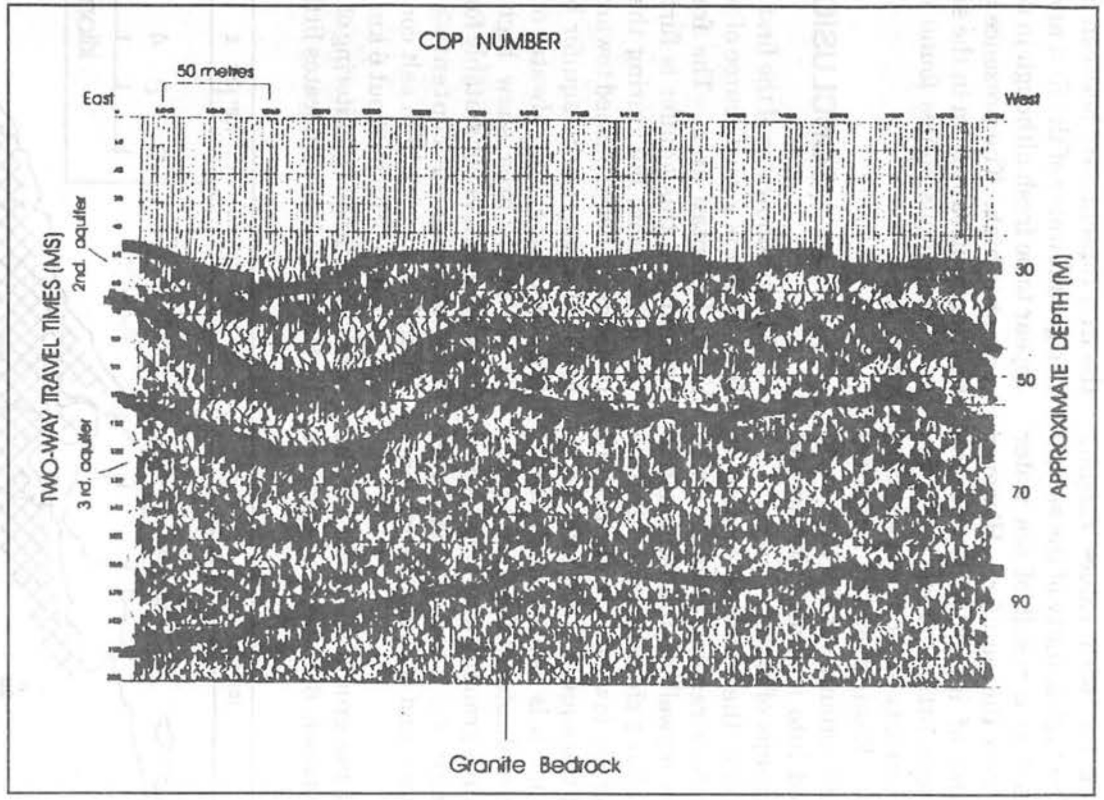

Figure 4. Interpreted seismic section at Bachok, Kelantan.

chloride appears to be low with values ranging from 2 to 110 mg/l. The high salinity of the second aquifer was interpreted as a result of sea water which had intruded into the aquifer. However continuous monitoring of its chloride content (Haryono, 1997) indicates little changes with time inferring that the high salinity is not due to seasonal sea water intrusion. Results of the chemical analyses indicate that the groundwater of the second aquifer can be divided into sodium chloride and sodium bicarbonate groups of water.

In the third aquifer, the chloride content is generally low with values ranging from 2 to 210 mg/l. Only one monitoring well located 4 kilometres away from the coast shows chloride concentration of 470 mg/l. The generally low salinity of the third aquifer indicates that the aquifer is not affected by sea water intrusion since it is located much deeper below surface. The groundwater of the third aquifer can be grouped into three groundwater types based on the chemical analyses: sodium chloride, magnesium bicarbonate and sodium bicarbonate groups.

The pH values of the groundwater for all the three aquifers are between 6.2 and 6.8, whereas the iron contents are between 3 mg/l and 10 mg/l. The groundwater of the first and the third aquifers appear to be fresh although in some places the iron content is high. The presence of iron is related to the iron mineralization in the sub-cropping schists and ferruginous shales found in the south of the study area.

