

Preliminary Assessment on the Hydrogeochemistry of Kapas Island, Terengganu (Penilaian Awal Hidro-Kimia di Pulau Kapas, Terengganu)

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ABSTRACT

Classified as a small island, Kapas Island experiences major problems especially in supplying freshwater where groundwater abstraction is the only way to meet the demand of drinking water and domestic use. Groundwater samples were collected from seven constructed boreholes to examine the hydrochemistry properties of major ions and in-situ parameters as these could provide a basis for future reference. The chemical composition showed strong and significant correlation for each studied parameter; an indication of the effect of environmental variables to the groundwater composition. The composition changed from Ca-rich to Na-rich are explained mostly by mixing and cation exchange processes. This study provided an input for water management at Kapas Island where groundwater is a crucial resource to maintain the hydrogeological balance of the island.

Keyword: Aquifer; groundwater; hydrochemical; Kapas Island; major ions

ABSTRAK

Dikelompokkan di dalam kumpulan pulau kecil, Pulau Kapas mengalami masalah terutama sekali dalam menyalurkan air tawar yang mana proses pengeluaran air bawah tanah sahaja yang ada bagi memenuhi permintaan air minuman serta penggunaan harian. Sampel-sampel air bawah tanah dikumpulkan dari tujuh telaga tiub yang dibina untuk dianalisis ciri-ciri hidro-kimianya yang terdiri daripada ion-ion utama dan parameter in-situ yang boleh disediakan sebagai garis panduan maklumat untuk rujukan masa hadapan. Kandungan kimia menunjukkan hubungan yang kuat dan signifikan antara setiap parameter yang dikaji menunjukkan kesan perubahan pemboleh ubah alam sekitar terhadap kandungan air bawah tanah. Perubahan kandungan air bawah tanah daripada yang kaya-Ca kepada kaya-Na dapat menjelaskan proses pencampuran dan juga proses penukargantian kation. Kajian ini sangat penting sebagai landasan untuk pengurusan air di Pulau Kapas yang mana air bawah tanah adalah sumber penting dalam memelihara keseimbangan hidrogeologi sesebuah pulau.

Kata kunci: Air bawah tanah, akuifer, hidrokimia, ion utama, Pulau Kapas

INTRODUCTION

Islands are vulnerable to human activities and natural disasters in relation to their features as being small in size, insularity and remoteness as described (Briguglio 1995). In Malaysia, islands are one of the biggest contributors to ecotourism activities, which support the national economic growth and help to sustain Malaysia's development. Apart from playing an important role in tourism, most of the small tropical islands faces similar problems regarding supplying freshwater. Due to the absence of surface water, small islands usually depends entirely on groundwater as the only water resource for domestic uses (Amer 2008; Aris et al. 2007b; Aris et al. 2010a; Sexena et al. 2008). Islands have become renowned locations among tourists where an increasing number of visitors to the island caused an increase of freshwater demand (Aris et al. 2009a; Aris et al. 2009b; Fleegeer 1999). Without proper planning and management, tourism could lead to degradation of an island environment. Over extraction of fresh groundwater significantly contributes to the contamination of fresh groundwater (Aris et al.

2010a) that generally reduces the groundwater storage and quality (Aris et al. 2010b; Gupta & Babel 2005; Jayaprakash et al. 2008; Langevin et al. 2007; Marghade et al. 2010; Petalas et al. 2002; Russak & Sivan 2010). Additionally, a groundwater system also comprises water quality and quantity aspects that need to be defined and quantified for its successful management.

Essentially, groundwater pumping activities are connected to seawater intrusion process (Aris et al. 2009a; Aris et al. 2010b; Fleegeer 1999; Praveena et al. 2010; Werner et al. 2009) where the encroachment of the lower saltwater layer (Ma et al. 1997) will further lead to seawater intrusion if it has exceeded the limits of abstraction. Seawater intrusion is basically a process where seawater in the lower portion of the aquifer has penetrated the fresh groundwater wedges in the upper portion of the aquifer (Ma et al. 1997). Theoretically, the fresh groundwater and saltwater wedges are separated by the different layers of density. Other than that, changes in fresh groundwater constituent can be caused by influence of agricultural, industrial activities and public utilities (Fleegeer 1999;

Wojciech et al. 2008). It also depends on minerals in the aquifer matrix and the detention time of storage. However, in attempt to meet the fresh groundwater demands, meticulous management is required on safeguarding the good quality and protection of small island ecosystem for sustainability of their respective resources, economy, country and peoples. This preliminary study focused on profound understanding of the hydrochemical processes of groundwater abstraction on Kapas Island in order to avoid the above stated problems as well as to provide a preliminary record for set of aquifer management guidelines and for a systematic development scheme of islands.

