Evaluating freshwater lens morphology affected by seawater intrusion using chemistry-resistivity integrated technique: a case study of two different land covers in Carey Island, Malaysia

M. F. Tajul Baharuddin · A. R. Othman ·
S. Taib · R. Hashim · M. H. Zainal Abidin ·
M. A. Radzuan

Carey Island is a populated ex-promontory island, named after a British agriculturist, Edward Valentine Carey. The island is located at the mouth of the Langat River, separated from the mainland by the Klang River in the north and the Langat River in the east. The Island with a total area of 16,187 ha (6 % of the Langat River Basin) (Figs. 1, 2) (JICA and DMGM 2002) is heavily cultivated with oil palm (10,552 ha) mostly in the coastal region; other land use comprises state land/settlements (4,310 ha) and mangrove forest reserve (1,877 ha) (Golden Hope Plantation Berhad 2006).

JICA and DMGM (2002) reported on the location of the area in the Langat River Basin (Fig. 1), which is hit by the northeast and southwest monsoons annually. The northeast monsoon is from November to March, whereas the southwest monsoon is from May to September. Rainfall intensity varies, most of the rain falling in April and November, with a mean rainfall of 280 mm. The least rain falls in June, with a mean rainfall of 115 mm. Wet seasons are in the transitional periods of the monsoons: March to April and October to November. Monthly rainfall average is 180 mm, whereas annual precipitation is approximately 2,400 mm (JICA and DMGM 2002). From analysis of Carey Island's local precipitation events and monthly rainfall data from 2000 to 2010, two seasons can be deduced: wet (August to December, mean 280 mm) and dry (February to March, mean 150 m) (Mohamad Faizal et al. 2011).

The island's groundwater resource relies substantially on its coastal aquifers for the domestic and cultivation requirements, which must remain sustainable without overexploitation under the threat of seawater intrusion. As groundwater demand increases under the tenth Malaysian Plan (2011–2015) development stress, it is timely to investigate the groundwater status and the influence of intruding seawater and irrigation water on freshwater under natural renewal and supply needed to support the island's eco-systems (GOM 2010). A coastal unconfined aquifer was the subject of investigation involving two distinctively different land covers, a naturally preserved mangrove forest and a severely deforested, eroded mangrove free coastal belt. Both the study sites directly confront the sea of the Straits of Malacca, implying the groundwater problems facing the island authorities might not seem as straightforward as for an ordinary sea-island, because Carey Island is ex-promontory (JICA and DMGM 2002). Such problems could have far-reaching effects on the island's the oil palm cultivation (the island's major income) as well as the domestic supply. The most recent concern is about rise in sea level that could affect the island's freshwater morphology due to seawater intrusion (IPCC 2007; Vaeret et al. 2009), which can aggravate due to the changing shoreline caused by the monsoon waves imparting major coastal erosion leading to consequent loss of mangrove cover. Reported loss of natural vegetation from barrier islands in Florida has influenced groundwater recharge to the extent of thinning down the freshwater lenses available in the islands (Schneider and Kruse 2003, 2006).

The best geophysical method for seawater intrusion mapping in particular is the geo-electrical method (Loke 2010a). The geo-electrical method is unique as it detects increased aquifer conductivity via increased pore-water conductivity (Abdul Nassir et al. 2000). Various researchers around the world have applied the geo-electrical method to demarcate coastal-area hydrology conditions, ever since the development of the interpretation technique by Loke and Barker (1996): for example, Schneider and Kruse (2003, 2006)in estimating the freshwater–groundwater interface as a check on their simulation results; Benkabbour et al. (2004) on saltwater intrusion evaluation in the Plioquaternary consolidated coastal aquifer of the Mamora Plains in Morocco; Maillet et al. (2005) in determining the infilling dynamics of the Pegoulier Channel in the Rhone Delta, France; Sathish et al. (2011) on the mixing effect of seawater with groundwater in the Chennai coastal aquifer, India; and in the local Malaysian scenario, Baharuddin et al. (2009) in the study of environmental impact affected by shoreline changes in Selangor, Malaysia.

Several studies have also attempted using the geoelectrical method combined with the geo-chemical method: for example, Di Sipio et al. (2006) for improved salinity interpretation in the Venice estuaries; Awni (2006) for detection of freshwater–saline water interface in the alluvial shoreline of the Dead Sea, Jordan; Sherif et al. (2006) for delineation of seawater intrusion in Wadi Ham, UEA; Adepelumi et al. (2009) for fresh-saltwater delineation using a vertical-electrical-sounding technique in the Lekki Peninsula in Lagos, Nigeria.

This present work has employed the same technique integrating the geo-electrical method with the geo-chemical method. Highlight on the island’s changing physical characteristics forms background to the study (Golden Hope Plantation Berhad (2006), and Affandi et al. (2010)), which provides an insight into the results of the study on groundwater chemistry.

Geological and hydrogeological settings

The study area (Mohamad Faizal et al. 2011) geologically comprises Holocene-age marine sediments (Gula Formation), similarly found in the coastal regions of West Peninsular Malaysia (Suntharalingam and Teoh 1985 and Baba 2003). The sediments consist of grey clay, sand, and minor gravel with fragmented shells and peaty materials. There is one granitic rock outcrop located in the Jugra Hills by the Langat River. Past studies revealed some chemical characteristics of the coastal groundwater aquifers. For instance, Ngah (1988) found freshwater in 15 m deep wells and saline–brackish water in shallower wells (\15 m deep) with chloride exceeding 250 mg/L. Also Tahir and Abdul Hamid (2003) found brackish water in their 96-m-deep well with chloride[250 mg/L. Ismail (2008) found saline–brackish water much deeper (185 m) with conductivity exceeding 2,000 lS/cm. Apart from the groundwater chemical properties, these studies confirm the presence of semi-confined aquifer in two layers (lower and upper) and the absence of confined layer in the study area with freshwater overlying brackish water.

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