Time-lapse resistivity investigation of salinity changes at an ex-promontory land: a case study of Carey Island, Selangor, Malaysia

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Salinity of groundwater aquifers, especially at coastal regions, changes naturally or through human activity. A major cause, sometimes affecting freshwater quality, is seawater intrusion. Excessive withdrawing of groundwater, and significant decrease in recharge, too, contribute (Pujari and Soni 2008). Aquifer-salinity changes naturally when low-density fresh groundwater interacts with high-density saltwater. The best geophysical method, particularly in salinity mapping, is geo-electrical method (Loke 2010a). Researchers demarcating coast hydrogeology have been using geo-electrical method to map salinity ever since development of the interpretation technique by Loke and Barker (1996). Electrical resistivity method is unique as it detects increased aquifer conductivity via increased pore-water conductivity (Abdul Nassir et al. 2000). Benkabbour et al. (2004) used geophysical method to characterize saltwater intrusion in the Plioquaternary consolidated coastal aquifer of the Mamora Plains, Morocco. Di Sipio et al. (2006) used geo-electrical method and geochemistry data to get better salinity profile of the groundwater system in Venice estuaries. Awni (2006) used 2-D geo-electrical method to detect subsurface freshwater and saline water at the alluvial shoreline of the Dead

Sea, Jordan. Sherif et al. (2006) integrated geoelectrical method with hydro-geochemical method to delineate saltwater intrusion at Wadi Ham, UAE. In Lagos, Nigeria, Adepelumi et al. (2009) used vertical-electrical-sounding survey to delineate Lekki Peninsula freshwater–aquifer saltwater Intrusion

The studies detected and mapped salinity at regions of spatial variations. Salinity changes are dynamic, happening every day in groundwater systems, especially at open-sea coastal, and estuarine, regions. Major factors relating to time and space are tide, season, and seawater density. Geo-electric imaging surveys of space have been done, and can be done for time (Loke 2010a). Image analysis, from spatially distributed resistances at specific time intervals, is through timelapse electrical-resistivity tomography (TLERT). TLERT's various applications have attracted many researchers: Barker and Moore (1998) for physical-model tests of groundwater flow and contamination; Kemna et al. (2002), Cassiani et al. (2006), and Oldenborger et al. (2007) for tracertest study of aquifers; Olofsson and Lundmark (2009) for impact monitoring of roadside-soil de-icing-salt in saltwater investigation; and Ogilvy et al. (2009) for study of near-coast saltwater intrusion; in each, TLERT images relate change in salinity to transport of solutes.

TLERT is capable of minimal-invasionmonitoring of hydraulic processes in porous media by capturing temporal conductivity variations (Ogilvy et al. 2009). TLERT measurements fill, less expensively, gaps in data on space between sets of boreholes (Maillet et al. 2005). Acquisition of TLERT-image resistance data requires good electrical grounding during TLERT monitoring.

Soil electrical conductivity is influenced by the complex interaction among soil's physical properties, water content, salinity, and ground temperature, all possibly influencing electrical grounding (Olofsson and Lundmark 2009). Poor electrical grounding disables data acquisition, resulting in incomplete resistivity data. Good electrical grounding takes time to prepare, but without it, image quality is affected, and the rate of change that can be captured with TLERT monitoring becomes limited. Discussed here are resistivity-acquisition techniques where poor electrical grounding is improved.

This work's concern is salinity changes to freshwater at Carey Island in the state of Selangor, Malaysia (Fig. 1). Carey Island, near Indah Island, is Malaysia's biggest trading port. Not only is it located in Malaysia's most advanced industrial and trading state (Selangor), it is also near Malaysia's administration centers of Putrajaya and Kuala Lumpur (capital city of Malaysia). Its infrastructure has grown rapidly, with highways mobilizing trade between it and South Peninsular Malaysia. Its population is expected to increase significantly when its entire infrastructure had been completed.

Selangor was predicted to be 1 million m^3 of water short daily in 2007 (Tahir and Abdul Hamid 2003). At Carey Island, the shortage was regular, so people harvested rain. Government agencies such as the Department of Mineral and Geo-

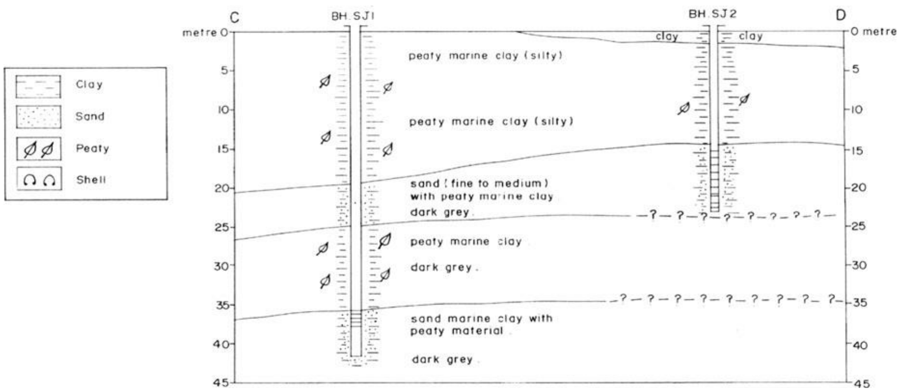

Fig. 2 Sg. Judah Village subsurface profile and geochemistry data at semi-confined aquifer (Ngah 1988)

Science were asked to determine the island's water-supply potential. On the district council's request, Ngah (1988) investigated groundwater at five aboriginal villages to determine shallowaquifer potential (Fig. 1). Sg. Judah study revealed freshwater in aquifers less than 25 m deep. Thicknesses of semi-confined aquifers ranged between 5 and 7 m (Fig. 2). Some shallow semi-confined aquifers there especially at borehole SJ3 400 m south of borehole SJ2 was identified as having brackish water, chloride concentration 620 mg/l (Fig. 3). Aquifers more than 35 m deep were identified as not having promising groundwater potential because saline and brackish waters were more dominant. Tahir and Abdul Hamid continued investigations in 2003, as requested by the Malaysian Government and provisioned in the Eighth Malaysia Plan (2000–2005) for northern region. They revealed brackish-water domination, chloride concentration >250 mg/l, still, in groundwater 95 m deep. In 2008, Ismail furthered the study, encountering screen level at depths between 175 and 180 m; no potential for groundwater extraction (the groundwater was dominated by brackish water, conductivity value >2,000 μS/cm).

Preceding effort was to understand the area's hydrogeology so its groundwater-exploration could be strategized. Efforts by relevant government agencies to identify the best strategy have been unsuccessful.

This study used TLERT at an ex-promontory land: Carey Island. It identified (via boreholedata, hydro-geochemistry analysis, and landtransformation history) changes in salinity of the tropical island's coastal aquifer system. Its results based a strategy for groundwater exploration of the island.

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