MATERIALS AND METHODS

SITE DESCRIPTION

Islands in Malaysia such as Redang Island, Sipadan Island, Tiga Island and Kapas Island are well known for their special features of tourism (Wong 1993), education and conservation sites. Kapas Island was chosen in this study particularly due to the lack of record on the hydrochemistry assessment of islands in peninsular Malaysia (Terengganu, Malaysia). Located between $5^{\circ} 12.6' - 5^{\circ} 14.1' \text{ N}$, $103^{\circ} 15.7' - 103^{\circ} 16.3' \text{ E}$ (Figure 1), Kapas Island is a renowned ocean paradise in Malaysia for its white sandy beaches and diverse tropical marine ecosystems. It is situated 3 km offshore, from east of Marang Jetty. The island is approximately about 2 km² in area (Abdullah 1981; Shuib 2003) and is classified as a small island. Indeed, approximately 90% of the area is covered by hill sand and the rest by recent coastal sediment and developed for tourism activities. Figure 1 shows the boreholes locations that have been constructed parallel to the coastal area.

Kapas Island was formed from various ages of carbonate rocks that can be divided into three units namely Permo-Carboniferous metasediments, conglomerate sequence and intrusive rocks (Shuib 2003). Metasediments rocks basically represent the sandstone, mudstone, shale and slit while the conglomerate groups was made up of sandstone and mudstone (Ali et al. 2001). Although the

exact age of these rocks remains unknown, it was suggested that these could be from Late Permian to Triassic age (Shuib 2003).

Groundwater recharge for small islands usually depends entirely on infiltration (Aris et al. 2010a) which was the case on Kapas Island. In addition, Kapas Island has a tropical climate which typically receives 100 to 700 mm rainfall monthly (Figure 3) and 2800 to 2911 mm of rainfall annually, experiencing constant temperature between 22°C to 32°C and humidity around 70-80% annually. Kapas Island receives heavy rainfall when the northeast monsoon blows between November and January. Abdullah (1981) reported the soil profile for selected study area and it was classified in Table 2 and Figure 2.

METHODS

The boreholes were installed 30 m from the coast line up to 150 m further landward. Polyvinyl chloride (PVC) pipes with diameter 6 cm were used in the boreholes installation after screening process. The wells were screened at different elevations between 2.5 and 11.5 m from ground surface level. Groundwater samples from the constructed boreholes were abstracted using low purging pump system. The boreholes' water was pumped out for 10 to 15 min prior to groundwater sampling to avoid non-representative samples of stagnant or polluted water. Before the water was pumped out, the water level from each borehole was measured using a water level meter. A total of twenty one groundwater samples were collected during a sampling campaign that was conducted in July 2010. Polyethylene bottles were used to collect and preserve the groundwater samples based on the methods described by APHA (2005). Polyethylene bottles and other glassware were pre-cleaned with a prepared solution containing 5% HNO₃ acids. *In-situ* parameters such as temperature, pH, conductivity (EC), salinity, total dissolved solid (TDS) and oxidation reduction potential (Eh) were measured on site. Bicarbonate (HCO₃⁻) analysis was performed immediately after each sampling based on titration method (HCl 0.02 N) since HCO₃⁻ is an unstable species. Sulphate (SO₄²⁻) and chloride (Cl⁻) analyses were also determined immediately after the sampling using a HACH (DR/2000) meter (HACH,

TABLE 1. Coordinates of borehole stations on Kapas Island, Terengganu

Station	Coordinate of borehole station		Distance from shoreline (m)	Depth of boreholes (m)	Water table (m)
KW1	05° 12.999 N	103° 15.799 E	119	11.5	2.08
KW2	05° 12.996 N	103° 15.787 E	98	9.1	2.27
KW3	05° 12.992 N	103° 15.778 E	83	3.5	3.22
KW4	05° 12.989 N	103° 15.771 E	68	3.0	2.09
KW5	05° 12.985 N	103° 15.762 E	48	2.9	2.64
KW6	05° 12.982 N	103° 15.754 E	31	2.5	1.91
KW7	05° 13.069 N	103° 15.774 E	150	4.4	2.90

