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Hydrogeochemistry of groundwater from different aquifer in Lower Kelantan Basin, Kelantan, Malaysia

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Abstract

The groundwater geochemistry of Lower Kelantan Basin was evaluated based on major ions characteristic to determine its suitability for drinking, domestic use and irrigation. Groundwater samples from different aquifer layers (shallow, intermediate and deep) were collected and analysed for pH, electrical conductivity (EC), total dissolved solid (TDS), Ca, Mg, Na, K, Cl, SO_4, CO_3, HCO_3, NO_3, Fe and Mn. The results show that the shallow groundwater is dominated by Ca-HCO_3 and Na-HCO_3 while intermediate is dominated by Na-Cl and Na-HCO_3, and deep aquifer by Na-HCO_3 water facies. The sodium adsorption ratio (SAR) and salinity hazard indicate that the groundwater from shallow and deep aquifer is suitable for irrigation purposes, and part of intermediate aquifer is not suitable for crop irrigation. Groundwater from shallow and deep aquifer is regarded as fresh water and suitable for drinking, domestic and agricultural irrigation use while groundwater from intermediate aquifer is slightly brackish water particularly closed to coastal area.

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Keywords: Lower Kelantan Basin; hydrochemical facies; Sodium Adsorption Ratio (SAR)

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1. Introduction

Groundwater is the world's largest accessible freshwater and important resource for drinking water supply, irrigation and industrial purposes as well as for global food security. Approximately one-third of the world's population depend on groundwater for drinking purpose [1]. Geology of an area, the degree of chemical weathering of various rock types and anthropogenic factors affect the chemistry of groundwater [2].

The combination of fertile, low-lying topography with shallow water table and widespread of aquifer with plentiful and easily accessible of water make the groundwater is the main source of water among the residents in the Lower Kelantan Basin. About 75% of the state populations living in the Lower Kelantan Basin are relied on groundwater for domestic water supply, agricultural and industrial activities. The groundwater consumption in 2009 is approximately 146 million litres per day (MLD) and estimated to increase at a rate of 2.5% a year [3]. The groundwater quality is acceptable for most uses which require minimal treatment, low capital cost for development and almost unaffected during long drought season. Almost the entire population (624,389 peoples) of Kota Bharu and Bachok districts [4] relied on either treated or untreated groundwater.

However, the low-lying coastal aquifers are generally fragile, easily depleted due to anthropogenic activities and over exploitation of groundwater. With the growing demands due to increasing number of population spreading over a large area, industry and agriculture, there has been increasing concern on the quantity and quality of groundwater resources. To manage and protect precious groundwater resources in a sustainable manner, the characterization and understanding of the natural evolution of groundwater chemistry is crucial to elucidate their geochemical nature and its relation. Presently, the hydrogeochemistry study of groundwater in this area has not been investigated in depth on a basin-wide scale and poorly understood. The aim of this study is to characterise the groundwater quality in the Lower Kelantan Basin multi-layered aquifer using geochemical analysis.

2. Materials and methods

2.1 Description of the study area

The study area lies between 5° 53' N and 6° 14' N and 102° 7' E and 102° 28' E, and covers an area of approximately 880 km2. It has an alluvial delta and coastal plain stretching about 40 km in length and 10 km in width on its coast and located in the most north eastern part of Peninsular Malaysia which cover the whole area of the Kota Bharu and Bachok district and part of the Pasir Mas and Tumpat district. It is bounded by the South China Sea to the east and by the Golok River basin to the west. The study area is underlain by the alluvial deposit, which made up of silt, clay, sand and gravel [5]. The alluvial deposits thicknesses are ranging from 25 m inland to more than 200 m near the coastal area and underlain by Mesozoic granites as bedrock [6]. Physiographically, study area is principally drained by the meandering Kelantan River in the west and Pengkalan Datu and Kemasin River in the east.

2.2 Sampling and analytical procedures

A total of 109 groundwater samples were collected from shallow (<22.0 m depth), intermediate (between 22.0-40.0 m depth) and deep aquifer (>40.0 m depth). The sampling locations were chosen in order to represent the groundwater quality in the study region (Fig. 1). The groundwater samples were collected after the well was emptied 3 times or the water was pumped out for about 10 minutes to remove the stagnant water. The physico-chemical parameter measured in the field immediately after were pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) using the YSI multiparameter instrument package with a built-in program and data-logging. The groundwater samples were filtered through 0.45 μm membrane filter and split into 2 polyethylene bottles 250 mL each, one filled with only sampled water directly while the other was samples were acidified with nitric acid (HNO_3) to a pH of less than 2 to minimise adsorption of metals to container walls and reduces biological activity. All groundwater samples are stored at approximately 4°C. All the groundwater collection method and the water sample analysis followed standard procedure [7].

