

Compositional Change of Groundwater Chemistry in the Shallow Aquifer of Small Tropical Island Due to Seawater Intrusion

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ABSTRACT

A detailed groundwater chemistry study were undertaken to examine the evolution of groundwater in the shallow aquifer of Manukan Island, Sabah, Malaysia since fresh groundwater aquifers especially for small islands are often exposed to heavy pumping and consequently to risks of seawater intrusion. Geochemical data on dissolved major constituents in analyzed groundwater samples revealed the main processes responsible for their geochemical evolution. The results of analysis showed that the groundwater was chemical highly enriched with Na⁺ and Cl⁻ an indication of seawater intrusion into the aquifer as also supported from the Na-Cl signature on the Piper diagram. Compositional change from Ca-rich to Na-rich water types can be explained mostly by simple mixing process. From the PHREEQC calculation, calcite and aragonite solubility showed positive values of the saturation indices (SI) indicating supersaturation which lead to mineral precipitation condition of water by these minerals.

INTRODUCTION

Groundwater usage for daily supply in the small island of Manukan, Sabah, well known as diver's paradise, has drastically increased over the last decade due to the rapid increase in visitors to the island. Increased groundwater demand leads to a decline of water levels and deterioration of water quality. With the current increased groundwater pumping, incursion of seawater into the island's aquifers is a natural and expected significance consequence, especially in the low lying area of the island. In general, small carbonate islands are highly susceptible to seawater intrusion due to the high permeability of the aquifers.

Increased knowledge of the geochemical processes that control groundwater chemical composition in small islands of tropical regions could lead to improved understanding of the hydrochemical systems in such areas, and lead to development of a sustainable scheme for groundwater management. In this paper, we report on the geochemical processes that changed the groundwater chemistry observed in Manukan, Sabah.

MATERIALS AND METHODS

Study site

Located about 7.45 km from Kota Kinabalu, capital city of Sabah, Malaysia (Figure 1), Manukan (5°57'-5°58' N and 115°59'-116°01' E) is one of the islands of the Tunku Abdul Rahman Park. Covering an area of 206 000 m², the island is a crescent shaped, one and half kilometer long and three kilometer wide in the middle. Almost 80% of the area of the island is high relief and covered by forest (western side of the island), while remaining 20% of the area is developed for tourism activities which are located on the low lying are of the island (eastern part of the island). Geologically, Manukan Island was isolated from the mainland about one million years ago (Basir *et al.*, 1991). The island is underlay by interbedded sandstone and shales of the Middle Miocene Crocker Range Formation. The main aquifer of Manukan Island comprises Quaternary

carbonates and coarse sandy alluvium, which overlie the older rocks. Overall the limited extent of the aquifer and low elevation of the island lead to very limited water storage, which is primarily dependent on the aquifer thickness, and distribution of the sands, which are often found at sites near the coast.

The groundwater recharge for Manukan Island aquifer depends entirely on infiltration. Sabah has a warm and humid climate with annual rainfall between 2000-2500 mm, humidity between 80-90% all year round and temperatures from 21 to 32°C. The climate is affected by the northeast and southwest monsoons, which are dominant during November to March and May to September respectively. The periods between the monsoons are marked by heavy rainfall.

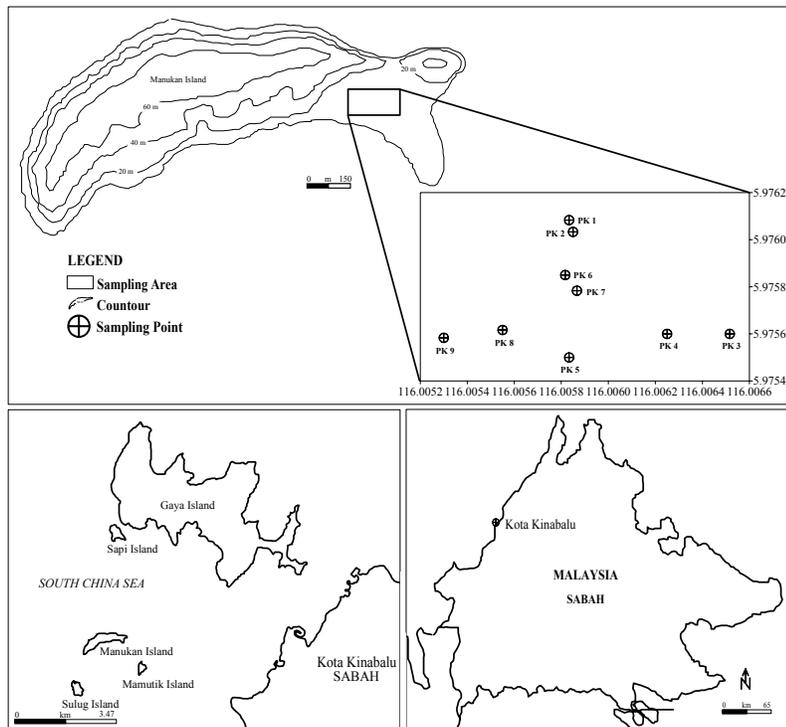


Figure 1. Schematic map showing the geographical locality of Manukan Island.