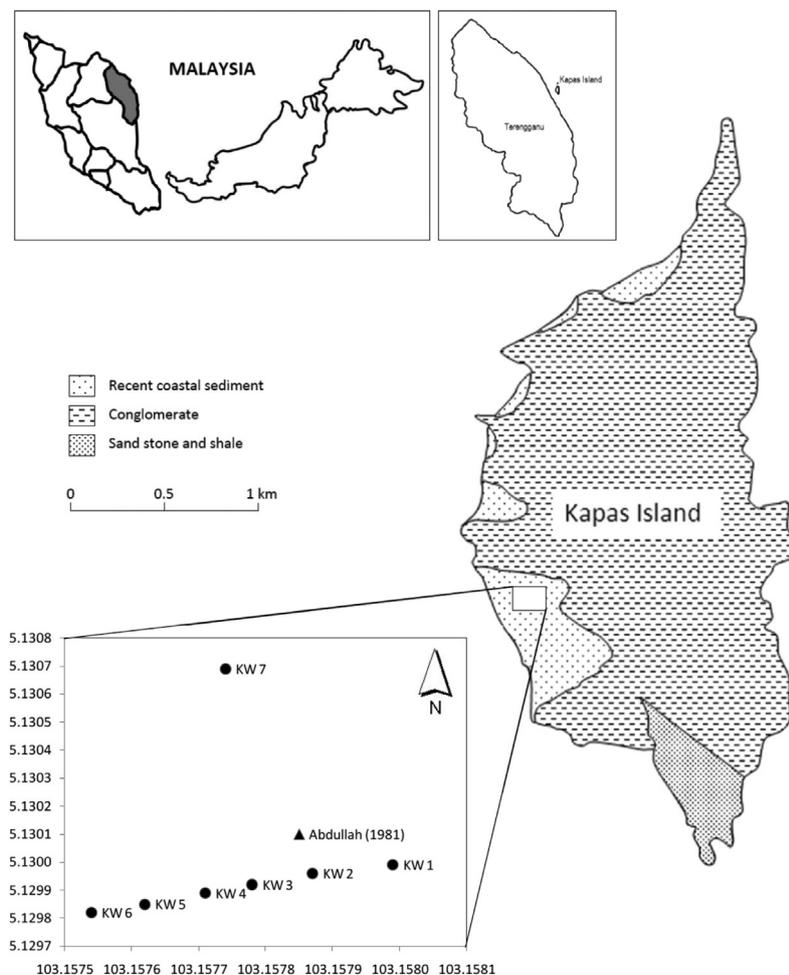


FIGURE 1. Schematic map of Kapas Island, Terengganu, Malaysia and the boreholes locations

TABLE 2. Geological profiles in the study area
(Modified from Abdullah (1981))

Depth (m)	Description of soil profile
0-1	Brownish fine sand
2-3	Light brown fine sand
3-4	Light yellow cemented sand coral
4-5	Light yellow coarse of coral
5-7	Coral shell fragment
7-9	Dark grey fine and medium sand
9-12	Grey fine sand, shell and silt clay

Loveland, CO, USA) and argentometric (AgNO_3) methods, respectively.

The samples for analyses of major ions specifically sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) were filtered through a $0.45 \mu\text{m}$ membrane filter paper (Whatman Milipores, Clifton, NJ, USA) and preserved using 1 mL concentrated HNO_3 acid in a 50 mL

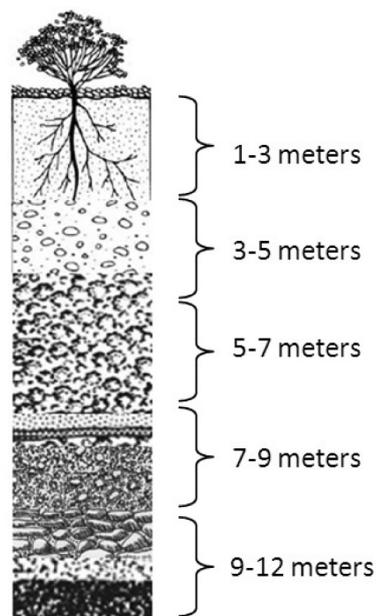


FIGURE 2. Soil profile in the study area
(Modified from Abdullah (1981))

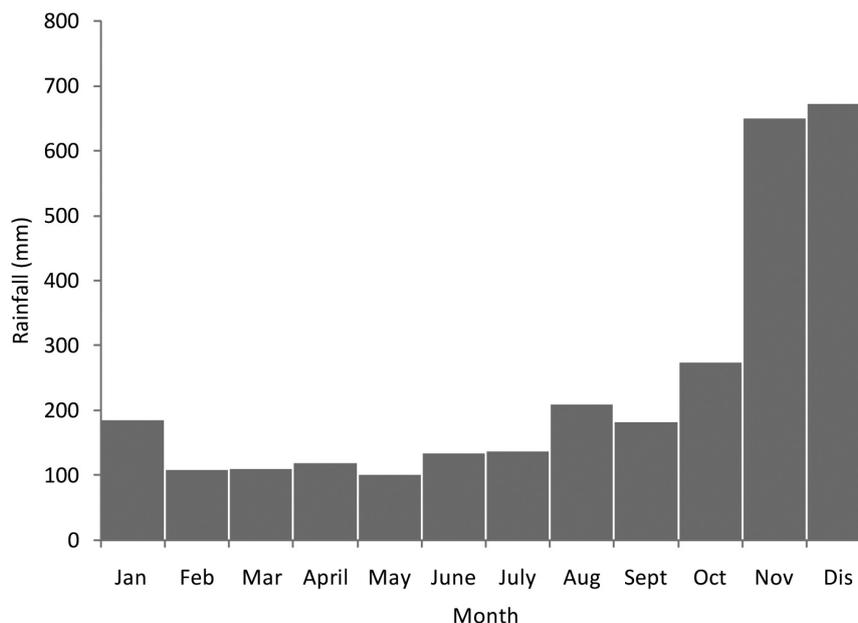


FIGURE 3. Average rainfall on Kapas Island in 2009 (Malaysian Meteorological Department (2010))

sample bottle as described by APHA (2005). The samples were then stored in a cooler box of approximately 4°C before being transported to the laboratory for further analysis. The filtered and acidified samples for major ions were analysed using flame atomic absorption spectrophotometer (FAAS, Perkin Elmer, Massachusetts, USA).