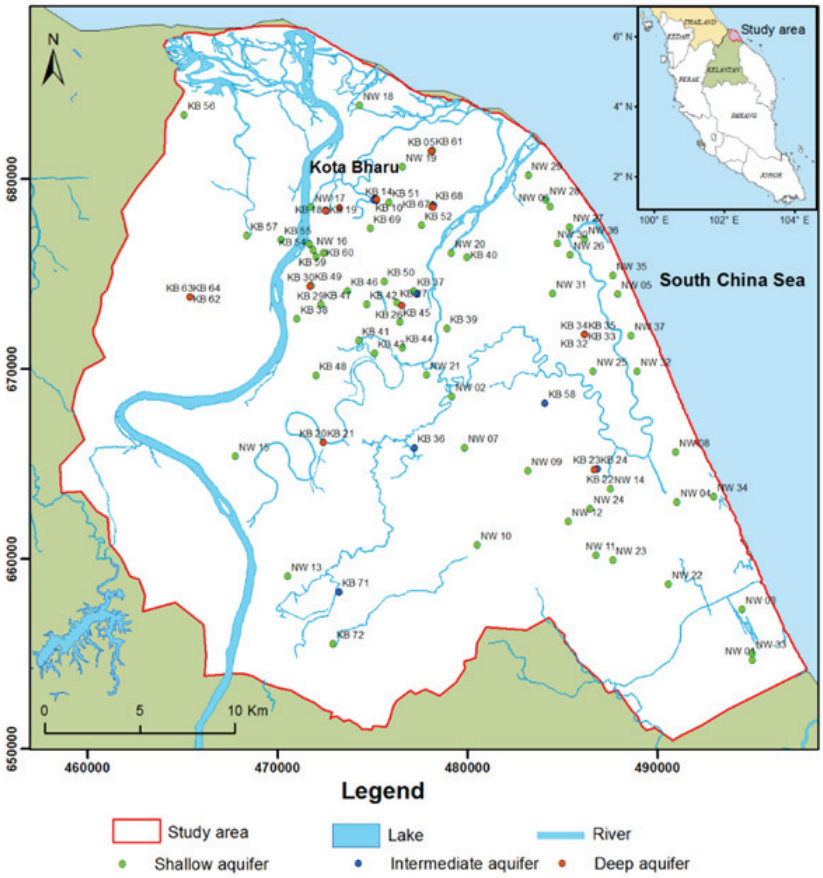

Fig. 1. Location map of study area and sampling location

The Ca, Mg, Na and K were analysed using flame atomic absorption spectroscopy (FAAS) while Fe and Mn using inductively coupled plasma-mass spectrometer (ICP-MS). CO_3, and HCO_3 concentrations were determined using acid titration method. Cl concentration was measured by $AgNO_3$ titration method; SO_4 measured by SulfaVer 4 method (HACH). All concentrations are expressed in milligrams per litre (mg/L), except for pH and EC. The analytical precision for ions was determined by the ionic balances calculated as (cations - anions)/(cations + anions) x 100, which is generally within ±10 % [8] and Aquachem 2014.2 software was used for the analysis.

3. Results and discussion

3.1 Hydrogeochemical facies

Hydrogeochemical facies interpretation is a useful tool for determining the groundwater chemistry based on the dominant cations and anions that reflected the water type [9]. The Piper diagram in Fig. 2a shows the prominent groundwater facies of the shallow aquifer is Ca-HCO_3 and Na-HCO_3 indicating fresh and mix-water types respectively while in the intermediate aquifer (Fig. 2b), groundwater is dominated by Na-HCO_3 and Na-Cl representing mix-water and saltwater types respectively. In deep groundwater aquifer (Fig. 2c), Na-HCO_3 type water is dominant. Ca-HCO_3 facies indicate that the groundwater samples are associated with calcite solution and probably from the shell deposits of fluvio-marine origin. The Na-HCO_3 water type could be due to albite solution of feldspar from subsurface schists and ferruginous shales found in the south of the study area. The large proportions of the intermediate groundwater showed Na–Cl type generally indicate a seawater influence [10] which is ancient seawater that may have been trapped during the deposition of the sediments [11].

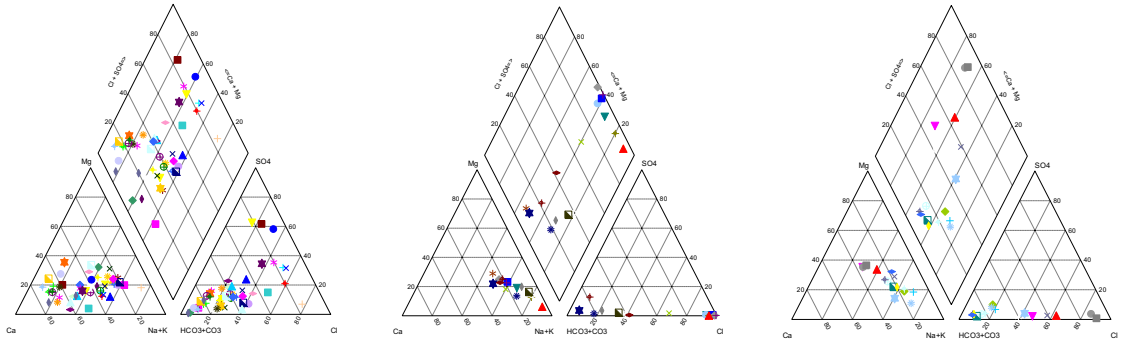

Fig. 2 Piper diagram in (a) shallow groundwater, (b) intermediate groundwater and (c) deep groundwater