Sampling and analysis

In order to assess the groundwater quality of the surficial aquifer on Manukan Island, water samples were collected from the existing wells every two month between March 2006 and January 2007. A total of 162 samples were collected during the sampling period from 9 wells located on the low lying area of the island (Figure 1). Sampling, preservation and water analyses were performed in accordance with the standard procedures devised by APHA (1995).

GENERAL HYDROCHEMISTRY

In the cationic triangle of Piper diagram, most samples were plotted on Na-dominant area. In the anionic triangle, the values are almost plotted near the seawater signature because of predominance of Cl⁻. The simple mixing process between seawater and fresh groundwater are clearly evidence in the cation triangle where most of water samples were plotted near Na-Cl water type area and some samples were plotted near Ca-Cl dominant water type area (Figure 2).

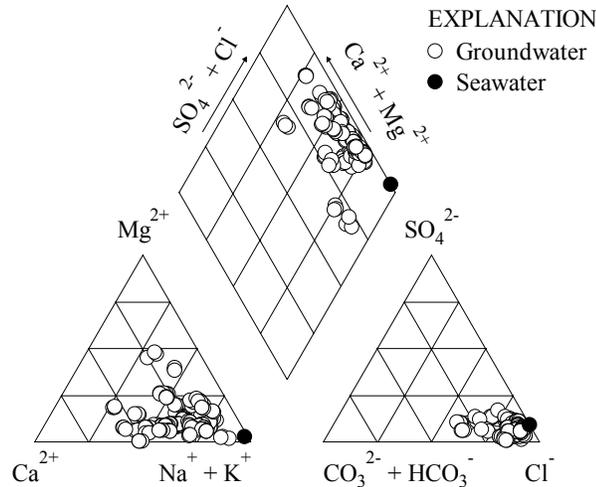


Figure 2. Piper diagram representing the groundwater chemistry of the study area.

The dominant hydrochemical process on Manukan Island is seawater-freshwater mixing as supported by the increased of its groundwater salinity and electrical conductivity (EC) values compared with Abdullah *et al.* (1996) data. The correlations (between major ions such as Na^+ , Cl^- , SO_4^{2-} with EC and salinity) clearly identified the main elements that contributed to the groundwater salinity and their tendency to exhibit a similar trend of salinization pattern.

The lower concentration of Ca^{2+} compared to Na^+ found in the study period is a result from the cation exchange process that occurs naturally when seawater intrudes into aquifer system. Presuming that Ca^{2+} is the dominant ion for the aquifer matrix of the study area, the following Equation 1 can describe the above-mentioned process (Appelo & Postma, 2005):



When Ca^{2+} exchanged with Na^+ , the water becomes saturated for calcite and precipitation resulted (Chappelle, 1983). At high pH, Ca^{2+} and Mg^{2+} are usually transferred to a solid phase; therefore their concentrations are controlled by mineral precipitation. With regards to the above condition, in this study the hydrochemical modelling of the water samples was performed using the aqueous speciation program PHREEQC. The results of the calculation for the degree of saturation index (SI) of the groundwater with respect to selected specified minerals are shown in Figure 3. From the plot, it shows that SI of calcite and dolomite are positive values higher than 1, indication supersaturation which lead to mineral precipitation condition of water by this mineral due to an extend effect from seawater intrusion.

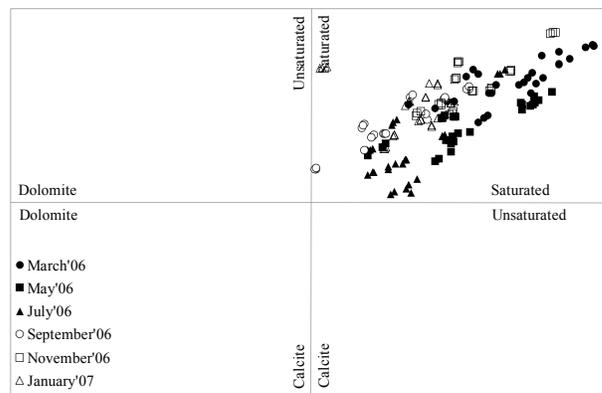


Figure 3. Saturation indices plot for calcite and dolomite.

CONCLUSIONS

A diversity of geochemical processes is taking place in the mixing zone of fresh groundwater-seawater is rather complicated; it represents an over exploitation of an aquifer. The salinization of the groundwater occurred as a result of increasing ionic concentrations attributed to seawater intrusion into the aquifer system. The increase in concentrations of major elements in groundwater with salinity (Cl⁻) leads to cation exchange processes and subsequently leads to carbonate minerals precipitation.

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