Statistical analyses (descriptive analysis and correlation coefficient) were performed for the obtained data using SPSS statistical package program version 17. These data represent spreading or variations of data distribution. The statistical analyses were performed in order to determine the similarities and the differences between samples for each variable. The ratio statistics procedure provides a complete list of summary statistics to describe the ratio between two scale variables. Ionic ratios had been widely used to evaluate the impact of seawater on aquifer chemistry using Cl as the groundwater chemical constituents with the ionic concentrations given in milliequivalents per liter (meq/L). Components that are usually used for ionic ratio are Na/Cl, Ca/Mg and Ca/SO₄. The hydrochemistry of the analysed groundwater in Kapas Island were graphically presented using a Piper diagram

to evaluate its composition and chemistry changes. Piper diagram is useful to show the water types of multiple samples and trends in major ions in the groundwater samples. It is also a tool used to decipher the geochemical evolution of groundwater.

RESULTS AND DISCUSSION

DESCRIPTIVE ANALYSIS

The descriptive analyses of data obtained in this study are shown in Table 3. The temperatures of groundwater were generally between 27°C and 30.7°C. Salinity value of groundwater varied from 0.20-0.39 ppt. The electrical conductivity (EC) values varied from 0.40-0.79 mS/cm, respectively with most of the samples measured were less than 0.5 mS/cm. Groundwater that is affected by seawater intrusion may have conductivity value of approximately > 5 mS/cm (Aris et al. 2010b). This indicates that the study area does not experience seawater intrusion based on the conductivity value.

The pH values for groundwater were similar in almost every sampling station where the mean value was

TABLE 3. Readings and concentrations of *in-situ* parameters and major ions for studied groundwater

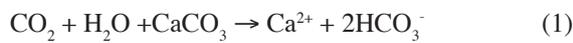
	Temp	pH	EC	Sal	TDS	Eh	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	Na ⁺	Ca ²⁺	K ⁺	Mg ²⁺
Mean	29.7	7.10	0.54	0.26	269	0.69	300	32.0	10.0	24.12	17.18	0.84	3.73
SD	0.92	0.08	0.13	0.07	66.21	4.69	49	24.6	3.9	3.42	17.70	0.11	6.29
Min	27.9	7.00	0.43	0.20	212	-5.60	242	11.5	4.0	21.21	6.34	0.73	0.02
Max	30.7	7.20	0.79	0.39	394	8.70	372	93.5	19.0	31.37	58.09	1.02	17.23

(Unit in mg/L except for temperature; °C, EC; mS/cm, salinity; ppt, Eh; mV and pH)

7.1. The pH value influenced the concentration of HCO_3^- in the aquifer system. High value of pH in this study may explain that the aquifer water was characterized as slightly alkaline where HCO_3^- is the predominant species at high pH value. The concentration of pH also affected the CaCO_3 dissolution and precipitation. Higher pH in the aquifer system may be effectuated by calcite dissolution and precipitations of calcite occurred due to lower pH state. The relationship between pH and Eh are strong ($r = -0.999, p < 0.01$) where Eh value indicated the oxidation and reduction process in the aquifer system. It can be elucidated that during the sampling campaign, KW2 had a trace odor which suggested that the borehole were under reduced condition.

Concentration of HCO_3^- varied from 242-372 mg/L, and it contributed 76-94% of the total anions in groundwater of the study area. The variations in HCO_3^- between boreholes are not consistent. Generally, HCO_3^- concentration in the aquifer was derived from weathering of minerals such as carbonates which supported the mechanism of dissolution or precipitation of calcite above.

The Ca^{2+} concentration of groundwater in the study area ranged from 6.3-58.1 mg/L. High concentration of Ca^{2+} ion are resultant of reaction between calcite and carbon dioxide (CO_2) in the aquifer. CO_2 controls the behavior of CaCO_3 dissolution or precipitation in the aquifer. High CO_2 would result in dissolution of calcite while precipitations of calcite would occur in low concentration of CO_2 condition. The overall reaction between CO_2 and CaCO_3 is:



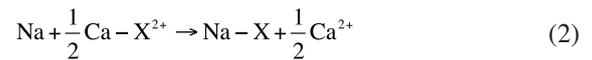
Descriptive analyses for ion composition showed various amount of chemical constituent in the fresh groundwater thus indicates that the fresh groundwater were affected by multiple processes such as ion exchange mechanism, weathering process and dissolution or precipitation processes of its sedimentary aquifer.

CORRELATION COEFFICIENT

Correlation coefficient analysis was performed to determine the relationship between the parameters which can later predict one another (Aris 2007b). Table 4 shows the correlation coefficient of each examined parameter.

There is positive and strong correlation between TDS and Cl^- ($r = 0.741$, with p value < 0.01). Additionally, correlation of Cl^- concentration with seawater component (Na^+) also indicates strong and positive relationship ($r = 0.907$; $p < 0.01$). Although it shows a strong relationship, other parameters (salinity and EC) did not portray the mechanism of seawater encroachment. The weak correlation was also observed between Cl^- and SO_4^{2-} , therefore indicating that there is no seawater intrusion for direct single pumping activities.

Most of the parameters were significantly correlated to HCO_3^- concentration, elucidated the aquifer system may undergo multiple processes such as ion exchange process and dissolution from the aquifer bedrock. HCO_3^- concentration has dominated the aquifer system and this suggested that dissolution of calcite occurred with carbon dioxide in the close system. The cation exchange process can be simplified as (2) where X indicates the soil exchanger (Apello & Postma 2005);



EC value in this study indicated the presence of dissolved ion in groundwater. It is proportional to TDS value as it indicated total dissolved salt in the aquifer system. Figure 4 shows the connection between EC and TDS with r value of 0.98 ($p < 0.01$). Other than that, TDS also affects the Ca^{2+} and HCO_3^- concentration in fresh groundwater. High TDS values are mostly correlated to the increased values of Ca^{2+} and HCO_3^- which mainly due to carbonate dissolution (Apello & Postma 2005). Figures 5 and 6 showed the relationship between TDS with Ca^{2+} and HCO_3^- .