3.2 Sodium adsorption ratio (SAR)

The groundwater quality from shallow, intermediate and deep aquifer were classified and compared with sodium absorption ratio (SAR). The SAR index quantify the ions of sodium (Na^{+}) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) proportion in groundwater samples. Sodium hazard of irrigation water is important in classifying the water for irrigation purposes because sodium concentration can reduce the soil permeability and soil structure [12] and calculated by using equation 1 [13]:

$$\mathrm{SAR}= \left(\frac{\mathrm{Na}^{+}}{\sqrt{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}/2}}\right) \quad (1)$$

The USSL graphical diagrams of irrigation water plotted the SAR versus salinity hazard values as shown in the (Fig. 3). Based on USSL diagram [14], groundwater samples from shallow aquifer fall in the C1-S1 (low salinity with low sodium), C2-S1 (medium salinity with low sodium) and C3-S1 (high salinity with sodium). Hence, the groundwater from shallow aquifer can be used on most crops for irrigation purposes. For the intermediate aquifer, majority groundwater samples fall in the C1-C4 and S1-S4 (low to very high salinity with low to very high sodium) which are not suitable for crop irrigation. For the deep aquifer, groundwater sample fall in the C2-C4 and S1 (medium to very high salinity and low sodium) where part of its sample are not suitable for crop irrigation. The groundwater samples taken from intermediate and deep aquifer that fall in S4 (very high salinity hazard) are located in area less than 8 km from coastal area. However, the groundwater samples obtained from area more than 8 km from coastal line in all aquifers are suitable for crop irrigation.

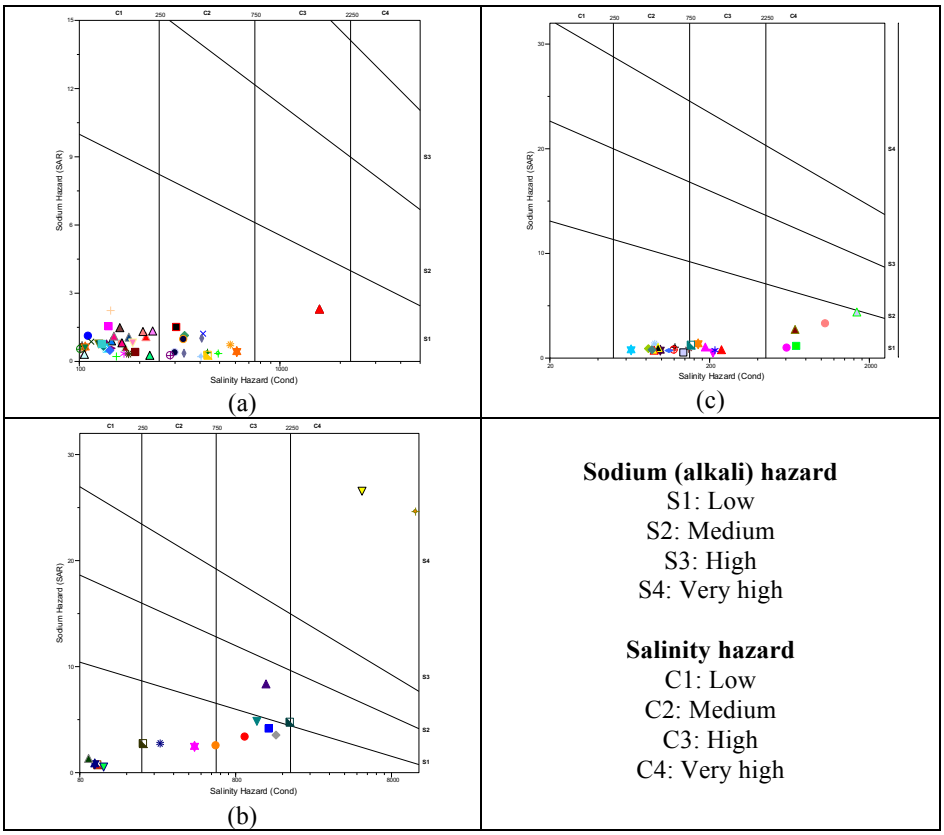

Fig. 3. USSL diagram from (a) shallow, (b) intermediate and (c) deep aquifer for irrigation water quality classification (USSL Diagram 1954)

4. Conclusion

Results of the analysis shows that the shallow groundwater type is dominated by Ca-HCO_3 and Na-HCO_3; intermediate groundwater by Na-HCO_3 and Na-Cl; and deep groundwater Na-HCO_3. The Na-HCO_3 facies could be due to albite solution of weathered feldspar from subsurface schists and ferruginous shales found in the south of the study area. The bicarbonates are mainly derived from carbonate mineral and silicate weathering. Generally, the groundwater of the Lower Kelantan Basin is suitable for drinking, domestic and agriculture irrigation use except from intermediate aquifer which located less than 8 km from the coastal area.

Acknowledgements

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