CONCLUSION

The groundwater of the first aquifer is relatively fresh and it is a good source of water supply for the north Kelantan area. The fresh and salt water boundary in this aquifer is furthest inland during the dry season, but during the rainy season, the boundary is being pushed towards the coast because of the flushing of the aquifer by fresh water. On the other hand, groundwater of the second aquifer in the study area show high concentrations of chloride and it is not suitable for domestic use. The map of chloride contents indicate that the groundwater with high salt content covers an area which extends up to about 6 km maximum from the coast. Continuous monitoring of the chloride content by Haryono (1997) indicates little change with time

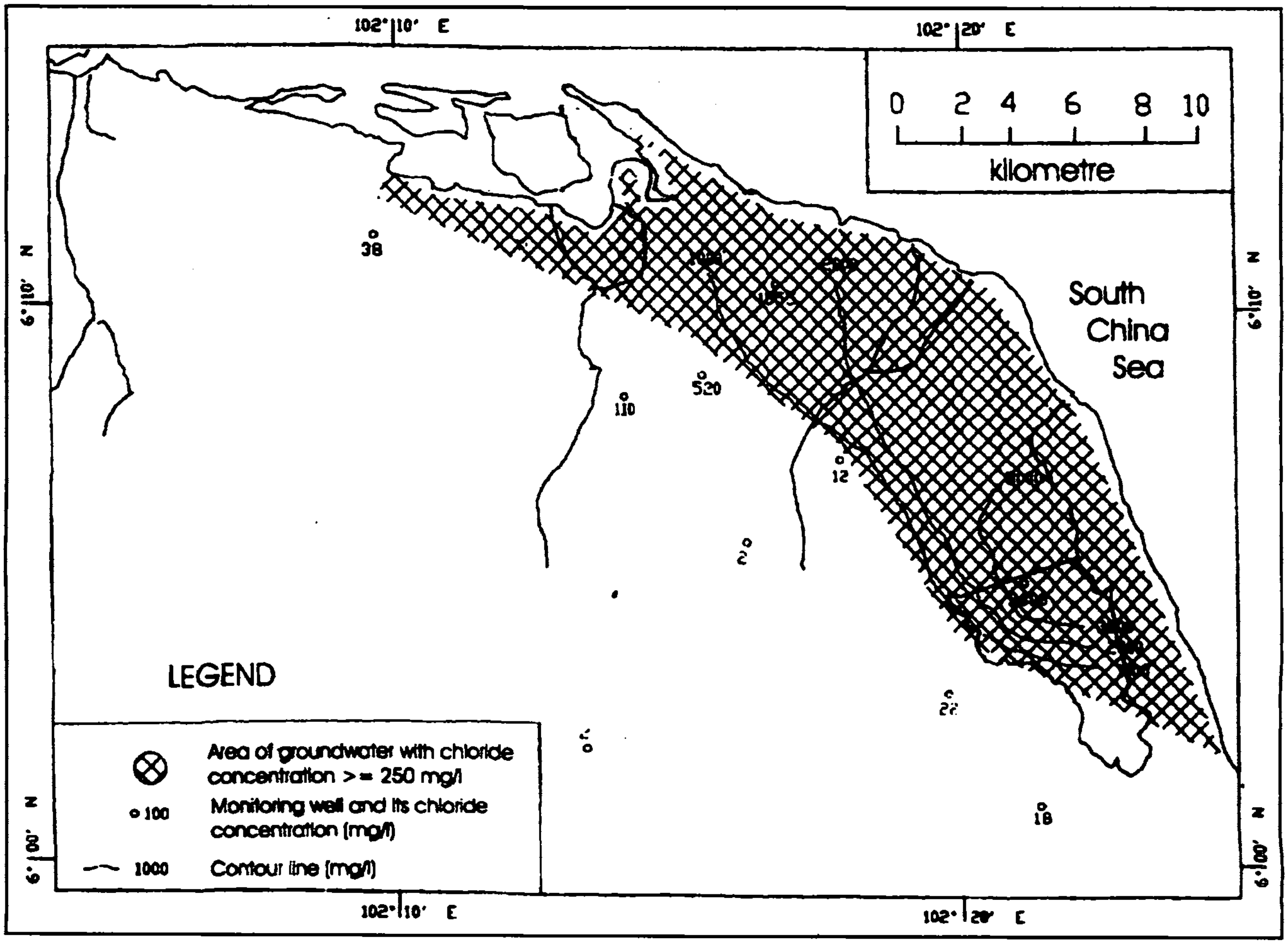

Figure 5. Concentration of chloride in the groundwater of the second aquifer.

inferring that the high salinity is not due to seasonal sea water intrusion. The analysis also reveals relatively low concentrations of sulphate which suggest that the groundwater of the second aquifer may represent fossilised sea water. At present, the groundwater from the second aquifer is not utilised but there is an effort to exploit the water for agricultural and fishery purposes. The groundwater of the third aquifer contains high iron which has to be reduced before the water can be used particularly in industry and agriculture.