TABLE 4. Correlation matrices of groundwater data in the study area

	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	TDS	EC
Ca^{2+}	1	0.000**	0.002**	0.001**	0.000**	0.001**	-0.877	0.000**	0.000**
Mg^{2+}	0.964	1	0.001**	0.000**	0.000**	0.001**	-0.339	0.000**	0.000**
Na^+	0.645	0.680	1	0.000**	0.001**	0.000**	0.110	0.000**	0.000**
K^+	0.665	0.737	0.830	1	0.000**	0.000**	0.196	0.000**	0.000**
HCO_3^-	0.703	0.738	0.670	0.827	1	0.001**	0.026	0.000**	0.000**
Cl^-	-0.656	-0.691	0.907	0.749	0.653	1	0.060	0.000**	0.000**
SO_4^{2-}	-0.036	-0.219	-0.359	-0.294	-0.486	-0.417	1	0.023*	0.028*
TDS	0.822	0.859	0.764	0.782	0.927	0.741	-0.492	1	0.000**
EC	0.779	0.815	0.770	0.814	0.928	0.730	-0.479	0.980	1

Significant value (upper triangle; $p < 0.01$ **, $p < 0.05$ *)

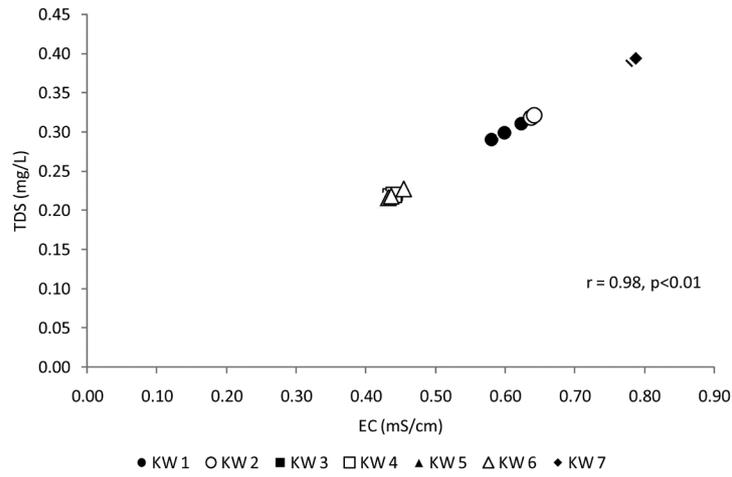


FIGURE 4. EC versus TDS plot for studied groundwater samples of Kapas Island

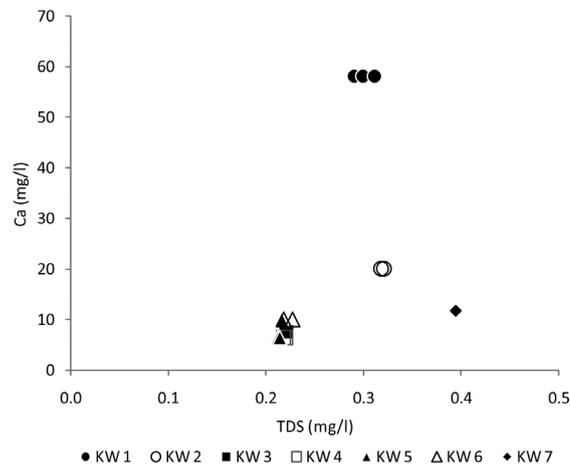


FIGURE 5. TDS versus Ca²⁺ concentration (mg/L) of collected data on Kapas Island

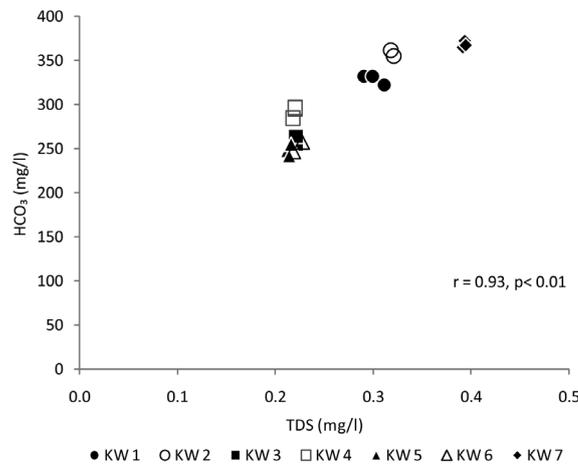


FIGURE 6. Relationship between TDS and HCO₃⁻ (mg/L) concentration in groundwater

HYDROCHEMICAL FACIES

The graphical method, Piper diagram is widely used for the determination of types of fresh groundwater. The trilinear diagram explains the concentrations of major cations and anions. It depicts the quality of groundwater as well as the possible pathways of fresh water and salt water movement. Coastal aquifers are usually dominated by Ca^{2+} and HCO_3^- generated by carbonate dissolution processes. Based on Piper diagram (Figure 7), the composition of fresh groundwater at Kapas Island showed different types as it moves toward the coastal area (Figure 1). KW1 demonstrate the water types fall under Ca-HCO_3 water types and shifted to Na-HCO_3 water types for station KW3 until KW7. Generally, the mechanism in the aquifer system at Kapas Island illustrated that the cation exchange process where Ca^{2+} ion has been replaced by the Na^+ ion naturally. The cation exchange process between Ca^{2+} and Na^+ can be clarified when the Ca^{2+} exchanged with Na^+ , the water becomes saturated with calcite and precipitation results (Aris et al. 2009b). Water types for KW2 (Mg-Na-HCO_3 ; Table 5) were attributed from dissolution of dolomite where it may contribute a small amount of Mg^{2+} in freshwater other than carbonate rock dissolution as shown below:

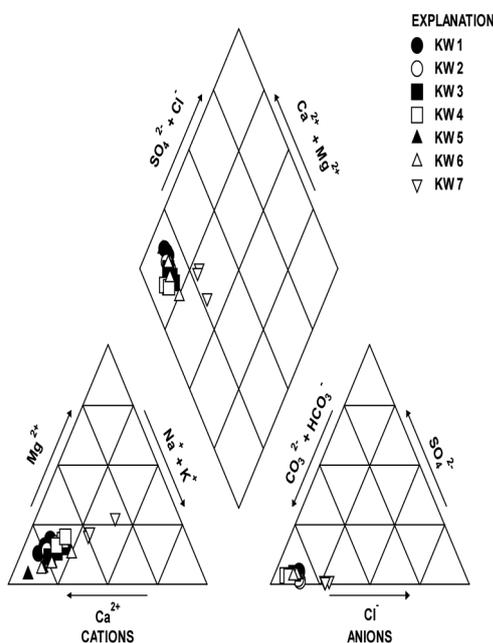
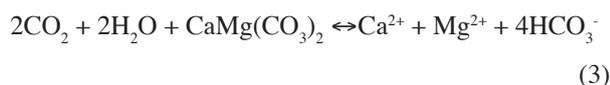


FIGURE 7. Piper diagram for the studied wells

Based on Table 6, the ionic ratios exhibit some relation that may explain certain processes such as cation exchanges in the aquifer system. The Na/Cl ratio for groundwater sample may explain that the aquifer system at Kapas Island has not experienced seawater intrusion so far where 90%

TABLE 5. Water types for each station of boreholes from KW1 to KW7 on Kapas Island

Station	Water types
KW1	Ca-HCO_3
KW2	Mg-Na-HCO_3
KW3	Na-HCO_3
KW4	Na-HCO_3
KW5	Na-HCO_3
KW6	Na-HCO_3
KW7	Na-HCO_3

of the ratio falls above seawater ratio ($\text{Na}/\text{Cl} = 0.67$; Aris et al. 2010b). In addition, based on the Figure 8 ($r = 0.85$; $p < 0.01$), 4 may be developed based on the ionic ratio for determining seawater intrusion occurrences in the future.

$$y = -0.719x + 2.174 \quad (4)$$

The Ca/Mg ratio (Table 6) illustrates that Ca^{2+} and Mg^{2+} have dominated the aquifer water due to the calcite dissolution process. According to Appelo and Postma (2005), an increase in Mg^{2+} concentration would likely increase Ca^{2+} concentration as shown in Figure 9. The outlier in Figure 9 indicates KW2 has Na-Mg-HCO_2 water type as a result of dolomite dissolution of which produces more Mg^{2+} .

CONCLUSION

Data from this study provides an initial understanding of hydrochemistry at Kapas Island which generally depends on the groundwater as a source of supplying drinking water and domestic use. There was a strong correlation between concentrations of Na^+ and Cl^- ($r = 0.984$; $p < 0.01$) and Ca^{2+} and HCO_3^- ($r = 0.703$; $p < 0.01$) while weak correlation exists between Cl^- and SO_4^{2-} ($r = 0.164$; $p < 0.01$). These indicated that fresh groundwater was influenced by several processes such as ion exchange process and dissolution of aquifer bedrock. Piper plot showed that Na-HCO_3 water type is the main hydrochemical facies for fresh groundwater at Kapas Island after it shifted from Ca-HCO_3 water types as it move to the coastal area. This study provided a platform for better water management at Kapas Island which will be able to control the abstraction of groundwater that may lead to serious problems of groundwater salinization. This research may valued to specific authorities such as Department of Mineral and Geosciences, Ministry of Tourism Malaysia and Department of Marine Park Malaysia that responsible to managed and controlled small island activities including the water resources management schemes as well as ecotourism activities. Continuous study of hydrochemistry at Kapas Island throughout the year would be carried out and recorded for good water resources management practices of small island as a well known and protected tourism site. In the next step, this study will be