Although to date the saline intrusion is not a serious problem in Kelantan, it is necessary to apply a proper groundwater management system especially in the coastal area of north Kelantan. Continuous groundwater quality monitoring undertaken by The Geological Survey Department should be conducted regularly to ensure the groundwater resources is not intruded by the sea water as well as by other contaminants. The effect of dry season withdrawal must be taken into account so that any proposed abstraction must be within the safe yield limit.

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REFERENCES

ABDUL RAHIM SAMSUDIN, ABD. GHANI RAFEK, UMAR HAMZAH AND HARYONO, 1995. Pengesanan kemasinan air tanah pada aquifer kedua dengan menggunakan kaedah kerintangan geoelektrik. Kajian kes: Pantai Bachok, Kelantan, Kolokium ke 7 FSFG, Universiti Kebangsaan Malaysia, Bangi, Selangor.

ABDUL RAHIM SAMSUDIN, UMAR HAMZAH, ABD. GHANI RAFEK AND HARYONO, 1996. Beberapa hasil penyiasatan geofizik di kawasan Bachok, Kelantan. *Sains Malaysiana*, 25(1), 29–43.

BHATTACHARYA, P.K. AND PATRA, H.P., 1968. *Direct current geoelectric soundings, Principles and Interpretation*. Elsevier, Amsterdam.

FLATHE, H., 1974. Geoelectrical investigation: Kota Bharu / Kelantan Malaysia. Ber. Arch. BGR, Hannover (Unveroff).

HARYONO, ABDUL RAHIM SAMSUDIN, ABDUL GHANI RAFEK AND NASIMAN SAPARI, 1995. Penggunaan kaedah-kaedah hidrogeokimia dan kerintangan geoelektrik untuk mengesan kemasinan air tanah pada akuifer kedua di pantai utara Kelantan. *Abstract Annual Geological Conference 1995*, 53–55.

HARYONO, 1997. Penggunaan kaedah Geofizik dan Kaedah Hidrogeokimia untuk Mengesan Kemasinan Air Tanah di sepanjang Pantai Kelantan, Utara, Malaysia. Tesis Doktor Falsafah, Universiti Kebangsaan Malaysia (Unpublished).

ISMAIL BIN MOHD. NOOR, 1979. Pre-feasibility study of potential groundwater development in Kelantan, Malaysia. Ph.D. thesis, University of Birmingham, U.K. (unpublished).

PFEIFFER, D., AND CHONG, F.S., 1974. Groundwater exploration in Kota Bharu — Report No. 1. Unpublished report Geological Survey of Malaysia.

PFEIFFER, D. AND TIEDEMANN, O., 1986. Hydrogeological studies and the development of groundwater in the Kelantan coastal plain (Malaysia). *Natural Resources and Development*, Vol. 24. Institute for Scientific Co-operation, Tubingen, Federal Republic of Germany, 72–82.

PENG, S.C., 1987. Salt water intrusion in groundwater in Peninsular Malaysia. An overview, in Groundwater and Environment proceedings of the international groundwater conference. Universiti Kebangsaan Malaysia.

PIPER, A.M., 1944. A graphic procedure in the geochemical interpretation of water analyses. Trans. Am. Geophys. Union, 25, 914–928.

SOFNER, B., 1992. Groundwater monitoring and groundwater protection at the Geological Survey Department (GSD) of Malaysia. Bundesanstalt fur Geoeissenschaften und Rohstoffe, Hannover.

TAN, E.H. AND SINGH, M., 1989. Groundwater supply studies in northern Kelantan. *Bulletin of the Geological Society of Malaysia*, 24, 13–26.

UMAR HAMZAH AND KING, R.F., 1988. Seismos pantulan cetek bagi skala kejuruteraan. *Sains Malaysiana*, 17(1), 53–65 (In Malay).

UMAR HAMZAH, ABD. RAHIM SAMSUDIN, ABD. GHANI RAFEK AND HARYONO, 1996. Application of shallow seismic reflection in delineating Bacok groundwater aquifers. *Warta Geologi*, 22(3), 167–172.

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