TABLE 6. Ionic ratios for selected ions (Ca/Mg, Ca/SO₄, Na/Cl) for this study

		Mean	SD	Min	Max
KW 1	Ca/Mg	4.43	0.00	4.43	4.43
	Ca/SO ₄	7.53	0.29	7.32	7.73
	Na/Cl	1.31	0.05	1.27	1.34
KW 2	Ca/Mg	0.71	0.00	0.71	0.71
	Ca/SO ₄	7.48	3.02	5.34	9.62
	Na/Cl	1.15	0.11	1.07	1.23
KW 3	Ca/Mg	115.68	0.00	115.68	115.68
	Ca/SO ₄	1.52	0.00	1.52	1.52
	Na/Cl	1.81	0.12	1.72	1.89
KW 4	Ca/Mg	130.99	0.00	130.99	130.99
	Ca/SO ₄	1.64	0.12	1.55	1.72
	Na/Cl	2.42	0.61	1.99	2.86
KW 5	Ca/Mg	192.24	0.00	192.24	192.24
	Ca/SO ₄	1.45	0.10	1.38	1.52
	Na/Cl	1.66	0.06	1.62	1.70
KW 6	Ca/Mg	86.03	0.00	86.03	86.03
	Ca/SO ₄	2.51	0.19	2.38	2.64
	Na/Cl	1.74	0.19	1.61	1.88
KW 7	Ca/Mg	9.35	0.00	9.35	9.35
	Ca/SO ₄	5.51	2.13	4.01	7.02
	Na/Cl	0.54	0.04	0.51	0.56

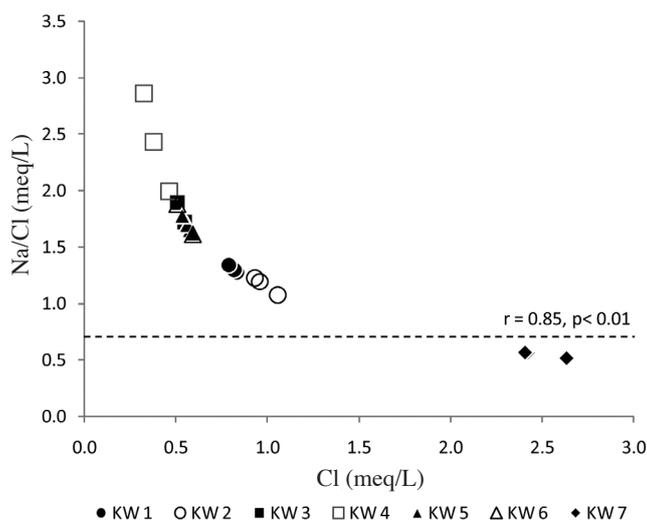


FIGURE 8. Ionic ratio of Cl versus Na/Cl concentration in meq/L in boreholes on Kapas Island where dashed lines indicates seawater ratio value

carried out to measure changes of hydrochemistry on Kapas Island. There are few considerations to be considered in continuing this study such as to evaluate the controlling mechanisms such as climate variability that happen throughout the year to explain the uncertainty data might found eventually in this study;

1. The changes happened should consider variety aspects such as hydrological balance, physical and chemical properties as to recognize the pro and cons of the processes.
2. Future study should be carried out to identify the interactions between seasonal changes as to clarify the mechanisms involved
3. Data and information that been collected would be used to overcomes long term effects in small islands such as seawater intrusions and anthropogenic activities

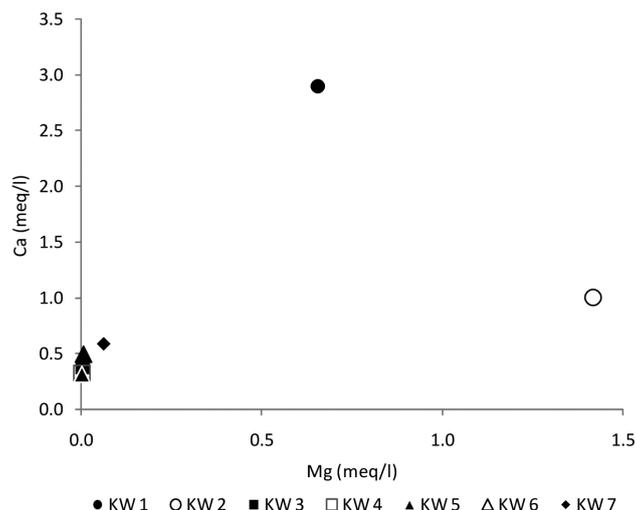


FIGURE 9. Ionic ratio of Mg versus Ca concentration (meq/L) of groundwater

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REFERENCES

- Abdullah, M.P. 1981. Laporan penyiasatan kajibumi, Ibu Pejabat Penyiasatan Kajibumi, Malaysia, Terengganu, Malaysia.
- Ali, C.A., Mohamed, K.R. & Abdullah, I. 2001. Pemetaan Awal Air Panas Kawasan Lojing, Gua Musang, Kelantan in Komoo, I., Tija, H.D. & Leman, M.S. (Eds.) *Warisan Geologi Malaysia: Selangor Malaysia, LESTARI*.
- Amer, K.M. 2008. Groundwater resources sustainability in Qatar: Problems and perspectives in Bhattacharya, P., Ramanathan, A., Mukherjee, A.B., Bundschuh, J., Chandrasekharam, D. and Keshari, A.K., eds, *Groundwater for Sustainable Development, Problems, Perspectives and Challenges*. London: Taylor & Francis pp. 25-37.
- APHA. 2005. *Standard Methods for the Examination of Water and Wastewater*. (21st ed) American Water Works Association, Water Environment Federation, Washington.
- Appelo, C.A.J. & Postma, D. 2005. *Geochemistry, Groundwater and Pollution*. (2nd Ed) Rotterdam: Balkema.
- Aris, A.Z., Abdullah, M.H. & Kim, K.W. 2007a. Hydrochemistry of groundwater in Manukan Island, Sabah. *The Malaysian Journal of Analytical Sciences* 2: 407-413.
- Aris, A.Z., Abdullah, M.H. & Praveena, S.M. 2009a. Evolution of groundwater chemistry in the shallow aquifer of a small tropical island in Sabah, Malaysia. *Sains Malaysiana* 38(6): 805-812.
- Aris, A.Z., Abdullah, M.H., Ahmed, A. & Kim, K.W. 2007b. Controlling factors of groundwater hydrochemistry in a small island's aquifer. *International Journal of Environmental Science and Technology* 4(4): 441-450.
- Aris, A.Z., Abdullah, M.H., Kim, K.W. & Praveena, S.M. 2009b. Hydrochemical changes in a small tropical island's aquifer: Manukan Island, Sabah, Malaysia. *Environmental Geology* 56: 1721-1732.
- Aris, A.Z., Praveena, S.M. & Abdullah, M.H. 2010a. Saturation states of carbonate minerals in a freshwater-seawater mixing zone of small tropical island's aquifer. *Chinese Journal of Geochemistry* 29: 278-286.
- Aris, A.Z., Praveena, S.M. & Abdullah, M.H. 2010b. The Influence of Seawater in the Chemical Composition of Groundwater in Small Island: The Example of Manukan Island, East Malaysia. *Journal of Coastal Research* DOI: 10.2112/JCOASTRES-D-10-00020.1
- Briguglio, L. 1995. Small Island developing states and their economic vulnerabilities. *World Development* 23(9): 1615-1632.
- Fleeger, G.M. 1999. *The Geology of Pennsylvania's Groundwater*. Harrisburg. Educational Series 3.
- Gupta, A.D. & Babel, M.S. 2005. Challenges for Sustainable Management of Groundwater Use in Bangkok, Thailand. *Water Resources Development* 21(3): 453-464.
- Jayaprakash, M., Giridharan, L., Venugopal, T., Kumar, S.P.K. & Periakali, P. 2008. Characterization and Evaluation of the Factors affecting the geochemistry of groundwater in Neyveli, Tamil Nadu, India. *Environmental Geology* 54: 855-867.
- Langevin, C., Sanford, W., Polemio, M. & Povinec, P. 2007. *A New Focus on Groundwater-Seawater Interactions*, pp. 3-10, Perugia.
- Ma, T.S., Sophocleous, M., Yu, Y.S. & Buddemeier, R.W. 1997. Modeling saltwater upconing in a freshwater aquifer in south-central Kansas. *Journal of Hydrology* 201: 120-137.
- Malaysian Meteorological Department 2010. Rainfall data for Kapas Island from January to December 2009.
- Marghade, D., Malpe, D.B. & Zade, A.B. 2010. Geochemical characterization of groundwater from northeastern part of Nagpur urban, Central India. *Journal of Environmental Earth Science*. In-press.

- Petalas, C., Pliakas, F. & Diamantis, I. 2002. The problem of seawater intrusion in coastal aquifers and methods of prevention. The case of East Macedonia and Thrace. Technical Annals Report.
- Praveena, S.M. & Aris, A.Z. 2010. Groundwater resources assessment using numerical model: A case study in low-lying coastal area. *International Journal of Environmental Science and Technology* 7(1): 135-146.
- Russak, A. & Sivan, O. 2010. Hydrogeochemical Tool to Identify Salinization or Freshening of Coastal Aquifers Determined from Combined Field Work, Experiments and Modelling. *Environmental Science Technology* 44: 4096-4102.
- Saxena, V.K., Mondal, N.C. & Singh, V.S. 2008. Assessment of groundwater resources by using a simple hydrogeochemical tool in coastal aquifers of Krishna delta, India in Bhattacharya, P., Ramanathan, A., Mukherjee, A.B., Bundschuh, J., Chandrasekharam, D. & Keshari, A.K., (eds), *Groundwater for Sustainable Development, Problems, Perspectives and Challenges*: London, Taylor & Francis, 3-11.
- Shuib, M.K. 2003. Transpression in the strata of Pulau Kapas, Terengganu. *Geological Society of Malaysia Bulletin* 46: 299-306.
- Werner, A.D., Jakovovic, D. & Simmons, C.T. 2009. Experimental observations of saltwater up-coning. *Journal of Hydrology*. 373: 230-241.
- Wojciech, O. & Krzysztof, P. 2008. Magnesium, Calcium, Potassium and Sodium content in groundwater and surface water in arable lands in the commune (GMINA) of Katy Wroclawskie. *Journal of Elementol.* 13(4): 605-614.
- Wong, P.P. 1993. *Tourist vs Environment: The Case for Coastal Areas*. P.P. W. (ed), Kluwer Academic Publishers, The Netherlands.

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